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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

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Monographs on Appropriate Industrial Technology
No. 12

APPROPRIATE INDUSTRIAL TECHNOLOGY FOR CONSTRUCTION AND BUILDING MATERIALS

UNITED NATIONS
New York, 1980

EXPLANATORY NOTES

A full stop (.) is used to indicate decimals.

A comma (,) is used to distinguish thousands and millions.

A slash (/) is used to indicate "per", for example t/a = tonnes per annum.

A slash between dates (for example, 1979/80) indicates an academic, crop or fiscal year.

A dash between dates (for example, 1970–1979) indicates the full period including the beginning and end years.

References to dollars ($) are to United States dollars.

References to rupees (Rs) are to Indian rupees. In October 1978 the value of the rupee in relation to the dollar was $1 = Rs 7.90.

The word billion means 1,000 million.

The word lakh means 100,000.

The following notes apply to tables:

Three dots (...) indicate that data are not available or are not separately reported.

A dash (–) indicates that the amount is nil or negligible.

A blank indicates that the item is not applicable.

Totals may not add precisely because of rounding.

In addition to the common abbreviations, symbols and terms and those accepted by the International System of Units (SI), the following have been used.

Economic and commercial terms

f.o.b	free on board
IS	Indian Standard
R and D	research and development

Technical abbreviations

DTA	different thermal analysis
EDTA	ethylenediaminetetraacetate
hp	horsepower (1 hp = 746 w)
RB	reinforced brick
Reba	Readymix Bade process
RMC	ready-mixed concrete
SP	suspension preheater kiln system
TGA	thermogravimetric analysis

EXPLANATORY NOTES *(continued)*

Organizations

ATDA	Appropriate Technology Development Association (Lucknow, India)
CBRI	Central Building Research Institute (Roorkee, India)
CRETP	Centre de recherches et d'études des travaux publics (Public Works Research and Investigations Centre, United Republic of Cameroon)
CRI	Cement Research Institute of India (New Delhi, India)
IT	Intermediate Technology
ITDG	Intermediate Technology Development Group Ltd. (London, United Kingdom)
KVIC	Khadi and Village Industries Commission (India)
NATO/ CCMS	North Atlantic Treaty Organization/Committee on the Challenges of Modern Society
PRAI	Planning Research and Action Institute (Uttar Pradesh, India)
RRL	Regional Research Laboratory (Jorhat, India)
SERC	Structural Engineering Research Centre (Madras and Roorkee)
VITA	Volunteers in Technical Assistance (United States of America)

The concept of appropriate technology was viewed as being the technology mix contributing most to economic, social and environmental objectives, in relation to resource endowments and conditions of application in each country. Appropriate technology was stressed as being a dynamic and flexible concept, which must be responsive to varying conditions and changing situations in different countries.

It was considered that, with widely divergent conditions in developing countries, no single pattern of technology or technologies could be considered as being appropriate, and that a broad spectrum of technologies should be examined and applied. An important overall objective of appropriate technological choice would be the achievement of greater technological self-reliance and increased domestic technological capability, together with fulfilment of other developmental goals. It was noted that, in most developing countries, a major development objective was to provide adequate employment opportunities and fulfilment of basic socio-economic needs of the poorer communities, mostly resident in rural areas. At the same time, some developing countries were faced with considerable shortage of manpower resources; in some other cases, greater emphasis was essential in areas of urban concentration. The appropriate pattern of technological choice and application would need to be determined in the context of socio-economic objectives and a given set of circumstances. The selection and application of appropriate technology would, therefore, imply the use of both large-scale technologies and low-cost small-scale technologies dependent on objectives in a given set of circumstances.

Report of the Ministerial-level Meeting. International Forum on Appropriate Industrial Technology

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Foreword

As part of its effort to foster the rapid industrialization of developing countries, the United Nations Industrial Development Organization (UNIDO), since its inception in 1967, has been concerned with the general problem of developing and transferring industrial technology. The Second General Conference of UNIDO, held at Lima, Peru, in March 1975, gave UNIDO the specific mandate to deal in depth with the subject of appropriate industrial technology. Accordingly, UNIDO has initiated a concerted effort to develop a set of measures to promote the choice and application of appropriate technology in developing countries.

Appropriate industrial technology should not be isolated from the general development objective of rapid and broad-based industrial growth. It is necessary to focus attention on basic industrial development strategies and derive from them the appropriate technology path that has to be taken.

The Lima target which, expressed in quantitative terms, is a 25 per cent share of world industrial production for the developing countries by the year 2000, has qualitative implications as well. These comprise three essential elements: fulfilling basic socio-economic needs, ensuring maximum development of human resources, and achieving greater social justice through more equitable income distribution. Rapid industrialization does not conflict with these aspirations; on the contrary, it is a prerequisite to realizing them. But, in questioning the basic aims of development, we also question the basic structure of industrial growth and the technology patterns it implies.

Furthermore, it is easy to see that the structure of industrial growth that should be envisaged and the corresponding structure of technology flows should be different from what they are today; a fresh approach is called for. This does not mean that the flow of technology to the modern sector and the application of advanced technologies are unnecessary. On the contrary, it is essential to upgrade the technology base in general, and it is obvious that to provide basic goods and services, there are sectors of industry where advanced or improved technology is clearly necessary. It would be difficult to envisage a situation where the dynamic influence of modern technology is no longer available for industrial growth and development in general. However, an examination of the basic aims of industrial development leads to the conclusion that there must be greater decentralization of industry and reorientation of the design and structure of production.

Such decentralized industry in the developing countries calls for technologies and policy measures that often have to be different from those designed for the production of items for a different environment, that of the developed countries. As a result, there is a two-fold, or dualistic, approach to an industrial strategy. Morever, the two elements in such an industrial strategy need to be not only interrelated but also integrated.

In approaching the question of appropriate industrial technology from an examination of basic development needs, a mechanism is necessary to link and integrate appropriate industrial technology to the overall development process. Through such a process the concept of appropriate industrial technology could be placed in the mainstream of the industrial development effort.

It is hoped that these monographs will provide a basis for a better understanding of the concept and use of appropriate industrial technology and thereby contribute to increased co-operation between developing and developed countries and among the developing countries themselves.

It is also hoped that the various programmes of action contained in the monographs will be considered not only by the forthcoming meetings of the United Nations Conference of Science and Technology for Development and UNIDO III but also by interested persons working at the interface over the coming years.

Abd-El Rahman Khane
Executive Director

Preface

To focus attention on issues involved in choosing and applying appropriate technology, UNIDO organized the International Forum on Appropriate Industrial Technology. The Forum was held in two parts: a technical/official-level meeting from 20 to 24 November 1978 at New Delhi and a ministerial-level meeting from 28 to 30 November 1978 at Anand, India.

In response to a recommendation of the ministerial-level meeting, UNIDO, with the help of a generous contribution by the Swedish International Development Authority, is publishing this series of monographs based mainly on documents prepared for the technical/official-level meeting. There is a monograph for each of the thirteen Working Groups into which the meeting was divided: one on the conceptual and policy framework for appropriate industrial technology and twelve on the following industrial sectors:

Low-cost transport for rural areas
Paper products and small pulp mills
Agricultural machinery and implements
Energy for rural requirements
Textiles
Food storage and processing
Sugar
Oils and fats
Drugs and pharmaceuticals
Light industries and rural workshops
Construction and building materials
Basic industries

The monograph on the conceptual and policy framework for appropriate industrial technology also includes the basic part of the report of the ministerial-level meeting and some papers which were prepared for the Second Consultative Group on Appropriate Industrial Technology, which met at Vienna, 26-29 June 1978.

PART ONE

Issues and considerations

Note by the secretariat of UNIDO

INTRODUCTION

The building materials industry is essentially a complement of the construction industry. Its development therefore broadly follows the pattern of the construction industry itself and is determined by the construction technology and inputs used and the character and composition of construction output.

Without construction there is no development. New construction is a requirement for most development projects. Construction itself constitutes approximately half of all fixed capital investments.

The lack of an adequate transport system has often been an obstacle to the expansion of construction and to the flow of products. Therefore, the construction of roads, bridges, railways, harbours, airports etc. constitutes an important step towards increasing the output of construction itself.

A shortage in building materials restricts the development of the construction industry and puts strains on a country's resources by necessitating imports of building materials. Therefore, an adequately developed building materials industry is needed in each country with aspirations of economic development.

A well-balanced increase of the output of construction contributes to the satisfaction of the population, because it improves the housing situation, creates new jobs in the new factories and reduces unemployment.

In most developing countries there are high population growth rates, especially in the urban population. Much new housing is needed and municipal services (water supply, electricity, sewage treatment etc.) have to be expanded.

Construction is a labour-intensive activity. As such, assuming a given fixed capital outlay it employs comparatively more workers than other economic sectors. The construction industry also has a "mission" to fulfil, owing to the fact that many workers come from rural-agricultural areas, for whom construction is the first organized work-place. Many of these workers leave construction after a certain period to become employed by the manufacturing industry or by other users of buildings produced by the construction industry. Thus, construction has in a sense a training-educational role in the overall industrialization process of a country.

Construction is an aggregation of many crafts. Many different types of craftsmen and enterprises have shares in construction (mason, carpenter, plumber, painter etc.). Construction is a purchaser of the products of many other industries. Therefore, the growth of construction makes itself extensively and positively felt whereas a slump in construction has far-reaching negative consequences.

The public sector's demand for construction is high and government interference has become necessary over a wide range. Public buildings, schools, hospitals, roads, airports are directly financed and contracted by central or regional (local) public authorities. In matters of new housing, public authorities usually also have much say. Government policy in increasing or reducing expenditures for construction works contributes greatly to the economic climate in the construction and the building materials industry.

Construction is at the same time a concentrated and a small-scale activity. Central government or large, privately owned industrial projects are realized by the concentrated efforts of the construction industry: local development projects are realized by small-scale construction activities. As a consequence, the construction industry equallv takes share of major central development projects and of implementing local development aspirations, including self-help in the non-monetary sector.

Construction activities in the developing countries can be classified into four broad categories: international modern, national modern, national conventional and traditional. Each category has its own pattern of demand on the building materials industry. The first two categories require sophisticated and costly building materials. For the national conventional and traditional categories of construction, however, the structure of demand is somewhat different and diversified. Demand for building materials for traditional construction is largely conditioned by the suitability and local availability of such materials and displays regional variations depending on climatic conditions. Thus organic materials such as timber, bamboo and reeds, which grow well in warm humid regions, are used for construction of dwellings in these regions. Hot, dry regions on the other hand, use inorganic materials such as stone, lime and brick. In most of these regions, however, a combination of organic and inorganic materials are used. The national conventional category of construction is found in urban and semi-urban areas. It is based mainly on traditional methods and materials supplemented by simply formed products derived from the modern industrial sector, such as corrugated-iron sheets for roofs and cement as a binder.

Hitherto, the major preoccupation of the developing countries has been with the establishment of the basic infrastructure of economic development in terms of basic industries, highways, major townships, massive irrigation projects, airports, bridges and so on. Such large-scale construction programmes involving application of sophisticated construction techniques have necessitated use of sophisticated building materials. These materials were initially imported, but production capacities were developed subsequently in varying degrees to produce them domestically. Since the major construction activities in developing countries are concentrated mainly in the modern sectors, the infrastructure for production of their materials has been oriented largely towards more sophisticated items such as cement, structural steel and glass. Consequently, the production strategy followed by the developing countries to date has benefited mainly the modern construction sector, which includes large-scale government construction and private residential constructions by the affluent sections of the urban and rural population. The subsistence sector is thereby excluded, thus depriving the lower-income population almost entirely of the benefit of development of the building materials industry because, first, the materials produced in the modern sector are too costly for them; second, these materials do not conform to the building specifications usually followed in this sector and third, the transport of the materials to the rural areas is hampered by poor communications.

The main feature that distinguishes the specifications of buildings in a subsistence economy from those in a richer consumer economy is that the materials used are substandard and the life of the structures built of them is therefore too short. Thus, while the affluent sections build houses that last longer and appreciate in value, the poorer sections build temporary shelters that require continual repair and restoration.

I. OBJECTIVES

Construction should be made possible both for major urban or other development projects and for the rural poor. Though this is a universally valid objective the different circumstances create different conditions for the construction and building materials industry.

If the poorer sections of the community are to be helped to build structurally durable and functionally adequate houses, the focus of attention will have to be on the provision of suitable building materials to them at a cost they will be able to bear. The materials should be such as are available locally and that do not require much specialized skill in their use. The basic purpose of such a strategy should be to enable these people to build dwellings that would serve as a store of value and an appreciating asset, so that the time and money spent in continual maintenance and eventual replacement of their non-durable dwellings would be freed for useful alternative purposes and the dwellings themselves would increase in value owing to their durability and become capital assets that could be sold or mortgaged. It is not enough however, merely to make essential building materials available to a low-income family at reasonable cost. Investment in better materials and physical efforts to improve the durability of dwellings is clearly not worthwhile if a family has no security of tenure of the land on which its dwelling is constructed.

The development of a building materials industry in the developing countries has thus an important social dimension or redistributive implication. In any strategy for the development of a building materials industry, therefore, highest priority would need to be given to the production of materials needed by the relatively poorer sections of the community. In any evaluation of production technologies, the primary objective should be to encourage production of building materials which are durable and inexpensive and which could be produced locally, using locally available raw materials and skills. In devising construction technologies for the less affluent communities, the design and specification of the dwellings should broadly correspond to the traditional design and specifications, so that there would be no inhibition against the use or adoption of the new designs and specifications or of alternative materials or serious technical difficulties in the application of new materials and techniques involving the use of hired skills. It is unrealistic to suggest better ways of building that require significant expenditure of cash because this is one resource that is always in short supply in a subsistence economy. There are just not enough resources in the world to build housing for everybody according to conventional standards, which may cost $100–$300 per square metre as against the $3–$10 required by the rural and urban-fringe communities.

The objective of development of building materials industries to meet the basic needs of the great majority of the population of the developing countries should be not only to make available the same kinds of input traditionally used by the low-income sections of the community but also, by modification of the production process and of construction techniques, to enable them to build structurally more durable and functionally more adequate housing.

Besides "traditional" materials many new materials and components are necessary for urban and large-scale construction. For many developing countries the market is not big enough to justify the production of all kinds of materials and components.

Within these limitations a starting point for the assessment of appropriate production technologies would perhaps be to:

(a) Identify and improve building components that require high performance in constructions;

(b) Identify and develop the production of building materials that should be considered for qualitative improvement;

(c) Facilitate greater use of improved building materials that can be produced locally, using local skills and materials;

(d) Encourage, through policy measures, the development of construction technologies that would harmonize with locally produced materials and with locally available skills.

All this is not to suggest that the building material needs of the modern sector should be totally relegated to the background. The imperatives of basic infrastructure development and long-term development needs do require that adequate attention be given to the development of certain basic materials required in large constructions. However, the relative priorities should be so arrayed that the requirements of the subsistence sector, which are of immediate relevance, receive the highest attention of the Governments of developing countries. The problem is somewhat simplified by the limited size of the modern sector, the comparatively narrow range of technologies used, and by the small number of building types that constitute so large a percentage of total construction.

II. THE PROBLEM

It is only recently that the deplorable living conditions of the vast majority of the people living in rural areas and urban slums have attracted the attention of Governments in developing countries. The quality of the vast majority of rural dwellings in the Economic and Social Commission for Asia and the Pacific

(ESCAP) region has been described as "usually small, insanitary, often in a dilapidated condition and made of locally available building materials that are flimsy and non-durable. The roofs are very low, and the windows, if provided, are very small and inadequate, on account of which rooms are dark and damp". This description can well be extended to slum dwellings in urban areas, with the difference that rags, tins and scraps, packing-box wood and the like are the building materials used, and the environmental conditions are worse, owing to overcrowding. A World Bank survey of the principal cities in 40 developing countries showed that more than half of their population lived in the slums, uncontrolled settlements and shanty towns of 28 cities.

The investment and materials required to meet the housing needs of the rural and urban poor would be colossal. The problem is made more formidable by the fact that the financial resources of a vast majority of the rural and urban homeless and inadequately housed masses are too meagre even to build modest houses, while the key building materials required to build more durable houses are either not available or available only at prices beyond their means. Population growth and unchecked migration from the rural areas to the urban centres have added to the dimension and complexity of the problems at both ends.

The factors that have so far inhibited the growth of building materials industries in the developing countries might be classified as follows:

(a) The absence of an organized sector for the production of materials other than cement and structural steel;

(b) The lack of adequate incentives and assistance for investment in the building materials industries;

(c) Delays in the commercialization of the results of R and D and general apathy towards proved alternative building materials and techniques;

(d) Problems of transportation, which restrict the market for the building materials that are produced;

(e) Fluctuations in the building activities of each country, and uncertainty about markets;

(f) The absence of institutional arrangements to study, monitor and deal with physical and financial problems of the small building-materials industries;

(g) Lack of standardization of some of the newer materials and construction techniques, which has restricted the demand for each category and the building materials produced.

The particular problem of rural areas, arising from difficulties in the financing needed for vital materials to improve the durability of dwellings, is most conspicuous in the appearance of houses in rural settlements and the fringes of many urban centres in developing countries. Because of the generally poor condition of rural roads, the cost of materials is substantially higher than the price paid by urban dwellers. There is also a scarcity of paid employment in rural areas, a factor which, combined with higher costs of conventional materials, makes it considerably more difficult for the rural people to upgrade the quality of their buildings.

To achieve the objectives formulated in the Lima Declaration it is absolutely necessary to increase the output of the building and construction materials industry substantially, not only in its traditional but also in its modern subsector. To achieve this, appropriate technologies have to be identified, developed and used. The process of industrialization in progress in developed countries cannot simply be copied in developing countries, though for the modern (both domestic and international) subsector it contains much to serve as a basis for decision making in choosing appropriate technologies. In the traditional domestic subsector appropriate technology has a different meaning. Here the decisive factors are small scale, low capital investment and maximum use of domestic (local) resources. There is not just one appropriate technology for one product; on the contrary, several technologies can be considered to be the most appropriate at the same time, depending on the scale of operations and other factors. The selection of appropriate technologies depends on factors changing with time. The relation between the prices of various materials, of labour, machines and other input factors changes, and this changes the cost (price) relations of different technologies.

III. TECHNOLOGIES FOR LOW-COST HOUSING

The critical components of the housing required by the low-income population are the roof, walls and building frame. Specific attention should be given to developing the availability of materials that would improve the durability of these three components.

Building materials that deteriorate quickly are generally either organic or mineral, in the form of soft stone or unconsolidated soil. Nevertheless, in suitably protected environments, traditional materials such as wood and dried mud can also last almost indefinitely. The wide differences in durability between the same materials in several situations relates to the configuration and details of building design or the use of protective measures to prolong the life of vulnerable components. The problem is simplified considerably when it is seen as one of obtaining durable surfaces rather than having to make the complete fabric of the building durable.

A correct understanding of the performance demands of various parts of buildings will help to limit areas of application of the more expensive materials and components, thereby reducing costs. Thus, to reduce the costs of walls, it should be possible to change the nature of the walls above the 2-metre level and use perhaps unfired bricks, which cost less than half as much as burnt bricks or concrete blocks. It should also be possible to make unfired brick walls reasonably impact-resistant by applying a suitable fibrous plaster to them.

The security of the roof cladding is of critical significance. The erection of a durable roof is a constant problem of the low-income communities. It is important to develop a roof that would outlast the brief life of the traditional thatch and protect and prolong the life of all other materials within the dwellings. The only example of a locally manufactured roofing product that begins to meet the essential criteria of durability and keeping the inside of the dwelling dry is clay tile. Indigenous styles of tiling in significant use include Mangalore tiles in India and Spanish tiles in Central and South America and some parts of Africa. Like other hand-made products, these tiles tend to be heavy and accordingly demand complex and timber-consuming roof structures. As a result, the indigenous clay-tiling technology has only prospered in areas where timber has remained plentiful and cheap. Countries where timber has become increasingly scarce and costly have tended to abandon the use of tiles in low-cost construction. The lighter machine-made tiles are generally unsuitable for manufacture in village plants, owing to high capital costs.

Many alternative systems and products have been developed and are in use, but none so far developed have solved the problem of obtaining durability at a low cost. Asphaltic coir-fibre cement sheets and the like that have longer lives than traditional materials like thatch, which costs only about half as much as asphaltic coir-fibre cement sheets, are still too costly for low-income groups.

Highly mechanized brickworks have not proved very successful in many countries because of a lack of sustained demand, heavy investment, high transportation costs and the like. These brickworks have largely catered to large-scale localized demands of urban areas and have not benefited the low-income sections of either rural or urban areas. It is essential to develop small, low investment brickworks to meet local demands in rural or semi-urban areas, using locally available soils for the production of bricks of reasonably good quality at low cost. In this connection the techno-economic aspects of the semi-mechanized brickworks developed by the Central Building Research Institute, Roorkee, India, might be further investigated for widespread use in developing countries. Sand-lime bricks, lime-silica cellular concrete and the like are also extensively used in the Federal Republic of Germany, Poland, the United Kingdom of Great Britain and Northern Ireland, and the Union of Soviet Socialist Republics and elsewhere. While such bricks may be ideal in many parts of West and South-East Asia, the capital cost of the technology is very high. Nevertheless, the possibility of scaling down the size of the plants now available and also of the simplification of some of the processes involved might be investigated.

The use of cementitious materials is indispensable in any construction. Most developing countries have already established large-scale cement plant or have plans to do so. However, the high costs of modern cement plants and the scattered and decentralized demand for cement, requiring transportation under difficult conditions, and also the need to conserve cement for essential construction in which its substitution is neither technically feasible nor economically viable, call for production of alternative cementitious materials for use by low-income groups. Technologies developed for establishment of mini cement plants would need to be carefully evaluated and investigated for their techno-economic viability. Technologies have been developed to produce masonry cement made from a mixture of waste lime-sludge from sugar and paper mills and cement, rapid-setting lime-pozzolana mortar and plasters based on lime-kiln rejects and locally available ashes, lime-sludge and rice-husk cementitious materials, and rice-husk pozzolanic materials, which can be a suitable binder in rice-producing areas. Almost any pozzolanic material such as fly-ash, cinder, burnt clay, kiln ashes, fuel ashes and rice-husk ash, can be used to prepare lime-based mortars that might be safely used for low-cost residential constructions.

To economize in the use of scarce and costly Portland cement, the feasibility of increasing the use of blended cements such as Portland-pozzolana cement, Portland fly-ash cement and Portland blast-furnace slag cement should be explored. Mines and mineral processing industries throw out enormous quantities of fine siliceous and dolomitic wastes that could be used to make masonry mortars, flooring tiles and the like. Siliceous limestone rejects, on burning, yield semi-hydraulic lime. Slate-mine rejects and limestone nodules can be good hydraulic binders.

Bamboo and wood are extensively used in developing countries for all of the basic components, as well as fittings and fixtures, of dwelling structures constructed by the low-income sections of the population and will continue to be indispensable for such purposes. However, because of their organic origin, bamboo and wood deteriorate quickly, entailing the constant repair of dwellings constructed with them. There are specialized techniques of using bamboo and wood all over the world. Use of bamboo and wood as reinforcement in cement concrete or in conjunction with lime-pozzolana mortar can be propagated for construction of cheap and durable structural frames for simpler dwellings. Pre-treatment of bamboo and wood against moisture swelling, decay and termite attack can considerably improve the durability of these materials when used in the construction of housing.

In most developing countries timber is costly. First-class timber is beyond the reach of the low-income population, while secondary species of timber deteriorate quickly and need frequent replacement. The solar kiln developed in India to season timber can be used to improve the durability of timber. The pre-treatment of timber used in building components, fittings and fixtures can considerably increase their durability and consequently that of the dwellings constructed with it.

Various technological alternatives for producing building materials have been discussed in detail in the background papers. However, more specific consideration is needed of alternative technologies for the production of cement alternatives and of bricks and structural materials, particularly those using bamboo and wood.

IV. APPROPRIATE CONSTRUCTION TECHNIQUES

There is considerable scope for bringing about improvement in conventional construction techniques that would minimize the use of costly materials without affecting the quality of construction.

There are several components of conventional building structures where, usually, more expensive building materials are used than are actually needed. The tendency to "over-engineer" is more common in conventional modern constructions. The techniques used in urban areas mostly utilize costly and scare building materials, with no attempt to utilize locally available material resources, and rural houses are constructed with local materials with no attempt to improve their quality or durability. Thus, the former are wasteful and the latter substandard. Techniques have been developed to economize in foundation work, walling specifications, doors and windows, building frames, roofing and flooring either by use of alternative building materials or by varying the conventional specifications. The objective is to reduce the cost of construction without detracting from durability of the structures. Some of these techniques have been discussed in detail in the background papers. The suitability of construction techniques in the special circumstances of the developing countries will, however, depend largely on their linkages with the locally available materials and skills, their employment potentialities and the savings they engender in the use of scarce and costly materials, as well as in construction time.

V. RESEARCH AND DEVELOPMENT

The developing countries are very anxious to improve the housing conditions of their low-income populations. Considerable R and D work has been done in a number of developing countries to improve the quality of building materials traditionally used for housing construction by these people, as well as of the techniques followed in such construction. However, since the problem is so vast and since the needs are so divergent, owing to regional variations in construction practices as well as of materials available locally and used, much more needs to be done to create the necessary impact. The problems of the subsistence sector in the rural areas would need particular attention on account of their special circumstances, requiring maximum possible use of local raw materials and skill. The objective of R and D in this respect should be to promote the establishment of building material production capacities in the rural areas, not only to ensure local availability of such materials but also to create employment opportunities there. The national R and D programmes may be aimed at:

(a) Developing suitable building materials from locally available raw materials hitherto unutilized, such as agricultural, industrial and forest wastes;

(b) Improving the durability of traditional building materials by making suitable modifications in the composition of raw materials or by modifying manufacturing processes;

(c) Evolving new construction techniques with a view to economizing on construction cost as well as in the consumption of building materials by the optimum use of their strengths;

(d) Evolving new building techniques to improve the speed and reduce the cost of construction.

The R and D agencies involved in the work should maintain close and constant liaison with both the producers and the users of new building materials and components in order to evaluate their performance. There should also be adequate interlinkage between research and educational institutions, so that the curricula of the latter would include the uses and applications of new building materials and components in order to evaluate their performance. Social institutions should be closely involved in field-testing new building materials and techniques, as well as in the demonstration of these materials and techniques to promote their wider use.

Above all, Governments should not only promote extensive R and D work in alternative building materials and construction techniques, but they themselves should adopt the proven results of R and D in these respects in their own construction programmes.

There is still a considerable gap in R and D work on alternative low-cost roofing materials, cheaper small-scale brickmaking techniques using local clays, and small-scale production of Portland cement. More R and D work is indicated to improve the techniques for seasoning timber and its use in structural reinforcement. Some of these aspects are dealt with in the background papers.

There is considerable scope for co-operation and interaction among developing countries in the field of R and D. Since the problem of housing now faced by all these countries is qualitatively the same, there is much to gain by international co-operation in R and D in this field, all the more so since the materials used in the subsistence sector in these countries for the construction of dwellings are more or less similar in character and origin. Even the traditional construction techniques in the subsistence sectors of many developing countries are substantially the same.

Significant R and D work has been done in a number of developing countries in improving the quality of building materials traditionally used in low-cost housing construction. Exchange of information about these achievements would be mutually beneficial to the developing countries. International agencies can help by establishing data banks on the newer building materials and techniques developed in some of the developing countries and facilitating exchange of technical information and experts between these countries. They can also assist in establishing regional research centres to undertake expanded R and D work on specific building materials and techniques that might be relevant to a number of neighbouring countries.

VI. POLICY

The development of the construction and building materials industry and specifically of production of the building materials needed by the lower-income populations in developing countries has significant economic, social and redistributive implications. As has been noted, the more affluent using costly and sophisticated building materials, construct permanent buildings that are not only stores of value but also appreciating assets, while the poor, using flimsy materials, construct dwellings that are continuous liabilities for them, in that they require constant repair. The richer sections thus gain by investing in building, while the poorer have no real solutions.

The strategy for development of building materials industries in developing countries must therefore be oriented towards the production of the materials needed by the poor to build durable dwellings for themselves at costs they can afford. The production of such building materials can be best developed on a decentralized basis through a policy featuring provision of fiscal and monetary incentives and support in the production of the building materials, and sustained government assistance in the marketing, of the materials produced. In the social construction sector, Governments themselves should, as far as possible, use materials produced in the decentralized sector instead of using, as at present, conventional building materials. This would encourage the extensive production of alternative building materials by expanding the demand for such materials. The production of non-conventional building materials may be left to entrepreneurs in the decentralized sector so as to ensure maximum use of locally available raw materials, to create employment opportunities in the rural areas, and to avoid long transportation of building materials, which increases their delivery price. The Government should, however, mitigate the risks of scattered small entrepreneurs who produce building materials by assisting in the procurement of such inputs as fuel, cement and sand and by guaranteed purchase of a portion of their production. The fledgling small-scale building materials industry would need to be assisted with subsidies, incentives and technical guidance through informal agencies until they become profitable.

The formulation of a governmental policy for the development of the whole construction and building materials industry could contribute to the balanced development of this sector.

Prefabrication, mechanization and the use of improved building materials and components are technical characteristics of industrialized construction. However, industrialization has a further characteristic feature, the use of up-to-date management and programming methods. Modern programming and management of construction activites can, however, be practised only by people with new skills.

All these changes can be promoted by organization, education and training, in order to help those employed in the construction industry to acquire the knowledge and skill needed in the industrialization process.

VII. PROGRAMME OF ACTION

National level

The programme of action at the national level may comprise the following elements:

(a) Formulation of a governmental policy aiming at an overall development of a domestic construction and building materials industry;

(b) Assistance in establishing the necessary organizational, research, education, documentation and financial framework in the construction and building materials industry with the objective of introducing appropriate technologies in these industries;

(c) Identification of the building materials traditionally used by the low-income sections of the population in housing construction so as to initiate a rational R and D programme for these materials;

(d) Promotion of the extensive use of alternative building materials developed through R and D in government construction programmes where the conventional building material can be substituted without impairing unduly the quality of the construction;

(e) Dissemination of information about alternative building materials and techniques;

(f) Establishment of appropriate financial institutions exclusively to assist, through liberal and subsidized loans assistance, the establishment of new enterprises in the decentralized sector for the production of improved traditional and non-conventional building materials;

(g) Establishing the necessary governmental financial or technical organization in order to influence the import of new technologies developed in other countries with the objective to assist the maximal development of the construction and building materials industry;

(h) Strengthening of the existing R and D structure to assume expanded responsiblity of developing all subsectors of the construction and building materials industry;

(i) Establishment of technology centres in the rural areas to provide technical guidance in production as well as in application of new building materials and techniques.

International level

The programme of work which could be taken up by the UNIDO Industrial and Technological Information Bank (INTIB) and other international agencies may comprise:

(a) A comprehensive data bank on the new technologies and processes that have been developed for the production of improved traditional materials and cheaper alternative materials, as well as of the alternative construction techniques for effecting economies in the use of building materials and in construction;

(b) Assistance in the exchange of technical information between developed and developing countries and among developing countries themselves through the establishment of regional R and D centres with technical linkages with the national institutions;

(c) Assistance in the transfer of technologies for the production of appropriate building materials between developing countries;

(d) Organization of training facilities for technical personnel in developing countries in the planning and execution of production programmes, as well as of new construction techniques developed in other developing countries;

(e) Participation, financially as well as technically, in specific R and D projects that might be of relevance and interest to a number of developing countries;

(f) Organization of seminars, expert group meetings etc. to discuss common problems and to exchange experience in the field of development, production and application of alternative building materials and techniques.

Report of the Working Group

SURVEY OF CONSTRUCTION AND BUILDING MATERIALS TECHNOLOGY

The technology for construction and building materials spans both the production and application of alternative building and construction materials and includes the following:

(a) Binders based on Portland cement, lime and pozzolanic and polymeric materials;

(b) Building components, such as natural building stones, mud bricks and stabilized soil bricks, burnt bricks and blocks, concrete and pozzolanic blocks, organic fibres and various roofing and structural materials;

(c) Techniques, manpower and skills for using these building materials in construction.

Binders

Portland cement

The tendency in the cement industry is to build increasingly larger factory units. A normal size is now 3,000 t/d, while units with capacities of 9,000 to 10,000 t/d are now contemplated. They are highly capital-intensive. Smaller sizes more suitable for developing countries with smaller needs use older but modernized technology without much sophisticated instrumentation. Good Portland cement can also be produced economically in a 300-t/d plant.

Still smaller plants, called mini cement plants, with capacities as low as 20 d/t, are being built and have proved to produce clinker of a quality equal to that from a large rotary kiln. However, a continuous control of the burning process is essential, and if this size of kiln is contemplated in another country, it is recommended that full-scale tests be carried out in an existing kiln, as the chemical composition of the raw materials, which varies from location to location, is of great importance. The mini plants would be more appropriate where, for example, there is need for catering to the scattered localized demand and where transports costs from distant large plants would be exorbitant. Also, such small plants have a positive impact on employment and dispersal of industrial activity.

Clinker-grinding plants are another means to lower cement costs and distribute it over a wide area, especially as the product can be transported in bulk and can withstand long storage.

The production of cement for masonry purposes and Portland and pozzolana cements are other ways to increase the output of cement from a given clinker production. The first of these is produced by intergrinding the clinker with up to 50 per cent of an inert filler, usually limestone, while in the second the clinker is ground together with natural or artificial pozzolanas, which can be volcanic aggregates such as pumice or tuff or calcined clays or fly ash. The Portland-pozzolana cements are slower setting, but they may eventuallly gain a strength which is higher than that of cement, and they are usually also sulphate resistant and adequate for certain constructions such as harbours, foundations etc.

The cement industry, as the producer of one of the most versatile building materials, is a key industry in national industrial development. Portland cement is indispensable for certain types of structures; but it can be substituted by simpler materials in other. Thus, building blocks are often produced from cement, but equally good or even better wall materials can be made from clay, soil, gypsum and natural stone with appropriate technologies. Cement production is not as flexible as many traditional building materials. Considerations of economy of scale make it practically impossible to build a cement plant with a conventional rotary kiln of less than 120,000 t/a production and, where the availability of limestone, low-volatile fuels and the like permit the use of shaft-kiln technology, a minimum capacity of 6,000 t/a could be achieved. All other basic building materials industries can operate on both small and large-scales. In some developing countries with low labour costs, smaller and less sophisticated plants appear to have been able to produce a comparable quality of cement at lower cost than the large conventional ones.

Quicklime and hydrated lime for mortar, building blocks and pozzolanic binder are important binding materials which could be substituted for cement in certain situations.

Clay is another versatile material which, reinforced with fibres, can be used as sun-dried wall material in rural housing as well as burnt in simple, well-controlled field kilns to make quality brick for multi-storey housing.

Characteristic uses of some of these cementitious binding materials have been examined in detail in some of the papers included in this monograph. The technologies of producing binding materials which are of immediate relevance to the developing countries in view of their local availability as well as the relative simplicity and convenience of their processing and application are considered below in some detail.

Lime

Next to Portland cement, lime and lime-based binders are of greatest importance as in certain cases they can be produced at much lower cost than cement, on a much smaller scale and with substantially lower investment. For small-scale production, a field kiln of the batch type, which can be put in production whenever there is need for lime, is recommended. For somewhat larger production, the simple shaft kiln using mixed fuel is advisable. It can be run either batchwise or continuously.

A semi-industrialized type of shaft kiln designed for Burundi, for instance, uses only local materials, needs no electricity and can, therefore, be built wherever lime is needed. It has a capacity of 5 t/d.

A more sophisticated kiln of similar design and with higher capacity was designed by a UNIDO expert in Indonesia. Its main features are draught control, gasification of the fuel oil directly in the kiln and recirculation of the flue gases, resulting in a long, soft flame, producing a medium-hard burnt lime. Its capacity is 10 t/d but it can be expanded up to 30 t/d.

Shaft kilns with larger capacities (50 t/d) use a separate fuel-gasifying chamber or gas generators that can use any fuel, including agricultural wastes. Shaft kilns producing 100–200 t/d are built in industrialized countries but are highly capital-intensive.

The rotary kiln is appropriate for large-scale output of a very uniform product. Manufacturers of calcium silicate brick and autoclaved aerated concrete, which are dependent on a uniformly burnt quicklime with a distinct slaking curve, prefer this type of kiln. The rotary kiln is also used where limestone gravel or marine shell deposits are calcined.

Pozzolana

Mixtures of hydrated lime and pozzolanas are excellent hydraulic binders that can often be substituted for or complement more expensive Portland cement. Some natural pozzolanas that can be used for this purpose are pumiceous tuffs, trasses, volcanic ashes, diatomite, and tripolis. The technology used involves drying the pozzolana and then intergrinding it with hydrated lime in a ball mill. Such a plant can be sized according to need.

The artificial pozzolanas are usually made from clay burnt at the temperature that, for a given quality, gives the optimum pozzolanic activity. The clay can be burnt as moulded bricks in a down-draught kiln, pellets in a shaft kiln, nodules in a rotary kiln or powder in a fluo-solid kiln. The last two methods are preferred, as the temperatures can be best controlled. The clay that yields the highest pozzolanic value is kaolinitic clay; rapid cooling by quenching in water has proved to be beneficial.

A new technique for producing a lime-pozzolana cement has been developed and is in use. In it, the clay is calcined together with a part of the quicklime at a temperature of about 800°C. A reaction between the pozzolana and the lime is said to occur. While the lime-pozzolana cements produced according to the first and most commonly used method give a strength of 100–150 kg/cm^2 and occasionally higher, the new method is said to give a strength of 250–300 kg/cm^2.

Gypsum

Another useful hydraulic binder is gypsum plaster. It can be produced in three different types of kiln: field kiln, kettle and rotary. The field kiln used is exactly the same type as that used for lime burning and can be made in any size. The kettle is usually made in sizes producing from 200 to 1,000 kg/batch. The rotary kiln is used when productions of 50 t/d and upward are desired. The main uses of gypsum plaster, which is an easily produced and inexpensive commodity, are for plastering and producing gypsum panels and gypsum board. The use of other suphurous materials as cementitious binders warrants attention.

Building components

Wall materials

The most important natural material used in walls for houses is natural stone. Many varieties are easy to shape and dress (for example, porous coral, slabby stones and volcanic ashes), whereas others need more elaborate techniques.

When suitable stone is not available, mud or clay can be used to form bricks. To improve their quality, these may be stabilized with cement, lime or asphalt. Other soils such as laterites and pozzolanic material can also very suitably be stabilized with lime to produce excellent building blocks and bricks if properly cured.

The next stage in the development is to fire the clay bricks, which can be moulded either by hand or machine. Stress has been laid on the importance of putting the clay through a pug mill before moulding. Such a mill could be of simple design and be animal powered. Kilns for firing clay bricks vary from the simple clamp, the up-draught kiln and the down-draught kiln to the Bull trench kiln, the Hoffman kiln and the tunnel kiln.

Where neither rock nor mud nor clay is available, it may be necessary to produce a building material from sand. Such a product is calcium-silicate (sand-lime) brick, which is made essentially by compacting a moist mixture of sand with a small quantity of lime under high pressure and then curing the green bricks in saturated steam at elevated pressure. Such bricks have high strength, are of exact dimensions and easy to use.

Another calcium-silicate product is autoclaved aerated concrete, which is produced by steam-curing an expanded mass of finely ground silica sand or pozzolana mixed with lime, cement or both. This produces a lightweight block with a high thermal insulation value and, thanks to the autoclaving, it is dimensionally stable. Autoclaved aerated concrete can also be produced in the form of reinforced panels and slabs which can be used not only for walls but also for floors and roofs.

Concrete is suitable in various forms as a wall material. Cast *in situ* (monolithic) methods and the manufacture and use of concrete blocks can be appropriate in many places.

Roofing materials

Natural stone (schist, slate and shale) and thatch are important natural roofing materials. The most common manufactured material is clay tile, which can be produced in many ways, from simple hand moulding to fully automatic industrial plants.

Of the composites, the asbestos-cement combination is used the world over, but conventional plants have very large outputs and are capital-intensive. In recent years much research has been done on the use of natural and artificial fibres. The results with sisal-fibre reinforced cement are very promising, but further studies with regard to its durability are needed. The technology used is either mixing chopped fibre with a rich cement-sand mixture and moulding the mixture into tiles or corrugated sheets, or embedding the strands of sisal fibre in the concrete matrix so that long elements can be produced spanning the whole length of a roof. It is calculated that the cost for a roof of this material would be about one half that of asbestos-cement material. Another advantage is that it could be produced on a small scale as well as in more advanced industrial plants.[1]

Another roofing material, but one that needs a protective cover, is wood-wool cement board. It is not only a roofing material but is also very well suited for walls, external as well as partition walls. The technology involved is to produce the wood-wool with calcium chloride and to mix it in a concrete mixer with cement. The mixture is poured into moulds that are put into a press, and the slabs are then left to cure. The slabs are structural and have a good thermal insulation value, but they must be plastered.

Reinforced concrete planks have been successfully used as roofing material. They have the additional advantage that portions which are required for supporting tiles can be eliminated.

Techniques, manpower and skills

The use of wastes should be encouraged. These include slag, fly ash, cement dust, mineral rejects and tailings, stone dust and chips for terrazzo, sawdust mixed with cement to produce insulating building blocks, and rice husks to be used as boiler fuel, as a fuel mixed in with clay and as a pozzolanic raw material mixed with lime sludge.

Not only is rice-husk ash useful as a pozzolanic material but there are other ashes obtained from the burning of dried banana leaves, bagasse and the like. Since such ashes are produced in large quantities in many places, the technology to produce a cheap and effective binder by intergrinding them with hydrated lime in a ball mill should be promoted.

Behind all processes for the production of building materials and their use in improving the human environment is an amount of experience and know-how that must be possessed by anyone who wants to introduce appropriate technologies. Therefore, special efforts should be devoted to promoting the transfer of technology by means of manuals, audio-visual aids and direct demonstration teams that actually start production, train personnel and return at intervals until the take-off point has been reached.

Adequate incentives in the form of infrastructural, fiscal and financial support would be needed in the initial stages to encourage production and application of alternative materials using local natural resources and labour-intensive techniques.

For the purpose of construction, many other materials and components not mentioned before are needed, such as windows, doors, partitions and fixtures. It is best to provide them from domestic sources as well. A gradual increase in the use of simple mechanical devices and of prefabrication techniques that are not capital-intensive can be foreseen and should be supported.

More rural-oriented research is needed for the better utilization of

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[1] For more detailed discussion of the subject see the paper "Sisal-fibre concrete for roofing sheets and other purposes" in part two.

available local materials and for the improvement of prevalent techniques to permit the construction of cheaper, better and more durable houses in rural areas.

Research into the development of integrated building systems utilizing the various building components (produced as a result of R and D on specific building materials) should be promoted.

In order to use more appropriate construction technologies, simple machines and mechanical devices (hoists, scaffolding and the like) are needed, and designs suitable for their local manufacture should be developed.

PLAN OF ACTION

National level

For the production and application of appropriate technologies, planners in developing countries must recognize that appropriate technologies for the production of alternative building materials and their use in construction, which may be relevant to most of the developing countries in their prevailing circumstances, do exist and provide viable options to the conventional materials as well as production and application techniques and methods. Urgent steps must be taken by the developing countries to identify, assess, select and use such alternative technologies and methods.

A survey or inventory of all raw material resources, large or small, must be carried out including:

Non-metallic deposits, including stone

Agricultural resources such as natural fibres

Industrial and agricultural wastes such as fly ash, mineral tailings, lime sludge and rice husks

Having carried out such an inventory, Governments should evolve a policy regarding the production of construction and building materials, notably cement and bricks. Due note should be taken of the availability of natural materials, such as stone, which require little or no processing. The policy should determine, among other things, where production facilities should be located and the scale of production, large or small, maximizing the use of locally available raw materials and other resource endowments such as manpower. In drawing up such a policy, due consideration should be taken of the fact that the appropriate technological mix should be viewed in a dynamic context. Appropriate technology derives its relevance from the overall circumstances in which it is applied and these circumstances are themselves dynamic.

Governments should establish R and D facilities and strengthen existing ones with a view to developing low-cost building materials, improving traditional construction methods and testing these in the field for suitability and social acceptability. They should also take the necessary steps to ensure that successful results of R and D are translated into action, through appropriate extension agencies with the responsibility and resources to demonstrate new or unfamiliar technologies and through suitable incentives, and financial and technical support.

In this connection, technology centres should be established in the rural areas to provide technical guidance, information and training in application of alternative building materials and construction techniques. Such centres might also be responsible for setting up pilot plants to demonstrate new process technologies as regards both the process and the product.

Government departments themselves should practise what they preach when advocating new appropriate technologies. For example, wherever possible, schools, hospitals and staff housing should be constructed of the same materials recommended for adoption by villagers.

In the initial stages, production of low-cost building materials, should be encouraged through adequate incentives and financial and technical support. The lending policies of the financial institutions should be so devised and liberated as to encourage the adoption of new or unfamiliar appropriate technologies by the private sector, whether by those manufacturing alternative building materials or constructing houses using such materials.

Governments should review the building regulations and standards carefully to avoid inhibiting the use of appropriate technologies in housing construction, especially for low-income groups. Standards should be flexible, varying according to application, as with single or multi-storey buildings, urban and rural areas.

Training of personnel in the characteristics and applications of new appropriate technologies is of utmost importance for the successful production and application of alternative building materials. For example, architects must know of the properties of newly available alternative cements, and masons must know how best to use such materials. Adequate training facilities should, therefore, be established in the developing countries at different levels.

International level

A wide range of building materials and construction techniques suitable for developing countries is now available in a number of developing countries and may be used with or even without adaptation by other developing countries. Measures that can be taken at the international level to facilitate information about such materials and techniques among the developing countries would include these:

(a) Manuals and handbooks giving details about alternative technologies for using stone materials and for making cement, lime, clay bricks and the like on a small-scale and providing information about where the technologies are being used and where further R and D is being undertaken, should be published and updated at regular intervals;

(b) Policy planners, R and D institutions, housing finance institutions and construction agencies, and the general public should be educated on the new and alternative technologies that are available;

(c) Consideration should be given to publishing a quarterly journal on appropriate technology for construction and building materials. Such a periodical would gradually build up a complete reference of appropriate

technologies and assist in eliminating unnecessary duplication of R and D activities.

Expert group meetings should be organized to exchange experiences in the field of development, production and application of alternative building materials and techniques.

Exchanges of persons between developing countries should be encouraged in order to facilitate the practical transfer of technologies. Such exchanges should involve not only policy-makers and R and D personnel but also supervisors and craftsmen, that is, those who really know the practical problems and methods of a technology.

UNIDO should, through adequate financial as well as technical support to existing institutions in the developing and developed countries promote specific R and D projects which may be relevant to a number of developing countries, and especially those which lack the necessary R and D facilities. More specifically further R and D work should be taken up at the international level on small-scale Portland cement plants in the range of 20–100 t/d. Such plants, able to make use of small limestone deposits near the points of demand, should have a low capital/output ratio and the minimum possible production cost per tonne of cement output. Further R and D is recommended in the use of high-volatile fuels for such plants. Within individual countries, research should be carried out to identify and classify alternative suitable locally available aggregate materials for concrete.

The technologies now available for small-scale mechanized brick production have certain services gaps. Further R and D is therefore required as follows:

(a) Simple roller mills suitable for field work are required for the preparation of clay for brickmaking;

(b) Improved technologies for grinding clay both animal powered and or machine powered are needed;

(c) A simple design of extruder needs to be developed for low-cost semi-mechanized brick production;

(d) Efficiency of manual handling systems for loading and unloading unfired bricks needs to be considerably improved;

(e) Further designs for simple furnaces suitable for rural areas should be developed;

(f) The Cinva ram technology for making small soil blocks needs to be suitably adopted and improved for giving greater compression required for larger blocks and for lime-soil and lime-sand mixes.

Wherever conveniently available, use of stone should be encouraged in rural as well as urban constructions. Simple technologies exist in various countries for low-cost processing and shaping of stones for different uses in building construction. A manual should be compiled on the general use of stone in low-cost buildings. More research is needed into the use of larger stone blocks and, in particular, the development of an impact breaker to break out large blocks.

No satisfactory alternative roofing materials have been developed for use in low-cost construction. Continued research is needed on production of low-cost roofing sheets. utilizing natural vegetable and animal fibres. Tests are required as to the durability and strength of such sheets and thereafter of the overall economic viability of their production.

Research on the use of quickly growing trees and bamboo for roofing structures should be promoted.

Research is required into the making of larger clay roof tiles with a view to reducing the extent and therefore the cost of their timber support structure.

General

Promotion of the production and application of alternative building and construction materials has to be sustained by a national scheme of incentives and government assistance, at least in the initial stages. While the use of alternative materials and techniques in construction would need a systematic extension and technical support from government and informal social organizations, extensive use of such materials and techniques should be made in government constructions themselves, especially in the social sector. New entrepreneurs should be encouraged to take up production of such building materials through financial and fiscal incentives, assured supply of raw materials at reasonable prices and marketing of products. Specifications of buildings constructed with assistance from financial institutions should also be liberalized to include buildings constructed using non-conventional materials and techniques.

PART TWO

Selected background papers

Building materials and components

*J. P. M. Parry**

Background

The dominance of the human species over all parts of the earth, in climates frequently hostile to other forms of life, has resulted mainly from two sectors of technology, namely clothing and building. The ability of human beings to protect themselves from extreme heat and cold and from exposure to dust and excessive precipitation has derived from their manipulation of natural materials to make protective clothing and shelters, without which they could not survive seasonal extremes of climate. This paper deals with building and in particular with the materials used to form protective structures.

Building materials can generally be classified into three categories: materials for the basic structure; protective and decorative finishes; and fixtures and fittings. The main distinction between building in a subsistence economy and building in a richer, consumer economy consists in the proportion of the total cost applied to each of these three categories. In the poorest communities, virtually all resources spent on building go towards materials for the basic structure, that is for the walls and roof. By contrast, in a prosperous community the cost of the walls and roof of a dwelling may amount to less than a fifth of the overall cost, the remaining four fifths being spent on finishing and especially on fixtures and fittings and the associated services.

A second distinction, not unconnected with the first, is the relative durability of the building materials used by different economic groupings. It is commonplace for the structures of the poorest groups to last just a few years, and in the case, for example, of houses made of grass and corn stalks, the life of the structure may be only a year. On the other hand, more well-to-do builders tend to build ever more permanent structures the more disposable income they have. Some buildings erected by very rich people have lasted hundreds or even thousands of years after their death. Permanent structures also tend to increase in value with age whereas non-permanent ones steadily depreciate in value. As a result of being able to build permanently, the rich builder gets richer while the poor builder gets poorer as the original investment deteriorates with age (see figure I).

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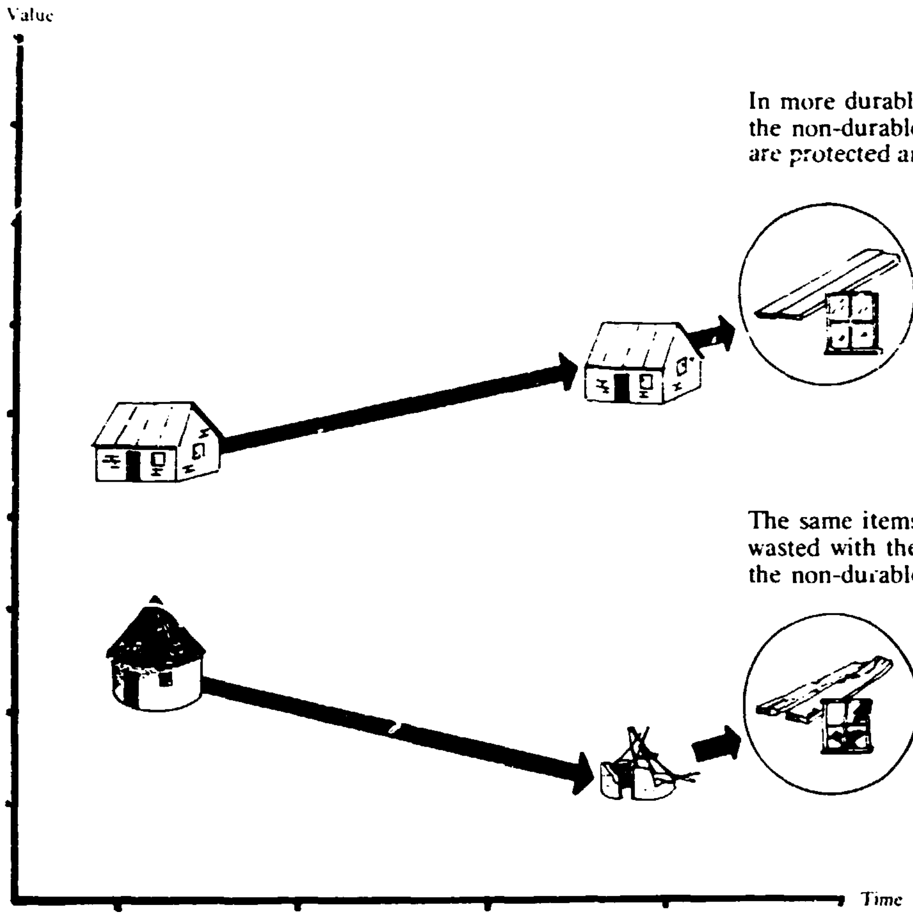
*Chairman and Managing Director of J. P. M. Parry and Associates, a Director of the Intermediate Technology Development Group Ltd. (ITDG) and Chairman, Building and Building Materials Panel of ITDG, on behalf of which this paper was prepared.



In more durable structures, the non-durable components are protected and last longer.

The same items are usually wasted with the demise of the non-durable structure.

Figure I. With time, durable dwellings increase in monetary value and conserve materials; non-durable dwellings diminish in value and spoil materials which, if used differently, could have a longer operating life

Objective

If any single course of action could break the poverty cycle of many of the world's poorer communities, it would be to make their dwellings last for at least the length of a human lifetime. Once their dwellings became a store of value and an appreciating asset, the people concerned would enjoy the following benefits.

(a) The time spent in continual maintenance and eventual replacement of their non-durable dwellings would be freed for income-generating activities;

(b) The parts of the original structure which had deteriorated as a result of general structural decay would in many cases have a long life-span if incorporated in a more permanent building;

(c) As the dwelling increased in value because of its durability, it would become a useful source of capital should the householder decide to sell it. Otherwise, upon the owner's death, the value of the dwelling would pass to the next generation, the most significant form of capital accumulation by the middle classes in many societies.

An important element influencing the care and attention put into the upkeep of a dwelling is whether the householder has any security of tenure of the land. The investment in better materials and the physical effort to improve a structure is clearly not worthwhile for a family facing the possibility of eviction from the land they are occupying.

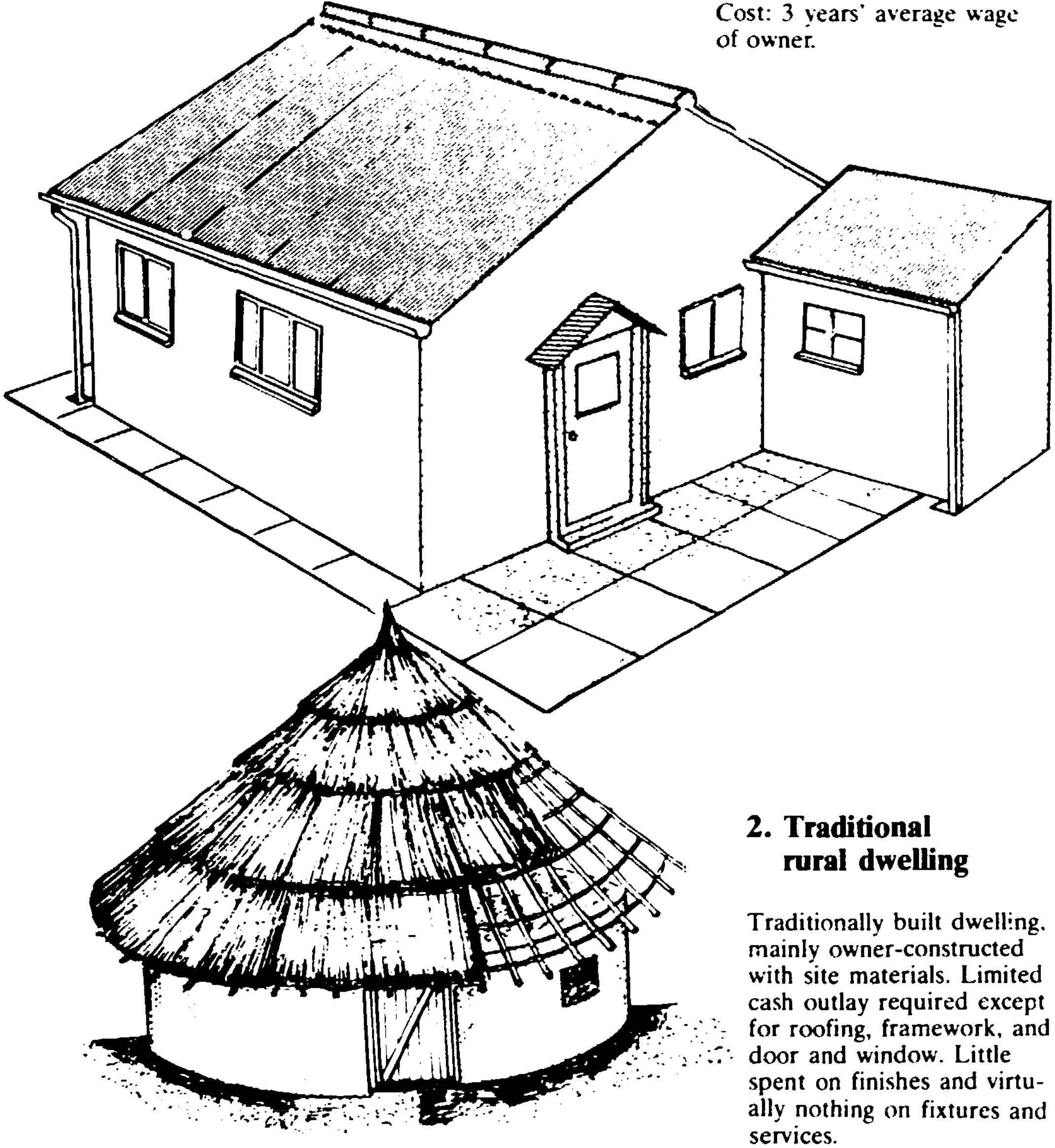
It should be a principal objective for organizations working in the field of appropriate industrial technology to seek ways of manufacturing durable, low-cost building materials. The low-cost element is especially important where it relates to the use of capital and material resources or skilled labour, and less important where it relates to the employment of a labour force which would be otherwise unemployed. In other words, in devising construction technologies for poorer communities, great care should be taken to avoid expenditure of resources that come from outside the community, because the lack of disposable income is the major constraint on all economic activities in a subsistence economy. It is no solution to suggest better ways of building which require significant cash expenditure, because this is the one resource that is always in scarce supply.

Relative building costs

Before attempting to bridge the gap between non-durable traditional structures and permanent conventional ones, the fact must be faced that just not enough capital resources exist to construct a dwelling for everyone at the current cost of conventional building. The difference in cost per square metre of a conventionally constructed building and a traditional unit is not just a few percentage points, it could be as great as a hundred times more. To take a very broad example, current house building costs, using conventional materials and built to conventional standards, now amount to at least $200 per square metre in many countries. Meanwhile, a simple African hut or shanty dwelling in Central America may occupy a floor space of 20 or 30 m^2, but the total cash expenditure on the whole structure could be as little as $50 or $60. Therefore the basic dwelling unit for many rural and urban fringe communities requires an outlay of only about $2 per square metre, compared with $200 per square metre for conventionally constructed dwellings, as shown in figure II. There will be many examples which differ considerably from these broadly based figures, but the extreme difference between the cost of conventional and traditional buildings will remain generally the same. As the proportion of permanent dwellings is so small in the total number of buildings in developing countries, it is therefore economically impossible to find sufficient resources to upgrade all the rest to the same standard using conventional technology. The most suitable approach would be to concentrate on the same type of inputs that the traditional builder employs, and by modifying either the method of building or the processing of these materials, to find ways of making them durable where previously they would have been subject to decay.

Building materials deterioration

In the long term, all building materials deteriorate. Some materials, such as hard-burnt brick, have shown themselves capable of lasting for centuries and will presumably only be worn down again to finer particles at the same rate as



1. Conventional urban dwelling

A conventionally built suburban house, erected by an estate developer at a cost of $200 per square metre.

High costs are more associated with finishes, fitments and associated services than with basic structure.
Cost: 3 years' average wage of owner.

2. Traditional rural dwelling

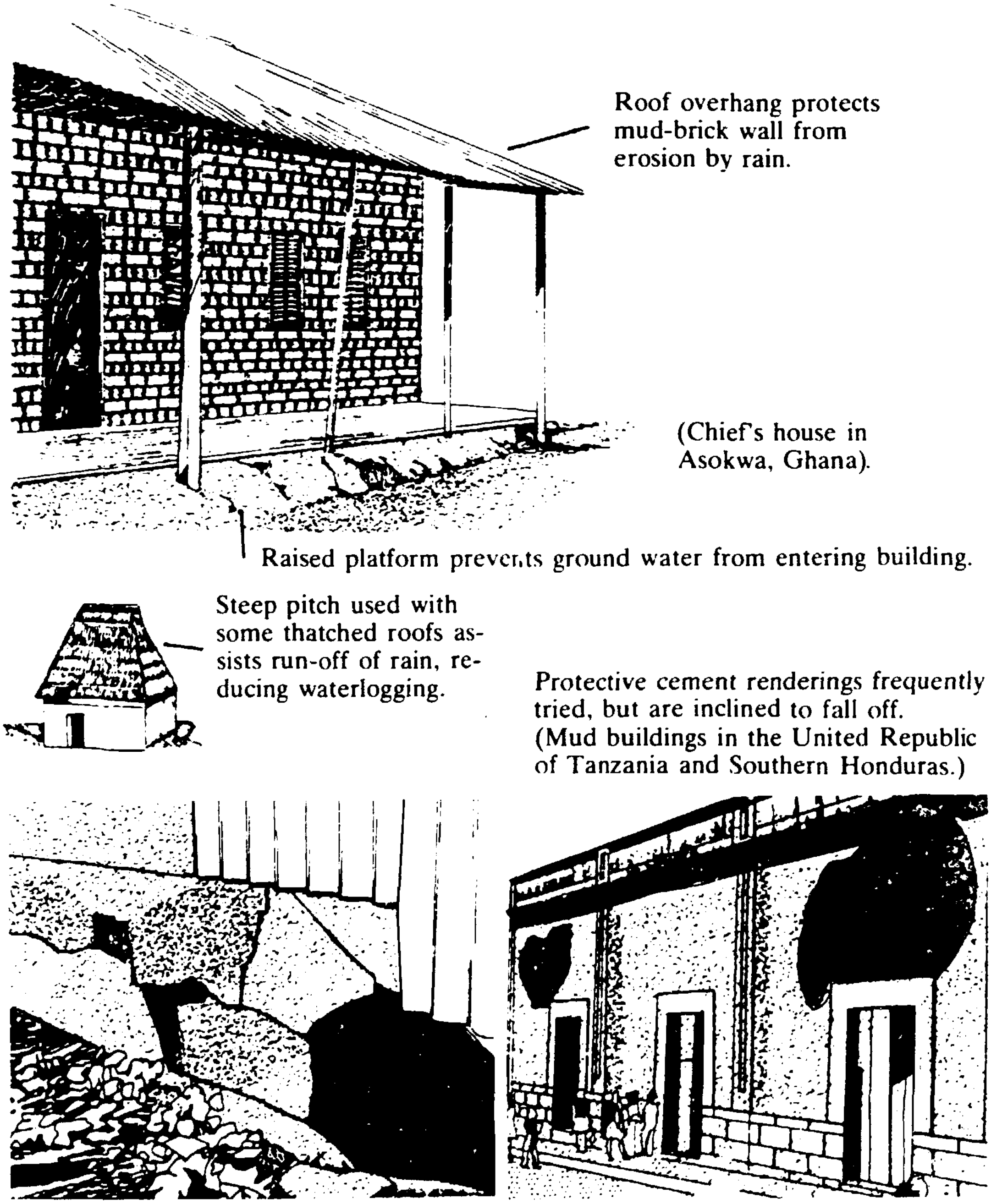
Traditionally built dwelling, mainly owner-constructed with site materials. Limited cash outlay required except for roofing, framework, and door and window. Little spent on finishes and virtually nothing on fixtures and services.
Total cash expenditure usually equivalent to under 6 months' wages.

Floor area 20–30 square metres;
cash expenditure around $2 per square metre;
expected durability, 3 to 5 years.

Figure II. Comparative features of long-life and short-life dwelling structures

the weathering of granite. Other more contemporary materials such as glass, steel and plastic will also maintain their form for a very long time. For this reason the term "permanent" though not strictly correct is usually applied to this group of materials.

The building materials which deteriorate quickly are generally either organic in origin, that is, vegetable and animal products, or mineral but in the form of soft stone or unconsolidated soil which can be disrupted readily by the wear and tear of human occupation, by biological attack or simply by heat, cold or moisture. Nevertheless, in suitably protected environments, ordinarily degradable substances such as wood and dried mud can also last almost indefinitely. Many historic buildings, including some in tropical countries, have significant parts of their fabric built of materials which in humbler structures would have rotted away after a few years. The wide differences in durability between the same material in several situations relates to the configuration and detailing in the building's design, or to the use of protective substances to prolong the life of the vulnerable components. Obviously in the second category the protective substances must be durable. The buildings illustrated in figure III



Roof overhang protects mud-brick wall from erosion by rain.

(Chief's house in Asokwa, Ghana).

Raised platform prevents ground water from entering building.

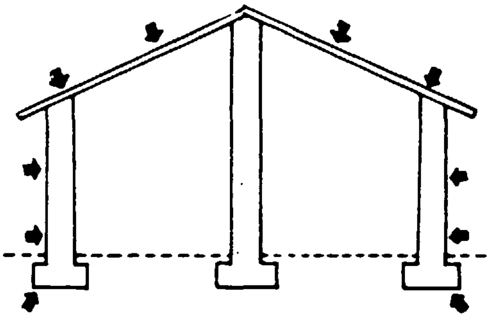
Steep pitch used with some thatched roofs assists run-off of rain, reducing waterlogging.

Protective cement renderings frequently tried, but are inclined to fall off. (Mud buildings in the United Republic of Tanzania and Southern Honduras.)

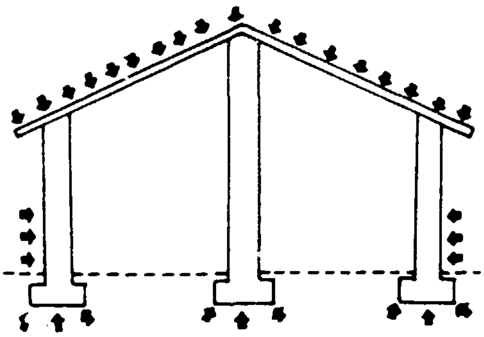
Figure III. Efforts to prolong the life of unstabilized or degradable materials by the use of special building details

involve some techniques used by traditional builders to try to prolong the life of structures. The problem eases considerably when seen as one of obtaining durable surfaces rather than having to make the complete fabric of the building durable. Conventional building technology tends to "over-engineer" parts of the structure particularly the upper sections of partition walls. These are often built of burnt brick or concrete, making them internally resistant to impacts, contact with water and biological attack even though they would normally never be exposed to any of these.

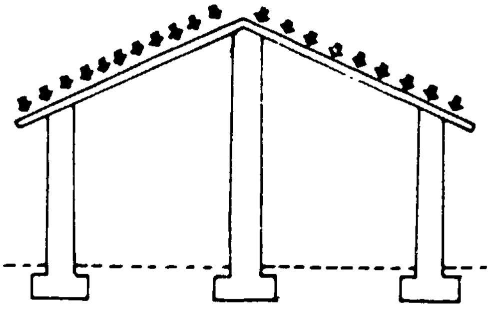
A good starting-point for consideration of appropriate technology in the building sector is to identify where high performance in the materials used is necessary and where it is not. The following summary is in a highly simplified form for the sake of clarity.



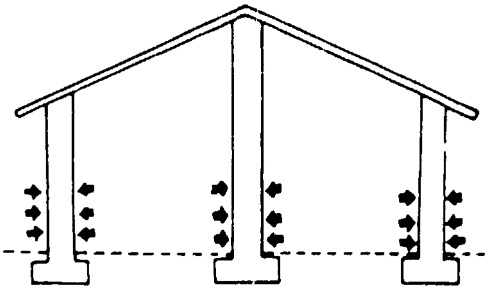
Biological attack
For a complete building "envelope" with secured openings, biological attack is usually confined to the external surfaces provided the building is kept reasonably clean and dry inside.



Contact with moisture
For buildings equipped with a moderate roof overhang, in most climates contact with water will be confined to the roof, the lower part of the external walls and the foundations.



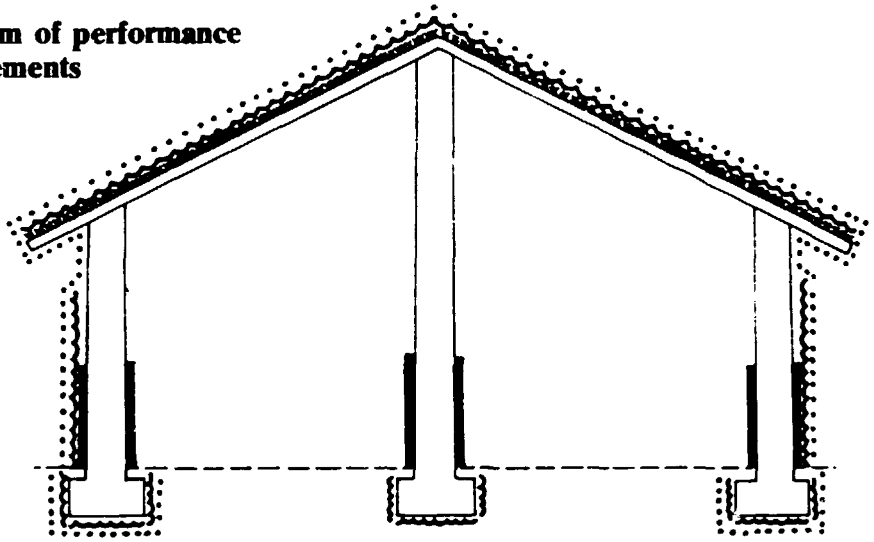
Temperature-change effects
Extremes of temperature change normally affect only the roof and those exposed walls which are not part of the main structure.



Potential areas of impact damage
In a single-storey dwelling, potentially damaging impacts are usually only incurred by the bottom 1.5 metres of the wall with the exception of the area of wall immediately adjacent to the door and frames or opening windows.

This type of analysis yields a set of general building guidelines for communities with limited resources. However, such guidelines would seem extremely tedious to a conventional builder, who is usually concerned more with saving labour than with the frugal use of materials. The basic guidelines would be determined by the expected performance requirements of each part of a building structure so as to reduce the consumption of more expensive durable materials, which would only be used where needed.

Diagram of performance requirements



Special resistance properties required against:

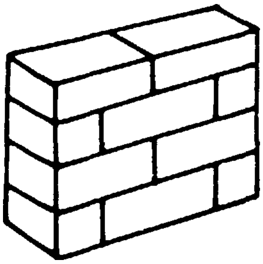
•••••• Biological attack
✕✕✕✕✕ Wide temperature variations
〰〰 Moisture contact
▬▬ Impact (wear and tear associated with human habitation)

In exposed applications it is obviously advisable to use a masonry which is either fully stabilized or protected by a surface skin. The choice will depend on the relative cost or scarcity of materials which have to be purchased for cash, such as cement. Measures designed to eliminate the purchase of heavy materials become increasingly important the further away a building site is from the point of supply. This is a special constraint on government building programmes, and as a result of the unacceptably high cost of construction using conventional standards in remote centres, public amenity buildings are frequently not put up at all, a factor which contributes to the deprivation of many rural areas.

Appropriate technology methods can help to remedy this problem. The four examples of wall building techniques illustrated in figure IV show the approximate weights of purchased materials needed to achieve acceptable standards of durability in a square metre of masonry wall. In the examples shown, the quantity of cement consumed varies from 30 kg to only 3 kg. However, in two of the systems described, other materials have to be used in the effort to save the cement, which would be needed for conventional blockwork. These include various fuels to provide heat in firing bricks or bituminous additives to achieve stabilization of soil bricks. Of the alternatives, the most promising one for resource saving is the use of a strong protective plaster over unfired brick masonry, provided correct techniques are used in formulating and applying the plaster (unlike the examples illustrated in figure III). In areas where indigenous fuel such as firewood is plentiful, the best option is often to build in burnt clay brickwork laid with mud mortar and pointed with cement.

(Example: 1 square yard of 9-inch (230-mm) brickwork, weighing 250 kg)

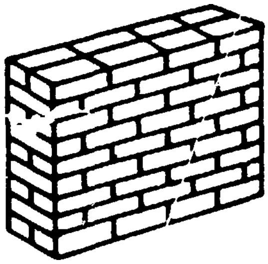
1. Sandcrete blockwork



Solid blocks	Hollow blocks
30 kg cement	20 kg cement

(including sand/cement mortar joints)

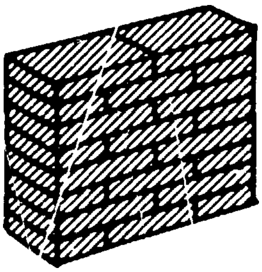
2. Burnt-clay brickwork



Full sand/cement mortar joints containing 10 kg cement	Clay joints pointed with cement mortar containing 3 kg cement

Plus fuel to fire the bricks:
15 kg gas oil (continuous kiln)
20 kg coal (coal-fired clamp)
40 kg wood (wood-fired clamp)

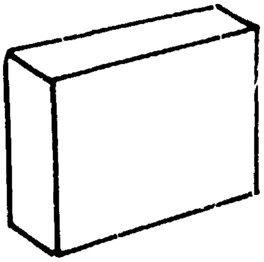
3. Asphalt- or bitumen-stabilized soil brickwork



Full sand/cement mortar joints containing 10 kg cement

Plus stabilizing additive for the brick:
18 kg bitumen or asphalt

4. Sun-dried bricks laid in mud mortar coated with protective sealer and plaster



3 mm fibrous plaster skin contains 3 kg cement

Plus 0.05 kg fibre (natural or artificial)

Figure IV. Comparative material inputs required to stabilize or protect soil or aggregate masonry

The processing of aggregates and soils to achieve a stabilized form often takes place away from the building site. This introduces an important division in the way the construction industry categorizes its technologies between the application techniques of building design and the manufacturing techniques for the production of building components. It is mainly in the manufacture of building materials that the most significant advances are being made in the development of appropriate technologies. Nevertheless, a correct understanding of the performance demands of different parts of a building will help limit areas of application of the more expensive materials and components, thereby reducing costs.

Designing for low cost and durability

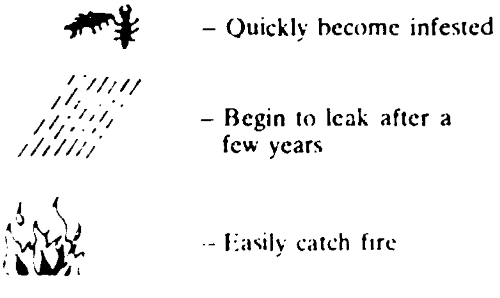
It has already been established that the objectives of durability and reducing costs are in conflict. However, as outlined in the previous analysis, there are several parts of a conventional building structure where more expensive materials are used than are actually needed. For example, provided a building is equipped with a sound roof, much of the masonry in the internal walls and the upper and inner part of external walls need not be fully stabilized as protection against contact with water. Moreover, only part of the masonry needs to be impact resistant and protected against biological attack.

Accordingly, to reduce costs it should be possible to change the nature of the wall above the 5 ft level and perhaps to use unfired brick, which could be less than half the cost of burnt brick and concrete block. Moreover, it should be possible to make even unfired brick walls reasonably impact-resistant by applying a suitable fibrous plaster, provided it is made to adhere properly to the surface of the unfired brick. It is therefore possible to conclude that a durable building could be made with only the lower 5 ft of the external wall constructed of conventional masonry. It would be possible to go further than this only if there were sufficient roof overhang to protect the whole of the wall from rain-water contact or, alternatively, if a protective plaster which could ensure both impact resistance and water resistance (and incidentally, prevent biological attack) could be applied.

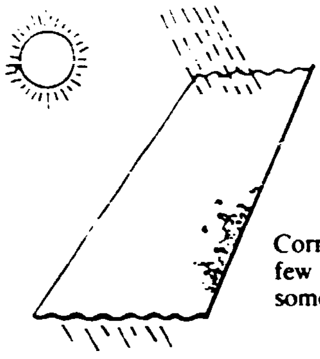
Obviously the critical item in all these specification decisions is the security of the roof cladding. The task of erecting a sound roof is a constant problem for poorer rural communities (see figure V). Many alternative systems are in common use, but none is able to solve the problem of obtaining durability at a low cost.

Several alternative systems are in common use, but each has one or more serious drawbacks

Traditional thatched roofs often look beautiful but are unhealthy and non-durable



Corrugated-iron sheets



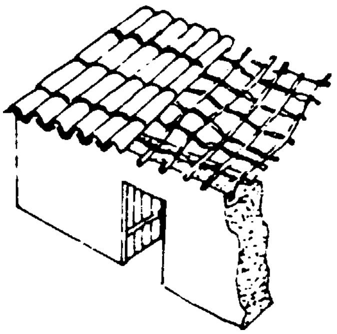
Are noisy when it rains

Corrode after a few years in some areas

Transmit the sun's radiation into the house

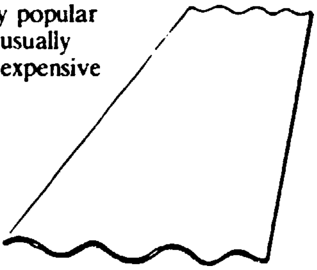
Often require the extra expense of installing ceilings

Spanish tiles are potentially lethal on an unsound roof structure

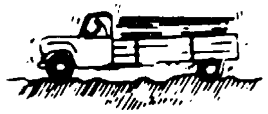


Many rural houses have incredibly ramshackle roof frames on equally insubstantial walls. A serious hazard in earthquake or hurricane areas

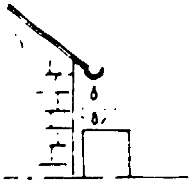
Asbestos-cement sheets



Very popular but usually too expensive



Often arrive damaged after rough rides



May be unsuitable for rainwater collection because of health risk associated with asbestos dust

Figure V. The roofing predicament of poorer communities

Thatch:	There is a double health hazard in the use of thatch. It provides a perfect shelter and breeding place, not only for vermin, rats, mice etc., but also for the various bloodsucking vectors of such diseases as trypanosomiasis.
Corrugated-iron sheets:	This material requires sophisticated manufacturing processes for the sheet steel and galvanizing process and is generally imported by developing countries. As imports they are costly, but in spite of this are a far from satisfactory roofing material. In countries where there are wide differences between day and night, summer and winter temperatures, corrugated roofs, being poor insulators, do nothing to mitigate the discomfort caused by temperature variations.
Tiling:	A minority of developing countries have traditional tiling industries which meet roofing needs of a significant part of the population. However, there are several disadvantages to this type of roof. In countries where sawn timber is scarce, use of tiles adds to the problem because of the complexity of the roof structure required. Elsewhere, in earthquake zones such as Central America, tiled roofs can be a major cause of loss of life because of the inadequacy of the walls and timber structure.
Asbestos-cement roofing:	This material shares an advantage associated with tiling, being a far better insulator than corrugated iron. The fact that it requires relatively little supporting timber structure enhances its popularity. On the debit side the sheets have the disadvantage of being brittle and subject to handling and transport damage on the rough roads in rural areas. The manufacturing process is essentially large scale and therefore unsuitable for application at a village level. Since rain-water collection from roofs is increasingly important for tropical communities, the suitability of asbestos-cement roofing is questionable. The dust produced by the sheets after installation is now regarded as a health hazard and for this reason it may be inadvisable to use water containing this dust for domestic consumption.

Special problems of rural areas

The difficulties people experience in raising finance for vital materials to extend the life of their dwelling is most conspicuous in the appearance of shanty settlements on the fringes of many urban centres in developing countries. The problems of rural areas are greater, and the costs of materials such as cement or roof sheets are frequently three times higher than the price paid by urban dwellers. Rural housing usually looks far more functional than most urban shanty town dwellings, but this is largely due to the well-learnt lesson of the value of maintenance and to the consistency of style and materials used. Moreover, as mentioned earlier, rural householders have greater security of tenure than their urban fringe counterparts, and so are prepared to take more pride in their dwellings.

The often pleasant appearance of traditional dwellings nevertheless conceals a host of problems, including the following: decay and eventual dereliction frequently in as little as five years and the need for continual maintenance in the meantime; increasing infestation by disease-carrying vermin; loss of much of the originally purchased material when the dwelling is finally abandoned.

There is a scarcity of paid employment in rural areas, a factor which, combined with the relatively higher costs of conventional materials, makes it considerably more difficult for rural people to upgrade their buildings by the use of protective and preserving substances.

Appropriate location of production facilities

While rural areas suffer the greatest deprivation in the use of building materials and components, the reverse should logically be true. Rural areas, being the source of origin of most materials used in building, should obviously be the location for many of the production plants. Why, for instance, should the process materials for brickmaking, that is clay, sand, firewood, water etc., be brought into the town to make bricks if all these resources are available in the nearby rural area? It is more logical to bring in the finished product which, for instance, is only half the weight of the sum of the process materials used in the course of manufacture. Furthermore, there is a strong commercial argument against quarrying in the near vicinity of urban areas if the end result is a loss of land area for building. Many urban fringe brick industries, such as those of Egypt and the Sudan, have their clay workings on river banks and actually consume land as they in effect widen the river. At a later time the land area previously consumed would be worth, for building, many times the value of the bricks originally produced.

If instead, bricks and other building materials were to be made further away from the town, the economic and social benefits would be multiple:

(a) Employment would be generated outside the city, providing a counter attraction to the strong desire of rural people to move to the city in search of paid jobs to generate cash to buy clothes, medicine and consumer goods;

(b) Any land consumed by the manufacturing process would be of marginal value compared with urban or future urban land;

(c) In many manufacturing processes, bulky or heavy materials such as water and firewood can be consumed on the spot without adding to the cost of transport into the urban market area;

(d) Additionally, the "waste" grades of damaged or imperfectly processed materials which might be burnt or dumped by an urban plant would be rapidly

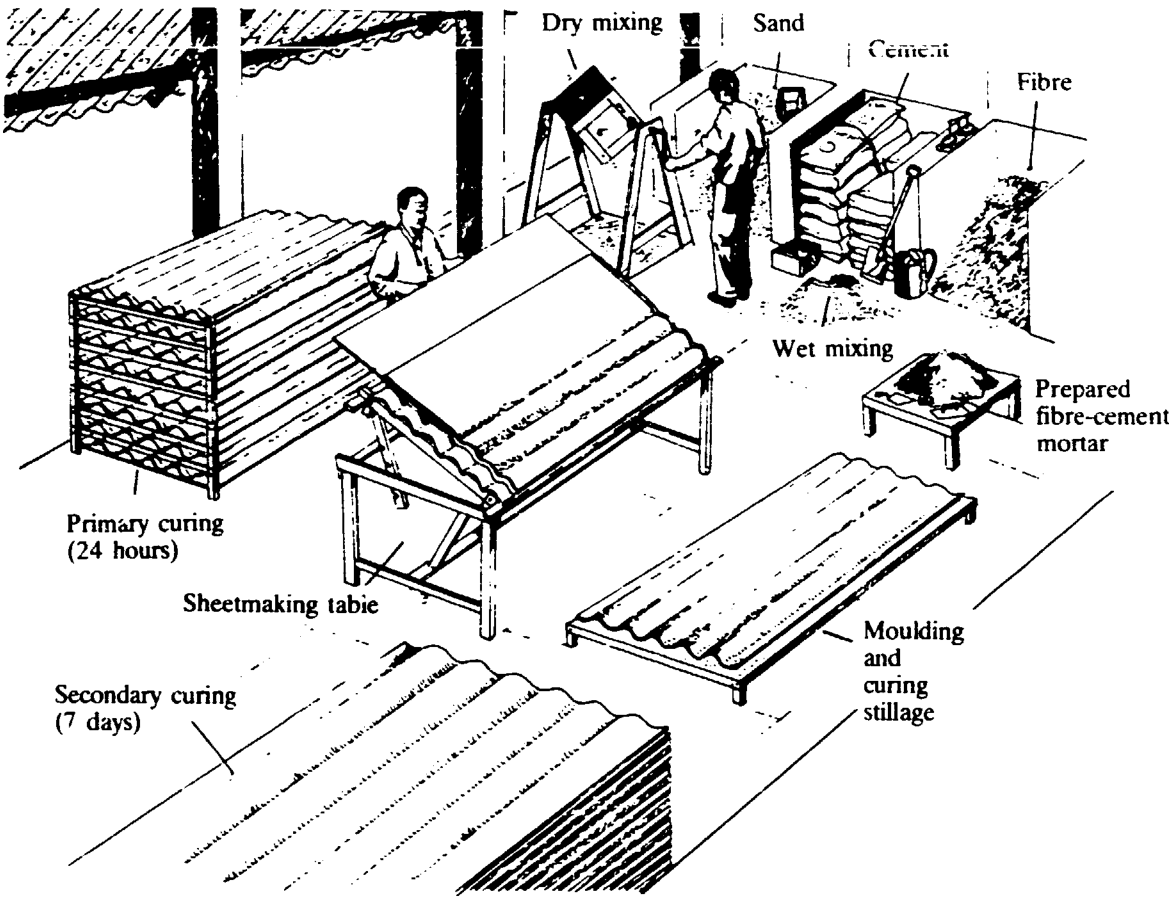
collected and put to some use in a rural environment. For example pieces of tile or brick cracked or broken in the course of manufacture are soon carried off for use in building bread ovens or house walls in the village.

However, many of the world's poorer communities live in areas which are so remote from any prospective urban market that much of the above argument does not apply, and emphasis is therefore on self-sufficiency. People in those areas have the least chance of building permanently, as they will tend to have the least prospect of earning cash to buy materials and the conventional products such as cement, which by the time they reach the village will cost far more than in the city.

Roofing products

Most important of all is the provision of a roof which lasts beyond the brief life of the traditional thatch and in the process protects and prolongs the life of all the other materials within the dwelling. The only example of a locally manufactured roofing which begins to meet the essential criteria of being durable itself and able to keep the inside of a dwelling dry, is the clay tile. Indigenous styles of tiling in significant use include Mangalore tiles in India and Spanish tiles in Central and South America and some parts of Africa. The latter and other handmade products tend to be heavy and accordingly demand complex and time-consuming roof structures. As a result, the indigenous clay tiling technology has only prospered in areas where timber has remained plentiful and cheap. The countries where timber has become relatively more scarce and costly have tended to abandon the use of tiles in low-cost construction. The lighter weight machine-made tiles are generally unsuitable for manufacture in village plants because of the initial capital requirements.

If the use of a tile product made with totally indigenous material and labour resources were impossible because of the cost of timber, the obvious substitute would be sheet materials, which demand far less in supporting structure. Moreover, tiles are generally too heavy to be used in constructing wide overhanging roofs to protect the walls. However, far from being a product suitable for village-level manufacture, corrugated-roofing sheets have hitherto been made in mechanically sophisticated factories and are mostly imported. In the case of galvanized corrugated iron or other metal sheets, this will continue to be the case. On the other hand, there are greater prospects for the small-scale production of other types of sheet made using a combination of fibres and a strong binder. Work on the development of asphaltic materials to bind together a fibrous mat for sheet production has reached an advanced stage. However, up to now, at least two of the production stages have required the use of machinery, thus ruling out the process for most village or self-help applications. Nevertheless, the use of the cement as the binder is leading to a more promising technology. It is technically feasible to make a full size roofing sheet entirely by hand using cement, sand and fibre, by means of a simple process illustrated in figure VI. The manual method of manufacturing fibre-cement roofing sheets which is in an advanced stage of development, uses about 20 kg of cement to make a corrugated sheet 2.5 m in length. Twenty kilogrammes of cement



Pilot plants now in operation in Botswana and the United Kingdom with capacity for producing 6 to 10 sheets a day, employing 2 workers. For 8-ft (2.4 m) fibre-cement sheets in low labour-cost economies, using local natural fibres, production costs are estimated at under $4 per sheet, approximately one half the cost of conventionally manufactured equivalents. If a local natural fibre is used, the bought material cost will consist of cash paid for cement only, and this could be as little as one sixth of the cost of buying ready-made sheets. Roof sheets are an imported product for most developing countries and so this development could lead to considerable import savings as well as reduction of building costs.

Figure VI. Illustration of a process in an advanced stage of development for manufacture of full-sized corrugated roofing sheets, using cement reinforced with artificial or natural fibres (ITDG Building Materials Workshop, U.K.)

represent four days wages for the rural worker in the example, compared with the 24 days of wages that would be needed to purchase a ready-made sheet.

Since the difference in cash expenditure is six to one, the installation of a handmade roof-sheet production unit in a village could greatly improve the prospect of people being able to roof their own houses with such sheets in the near future.

The key to sheetmaking technology is the type of fibre used. The simplest fibres to use are the artificial ones such as alkali resistant glass or polypropylene, but the purchase of artificial fibres would reduce the economic benefits of local sheet manufacture as the fibre might cost nearly as much as the cement. Fortunately a number of natural fibres show promise as cement-reinforcing materials. These include human and animal hairs, various grasses and most of the wide range of natural fibres used for manufacturing ropes, mats and sacking. If fibre from the local village area could be used in sheetmaking, the relative cost would make the installation of a handmade roof sheet system an extremely attractive commercial proposition.

Viable labour-intensive manufacturing: the brick industry

In studying appropriate industrial technology in developing countries, many researchers have failed to note the significance of the active, independent and self-sustaining manufacturing industry, that of brickmaking, in many poor and middle-income countries. It is ironic that where government has intervened and encouraged the introduction of advanced technology in capital-intensive brickmaking plants, the ventures have frequently resulted in failure. There are some essential differences which have led to the survival of traditional brickmaking while so many modern plants have failed. In contemporary burnt-clay brick plants serving the building trade in Europe and North America, the manufacturing technology has gradually evolved towards ever higher labour productivity and use of large-scale energy consuming machinery. The only change in recently established trends has been a return to slightly smaller-scale plants, which are now turning out to be more economic from the standpoint of market distribution costs and ease of administrative control.

When highly mechanized brick production plants are introduced into low labour-cost economies, the inappropriateness of the technology becomes immediately apparent even before the bricks go to the most capital-intensive unit of all, the kiln. In the process stages leading up to the shaping of the brick out of wet clay, conventional modern technology plants can produce vast outputs of bricks, up to 20,000 in an hour with as few as six employees. To make a virtually identical product by hand-moulding, the same six employees would be doing well to make 200 bricks. However, such is the cost of running the heavy machine line, the enormously higher productivity only outweighs the capital, energy and maintenance costs if the labour replaced would have been earning over $3 a day.

Fixed and variable costs

The most significant cause of many of the failures of mechanized brickmaking plants in developing countries is probably the make up of the total cost structure. The majority of the cost incurred by an advanced technology brick plant remains the same even when output varies. In other words, the factories have a high element of fixed costs, and even some of the variable costs, such as the payment of skilled labour to operate the kilns, are in fact fixed, unless the plant actually closes down. Plants with high fixed costs are extremely vulnerable if the market for the products fluctuates, as tends to be case on construction markets. Nearly all the advanced technology brick plants in both developing and Western countries are based on single kilns or two kilns. As these units are designed to run with a fixed output, there is little flexibility in production levels. Indeed the high fixed cost component makes it essential to run at maximum output to keep unit costs down even when there is a recession in market demand. What happens next is an attempt by management, faced with cash flow difficulties to economize on operating costs. A capital-intensive brick plant running at half the designed output frequently incurs total unit costs 70–80 per cent higher than when run at normal output. Privately operated units generally close down after operating for a time under these conditions. The traditional plants will no doubt have suffered equally from falling demand during this time but their reaction will have been entirely different, and this accounts for their resilience. A feature common to traditional brickmaking industries throughout the world, for example in Egypt, Honduras, India, Indonesia, Lesotho, Malawi, Mexico, Sudan and Turkey is that brick plant owners do not expect the same constant output. In fact brickmakers in most of the above-mentioned countries operate only seasonally and stop production during the rainy season. Having very little in the way of fixed costs to worry about, they only resume brick production if they feel fairly certain there will be a market. Such a policy does not work to the benefit of the building trade, which in many countries puts up with a period of severe brick shortage while waiting for the traditional producers to decide that the rains have stopped and that it is safe to make bricks again.

The resilience of traditional brickmakers and their ability to survive when normal commercial undertakings would have failed may be explained as follows:

(a) While most mechanized units are utterly dependent on supplies of energy and spare parts, all usually imported, many traditional brickmakers can keep themselves going, obtaining their own supplies of firewood for fuel, and making and refurbishing most of their own simple production tools;

(b) Stockpiles of finished bricks do not need to be expensively managed and provided with extra facilities. Instead, the inventory could just consist of fired clamps of about 40,000 bricks left to stand without further attention until the market requires them. It is even possible to stop the outflow of cash before a clamp is fired, by leaving it with the bricks still in the dry form, sheeted down for protection against rain;

(c) Even though labour laid off from a traditional plant will suffer hardship during times of low market demand, it does not usually depend completely on the plant for employment, and can drift into other work until things improve. This is certainly preferable to the brickmaking operation going out of business altogether;

(d) During a time of crisis and prolonged market stagnation, if all else fails the traditional brickmaking establishment can simply disappear and lie dormant. The only essential assets that should be preserved intact are the technical know-how and management ability of the individuals concerned, which can ensure the resumption of brickmaking when conditions again become favourable, whereas mechanized plants, dependent on imported resources frequently become unworkable.

The most commendable feature of the traditional brickmaking industries therefore is that they usually survive. Only in occasional instances have general market conditions or the arrival of mechanized brick production eliminated the traditional operator.

Since the time of the big rises in the cement price there has been a notable revival in some traditional brick industries, and many developing countries where brickmaking had either died or never existed at all have attempted to establish new industries.

Gaps in traditional brickmaking technology and the manufacture of other building materials

In contrast with the desirable features of the traditional brick trade, there remain a number of shortcomings which might be overcome by officially sponsored research and development (R and D) programmes. It should be noted that traditional brick and tile producers have operated for decades virtually without any R and D and with little or no help from outside. Thus care must be taken to ensure that in encouraging the introduction of improved methods, the vital survival ability of the traditional production units is not lost.

An examination of R and D priorities was recently commissioned by the Overseas Division of the United Kingdom Building Research Establishment. The conclusions reached were that in most places where it was technically possible to make bricks and a good market for them existed, bricks of some kind were usually being produced already. The prevailing need appeared to be not so much to create brickmaking technologies for people who had previously lacked them, as to help existing producers make better-quality bricks more efficiently, less impeded by climatic changes and in more congenial conditions.

Even in 1978, it could be observed in many brickmaking enterprises in developing countries that the wheel has not yet been "invented". Heavy loads of clay and bricks are manually carried from quarry to moulding station and to and from the clamp kilns. In many production units working conditions are very poor, especially for the moulders and brick carriers, who must endure work that is dirty and which continually exposes them to the full heat of the sun. In the event of unseasonal rainfall, several days' production of bricks can be spoiled in one night, and during the rainy seasons, the building trade can be brought to a standstill because of the lack of bricks. Gaps in the technology for many of these industries need to be filled, but to avoid undermining the essential independence and strengths of the enterprises, the solutions proposed should involve low capital costs and the resources used in carrying them out should remain under the brickmakers' control.

Most important of all is the need for a low-cost working shed consisting of little more than a support roof under which to mould and to dry the bricks without danger of their being spoilt by rain. An elementary roof providing just a minimum head clearance of 2.5 m and similar distances between upright supports would suffice. Although less convenient than the high, wide-span roof, such a structure would involve a fraction of the cost. Ideally, the basic structure should be built first, later extended piecemeal, and financed out of the cash flow rather than through raising capital for investment.

In the production processes it is clear that the traditional brickmakers are very responsive to simple ideas to improve working methods, and there are numerous examples of equipment and techniques which have come into use once the benefits were realized and the equipment became available. For example, brickmakers in Malawi have adopted a special clay-breaking hoe with a weighted end, in the Southern Sudan they have recently taken to using wheelbarrows, while in Honduras "Scotch" kilns have come into use with corbelled brickwork fibreboxes increasing control over burning. In Lesotho and Turkey horse-propelled pugmills have been introduced to assist clay mixing while the Northern Sudan brickmakers now use accurately welded metal moulds in place of the wooden formers previously used.

Many other problems remain unsolved, most of them relating to the use of a wider range of building components such as roofing tiles, floor tiles, pipes and any other products made from clays, sands and aggregate. Matters of priority concern include the following:

(a) Facilities to quarry materials in a form which produces an evenly proportioned material taken from the working face at all levels;

(b) Better and less costly means of obtaining and storing water for the production process. (Much of the process water used in traditional building material manufacture has to be physically carried from rivers.);

(c) Simple systems for grinding and screening materials to the desired grain size;

(d) Moulding and shaping systems which can work with the raw material in a less wet and plastic form. Such a development would speed the drying process, saving space while at the same time producing items which are more likely to retain their original moulded shape without subsequent distortion;

(e) Developments in the design of buildings used for drying to enable them to adjust to and make the best use of ambient conditions, catching all available wind when required, but able to prevent overrapid drying in other conditions while also providing protection against the weather;

(f) Improving fuel utilization through the development of simple techniques for continuous or semi-continuous firing of the products;

(g) Development of technologies for the application of waste heat from other industrial processes, such as charcoal burning, to the drying or burning of ceramic products;

(h) Improvements in the design of hearths, grates and flues to make more efficient use of firewood for burning and of new techniques for burning agricultural and forestry by-products such as sawdust or chaff;

(i) A system of hand-operated industrial trucks or barrows to ease the movement of heavy or bulky materials. Conventional wheelbarrows are being used in some instances, but they are not suitable for the handling of bricks.

One of the priority areas outlined above has already been taken up in a combined programme by the United Kingdom Building Research Establishment and the IT Building Materials Workshop to develop improved brick-moulding techniques.

Implementation of improved technologies

It is one matter to innovate new technologies for building materials industries, but another question entirely to formulate how these can be successfully tested and implemented.

Governments can do much to promote fledgling building materials undertakings by helping to mitigate procurement and marketing risks. The procurement risk can be eased by official help in ensuring supplies of essential materials at consistent prices. For example, if it were decided to assist in establishing small enterprises producing handmade fibre-reinforced roofing sheets, official help could be given in procuring cement when this commodity is in short supply on the open market. Alternatively, it would be a considerable help if, in the early days of the venture, lorry loads of the appropriate grade of sand were supplied by the Public Works Department.

The marketing risk could be lessened if the public sector undertook to purchase a guaranteed proportion of the output in the early days of a venture. In the case of a handmade roofing sheet project, it could be arranged for the new product to be used in current school building projects or for public housing.

With two of the major areas of risk partially removed, it would be much easier for a person who had never previously run a business to embark upon a new venture and to concentrate on ensuring that production starts up well. Subsequently, the need for the official procurement service would probably decrease as the enterprise began to identify its own sources of supply. At a later stage it would be able to study the market, and could well find that better prices could be secured from private sector sales, thus reducing the need to rely on officially supported marketing arrangements.

To promote the development of appropriate building technologies for developing countries, international efforts should be made to identify the most promising technologies and to prepare them for marketing in the private sector, including the poorest rural communities. The technologies may already exist, but their potential has not yet been fully exploited. Other potentially valuable technologies are offered by materials or production systems being developed by various organizations, but which have not yet been fully worked out.

Appropriate building material technologies should meet the following criteria:

(a) Equipment should be easy to operate and maintain by the operators themselves, and also suitable for duplication at a cost accessible to its intended users in the small metalworking or carpentry workshops found in most towns in developing countries;

(b) Materials and components should be designed to strengthen traditional building structures and improve their amenities and sanitary conditions;

(c) The use of high-cost items and purchased processing materials, such as cement, should be kept to a minimum.

The programme will require the full co-operation of Governments and development agencies in channelling assistance to poor rural communities that have hitherto benefited least from such programmes.

10281

Recent trends in integrated stone development planning

A. *Shadmon**

Planning and management of stone resources (including basalt, granite, marble and building stone) is a basic necessity in a young economy. A return to fundamentals, easier in the developing than developed countries, is essential. A quiet revolution has taken place in stone utilization since the beginning of the energy crisis.

In various parts of the parts of the world, chalky limestone and volcanic tuffs lend themselves to easy extraction and subsequent use in construction without any intermediate processing.

Where the construction economics are right, and mechanized quarrying is feasible, many tuffs may become important for popular housing programmes and compete with prefabricated units, which use little natural stone.

Large housing projects benefit from using quarry-to-site blocks and justify mechanized lifting equipment for placement of the masonry. The blocks loaded on to large trucks are transported without any further fabrication or processing to the building site to be mechanically lifted and placed in position. In developing countries, where stone is often the only locally available building material which does not have to be transported on the human back, simple lifting devices will do.

It is absurd to pass broken stone through a technological process and return it to an unbroken state in the form of concrete. Technological advances in extraction and processing have enabled stone to be used in ways economically unthinkable not so long ago. The use of epoxy, prestressing techniques, and innovations in processing and at the quarry are a few of the factors contributing to the extended use of stone in building.

In extraction, besides the advances in heavy-duty equipment, new sawing and splitting techniques applied by hand-operated machines help to save much of the energy consumed by other types of motorized equipment. These advances have given an impetus to new training techniques based on the fundamental principles of rock mechanics, and stone splitting is revolutionizing low-cost housing in hilly areas. Only proper training in fundamentals provides the knowledge to make optimum use of the physical properties of the weakest labour-saving stone materials.

Stone development is perhaps one of the few fields in which the prospects for success are apparent throughout the world. Additional positive development

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*Senior Consultant, Stone Technology International, Jerusalem, Israel.

aspects include low initial investment, labour intensiveness, small energy requirements, the possibility of small-scale production units, and the provision of a low-cost, and at the same time prestige, material with high added value for export.

The intensive development of stone in the last decade has brought with it a new concept called integrated stone technology planning. It applies to both developing and developed countries. A national master plan, under this concept, would include physical, industrial and socio-economic aspects. Such a plan could ensure, for example, that stone prospects unique for a certain area would not be lost to posterity as a result of urban development on an economic deposit.

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Non-cement-based hydraulic binders

*P. O. Grane**

Portland cement is today the most important hydraulic binder, and lime-based binders rank second. Although the properties of lime-based binders do not reach the same standards as those of cement, they are quite good enough for the purpose for which they are used. They are also cheaper, and the investment required for their production is far lower than that required for a Portland cement plant. In addition to natural hydraulic lime, artificial hydraulic lime can be produced by intergrinding high-calcium lime with pozzolanas, natural or artificial. Such binders have considerably higher strengths and can replace Portland cement in many instances.

Another hydraulic binder is calcined gypsum which has the advantage of reacting quickly with water and of hardening in a very short time. However, its exterior use is restricted because of its high water absorption and resulting decrease in strength.

Lime

The lime industry has grown into a highly mechanized industry with very large plants, but despite this development all the intermediate stages of lime production are still being practised. Primitive kilns are still commonly used today in many countries.

The simple type of shaft kiln has been further developed into a variety of highly mechanized forms with large outputs using different types of fuel. Such large modern kilns are very economical in terms of fuel and labour inputs and especially suitable for industrialized countries, but their investment cost is high. They can be fired by gas, oil, coal or other means, as in the case of Argentina, where they are provided with a gas generator in which wood or any available solid fuel (even grape seed and olive remains) may be used. For developing countries, kilns with capacities in excess of 100 t/d are as a rule unsuitable. Smaller, more simply designed and labour-intensive kilns with low fuel consumption represent a more appropriate technology which can be distributed over larger areas and thereby promote the dispersal of industrial activity. One such kiln with a capacity of 10 t/d was designed by a UNIDO expert in Indonesia. It has an effective shaft height of 11 m, an inner diameter of 1.6 mm and a sinking speed of 0.2 m/h. Fuel consumption is 1,150 kilocalories per kilogramme of lime. The kiln also has the following characteristics:

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*Consulting Engineer, Indústrias Betcel S. A., Buenos Aires, Argentina.

(a) Draught control, achieved by installing an injector tube for low-pressure compressed air in a short chimney;

(b) Gasification by direct injection of oil from burners moving back and forth in the fire openings;

(c) An outer shell of steel to prevent air entering through cracks in the masonry.

This kiln, of which three units now exist in Indonesia, can be built for approximately $60,000. However, even that is considerable compared with the cost of a traditional shaft kiln. A much cheaper kiln of similar type was designed by the author in 1976 for the Government of Burundi. The total height is 10.5 m and its inner diameter is 1.2 m. It is a mixed feed kiln with additional firing using wood or peat. It was intended to be put up in the bush where no electricity is available. Instead of costly refractory brick, natural stone such as diorite or sandstone is used. The kiln is built around a pile of thin-walled steel against which the stone is laid in a refractory mortar consisting of diorite powder from the crushing of road gravel, and mixed with a kaolinitic clay and a small amount of alkali. An outer wall is made of red brick laid in cement mortar. The kiln is banded throughout its entire length with 100 x 8 mm steel bands to prevent cracking or openings in the wall. After a period of continuous firing the inner shell will be burnt away, but then a hard and tight wall of refractory material will have formed.

The kiln has a capacity of about 5 t/d and costs approximately $20,000. By increasing the diameter a higher capacity could be achieved without much of a rise in the cost, given the cheapness of the construction material. Where needs are moderate and electricity is unavailable, such a kiln would perform very well.

Lime-pozzolana cements

Through the addition of a pozzolana to lime, or rather by intergrinding the two, a hydraulic binder of great strength is obtained. Hydraulic binders harden under water, are sulphate-resistant and the hardening process continues for a long time. Such binders were already used by the Romans, and their constructions have endured to this day.

The pozzolanas used to produce lime pozzolana cements may be either natural or artificial. The first group includes tuff from Pozzouli in Italy, from which pozzolana derives its name, Santorin earth, Rhenish trass, rhyolitic pumicite, diatomite, gaize, tripoli etc. Among artificial pozzolanas the most common is calcined clay, followed by flyash, which is the waste product from the burning of pulverized coal, and which is used on a very large scale in countries like the Federal Republic of Germany, France, the United Kingdom and the United States. Another artificial and commonly used pozzolana is Indian *surkhi*. Other raw materials for artificial pozzolanas are siliceous and opaline shales, in addition to spent oil-shale, which has been used in large quantities in Sweden for the production of gas concrete. Finally, ashes from the burning of rice husks, dried banana leaves and sugar cane stalks have shown good pozzolanic activity. Rice husks are burnt in large quantities and usually the ash is thrown away. In one instance the author has seen ash sold for use as an abrasive in a cleanser.

Large quantities of ashes are produced in firing clay bricks and tiles when such fuel as banana leaves and sugar cane stalks are used. Ash from banana leaves has been used to stabilize earth together with lime.

Production of artificial pozzolanas

The technology used to produce artificial pozzolanas in its simplest form involves crushing the rock or the clay and then moulding bricks from the resultant powder. These bricks are sun-dried and then fired in a clamp or preferably in a down-draught kiln. No temperature control is possible in a clamp, and even in a down-draught kiln it cannot be avoided if the outer bricks in the stack are burnt harder than the inner ones, resulting in a variation in pozzolana quality.

The most commonly used type of kiln in industrial production of artificial pozzolanas is the rotary kiln, which can be built in any size to suit desired capacity.

After crushing, drying and grinding, the clay is nodulized in a pan pelletizer and fed directly to the kiln, where it is fired to the appropriate temperature established by making activity tests on samples burnt at different temperatures. Kaolinitic clays are calcined at 750°C, while montmorillonitic clays require a temperature of 600°–800°C, depending upon the chemical composition, degree of alteration and exchangeable cations of the clay. Illite clays require firing at 1,000°C to give maximum strength when combined with lime.

For the installation of a rotary kiln plant, a feed-bin, a sluice-gate, a preheater (optional), a rotary kiln with refractory lining, an oil burner with blower, an exhaust fan and a dust collector are required. The size of the kiln can be easily adjusted to the desired output, for example a small kiln of pilot plant size with a diameter of 1.0 m and a length of 10 m will have a capacity of approximately 7½ t/d. The investment required would be about $110,000. A somewhat larger kiln with a diameter of 1.25 m and a length of 18 m would be able to produce 15 t/d, the investment being about $160,000.

A final installation for producing lime-pozzolana cement would require two feed-bins for hydrated lime and pozzolana, two disc feeders, a ball mill, an elevator, a storage bin, a dust collector and a packaging machine. Exact cost estimates for this installation are not at present available.

A more sophisticated approach and a considerably larger output of 820 t/d of lime-pozzolana cement would cost $10 million. A Portland cement plant with the same output would cost $45 million.

Building components based on lime-pozzolana binders

The most obvious product made from a lime-pozzolana cement is mortar, either in the form of a binder or in the form of building blocks or bricks.

The author has carried out a series of tests with a trass-lime cement consisting of one part of trass and two parts of hydrated lime, which were ground together in a ball mill. Bricks were made using a river sand in the proportions 1:3, 1:4 and 1:5.

Curing was done in a humid atmosphere, in a plastic tent, in a water-bath at 95°C and in an autoclave at 130°C. The curing in the plastic tent lasted seven days, in the water-bath 10 hours and in the autoclave 2 hours. The bricks were handmade by ramming the mortar into the moulds and then vibrating them. The resulting strengths were as follows (kg/cm²):

Mix	*Plastic tent, 7 days*	*Water-bath, 10 h at 95°C*	*Autoclave, 2 h at 130°C*
1:3	72	103	89
1:4	81	89	88
1:5	74	86	88

It is interesting to note that there is very little difference in the mixes and that the different types of curing have produced very similar results. Thus, instead of waiting for seven days, a rapid curing in live steam for 10 hours will produce a brick that can be sold and used the next day. If greater production is desired, curing in a low-pressure autoclave at less than two bars for only two hours will produce the same quality of brick or block.

The analysis of results must include the determination of tensile strength, shrinkage and frost resistance, which is a measure of the stability of the brick. Water absorption should also be tested. If the latter is considered too high, the addition of 2 per cent of asphalt, Rockwell hardness number C-70, can be made. Such tests have been undertaken, but remain inconclusive. However, the technique has been successfully used in Peru to stabilize adobe bricks.

Calcium silicate (sand-lime) bricks

The rate at which a finely divided siliceous material combines with calcium hydroxide apparently depends on a number of factors, most of which are not clearly explained. It appears that any siliceous material of sufficient fineness, regardless of its mineral structure or composition, will combine with calcium hydroxide, or, in other words, will have a certain pozzolanic activity. This property is applied in the production of calcium silicate bricks using quartz sand as the basic raw material. Another product using the same raw material is the cellular light-weight concrete called gas concrete. However, because of the slow rate at which quartz sand and lime react, it is necessary to increase the velocity of the chemical reaction by raising the temperature close to 200°C, which is done by autoclaving the products in saturated steam at 10 to 12 bars. This results in stable hydrated calcium silicates, of which the most important is the mineral tobermorite.

The use of calcium silicate bricks has grown considerably in recent decades thanks to higher quality bricks based on improved production techniques. The need for calcium silicate bricks grows stronger when brick clay is unavailable or unsuitable, or when it produces low quality bricks. An added attraction, which is the main reason for its use, is that calcium silicate brick can be used directly as a facing brick and its white colour increases its appeal and demand.

The required raw materials are quartz sand and lime. The quality of the sand, which accounts for more than 90 per cent of the raw materials, is important. However, the grading of the sand, which in a high degree influences the quality of the finished product, is more important than the silica content, which should be at least 80 per cent. If an available sand does not have the proper grading, it will have to be corrected by blending two sands or by grinding part of the sand in a ball mill.

The manufacturing process consists essentially of compacting an intimate moist mixture of hydrated lime and sand under high pressure into the required form and curing the green bricks in high-pressure steam. The smallest calcium silicate brick plant that can be effectively operated is a single rotary-table plant with an output of about 2,500 bricks per hour and manual stacking of the bricks. A single eight-hour shift operating 250 days a year would make about 5 million bricks per year. With a standard brick of 240 mm x 115 mm x 71 mm, this would mean a production of about 20,000 t/a, or 10,000 m^3. Daily output would be 20,000 bricks, or 80 t. Machinery and equipment for the plant would cost about $1,040,000 f.o.b. at a European port, and land, factory buildings etc. would cost another $300,000. The estimated cost of production is $35–$40 per 1,000 bricks.

If built in an industrialized country, a large plant such as that described above would be designed for two presses, each pressing two bricks at a time, with a capacity of 6,000 bricks per hour. Operating on two shifts, for 300 days a year, it would produce nearly 30 million bricks with a volume of 60,000 m^3, per year. This would be equivalent to a half-brick wall of approximately 500,000 m^2. The investment cost for such a plant, with automatic off-loading and brick-stacking machines, would be about $1,400,000 f.o.b. at a European port, to which another $350,000 should be added for land, buildings etc. The cost of production in this larger plant is estimated at $25–$35 per 1,000 bricks.

Gas concrete

The remarkable growth in the production of gas concrete (autoclaved cellular light-weight concrete) since it was first developed in Sweden in 1924 is due to the light weight, high thermal insulation and low shrinkage of the product. Siliceous and calcareous raw materials, generally quartz sand or a pozzolana and lime or cement, are required. The finely ground materials are mixed with water and aluminium powder. The aluminium then reacts with the lime and produces hydrogen gas that makes the mix rise in the moulds. After an initial setting, the mass is cut in blocks for curing in saturated steam at 12 bars. Not only building blocks, but also reinforced slabs and wall panels are produced.

Modern plants for the production of gas concrete have a minimum output of 600 m^3/d and machinery costs of up to $9 million, while buildings, infrastructure and land would cost approximately $3 million. Output and investment of this order are generally too high for a developing country, especially for its first plant. However, many companies that are licensing their production methods decline to deliver smaller units, although these may be economically viable.

Recently, the author, as chief of a project group specializing in the design and construction of gas concrete plants, developed a compact plant with a capacity of 135 m^3/d and costing only about $2 million. This was achieved by limiting automation, simplifying moulds and cutting machinery, and making transport within the plant labour-intensive. A summary of specifications for this plant is given below.

Compact gas-concrete plant

Annual capacity:	40,000 m^3 in two shifts
Operation:	300 d/a in two eight-hour shifts
Density:	625 kg/m^3
Block dimensions:	59 cm x 19 cm x 9 cm
Compressive strength:	40 kg/cm^2 dry cubical strength. May vary according to raw materials

Specific requirements

(a) Raw material plant, including transport equipment, ball mill, slurry tanks with agitators, pumps, tackles etc.;

(b) Mixer plant, including mixing vessels, measuring tanks, weighing hoppers, electro-tackles, valves etc.;

(c) Production plant, including moulds, bogies, longitudinal and cross-cut saws, electro-tackles, transverse carriages, unloading cranes, forklifts etc;

(d) Autoclave plant, steam boiler, autoclaves etc.;

(e) Generator plant consisting of a diesel-driven generator for the whole plant:

(f) Laboratory, including all equipment necessary for control of production;

(g) Miscellaneous equipment and infrastructure, including rails, water and steam pipes, insulation material, tools etc.;

(h) Erection, including supervision of erection and start-up, plus training of key personnel.

Approximate price, depending on local circumstances, $2,125,000 (September 1978 estimate), excluding buildings and infrastructure.

Cost of production

As cost of production will naturally vary from country to country, a general cost estimate is impossible to make. However, it can be based on the data outlined below.

Raw materials consumption (kg/m^3)

Quartz sand:	450	Portland cement:	70
Lime:	130	Aluminium powder:	0.5

Utilities

Electric power:	20 kWh/m^3
Fuel oil:	15 kg/m^3

Labour

Foremen, labour, laboratory and storage: 45 persons

Administration and technical staff

Manager, accountant, chemist, secretaries, clerks, production superintendent, production chemist etc.: 12 persons

As mentioned above, the cost production will vary according to local circumstances, but calculations made in one particular case showed that a break-even point would be reached with a production of 9,000 m^3 and at full production the profit would be handsome.

The plant is so designed that it can be enlarged easily and equipped with facilities for the production of reinforced products at a later stage.

Gypsum products in the building industry

Raw gypsum

Raw gypsum is a hydrous calcium sulphate mineral containing 80 per cent calcium sulphate and 20 per cent water. The water can be driven off wholly or partly by calcining. It is then called plaster of Paris. The plaster, if again mixed with water, sets to a hard solid mass, like cement, and often can be used to replace cement.

Crude or raw gypsum, besides being a raw material for further processing, has few major uses, but these are important:

(a) Crushed to a size of 4 in. and finer, it may be added to Portland cement as a controlling agent;

(b) Ground to 40 mesh or finer, it becomes a stable, non-toxic, tasteless, odourless, non-abrasive, practically inert powder known as terra alba, which is used extensively as a filler for paints, paper, pharmaceuticals, insecticides, yeast manufacture, in water treatment and in many other industries;

(c) Gypsum is used on a large scale in powder form to restore impervious or dispersed soils and as a fertilizer.

Calcined gypsum

Vast amounts of calcined gypsum are used for a large variety of purposes, the more important of which are as follows:

(a) For wall plaster, alone or mixed with lime and aggregates such as sand, vermiculite, perlite, pumice or sawdust;

(b) In the manufacture of large-sized panels for partition walls and reinforced gypsum plank for roofing;

(c) In the manufacture of acoustical tiles;

(d) Mixed with wood fibre, sisal etc. to produce large sheets as internal lining for walls or as ceiling panels;

(e) Mixed with glass fibre, it produces fire resistant structural elements of high strength;

(*f*) As a core in paper-faced wall-board;

(*g*) As moulding plaster in the foundry and ceramic industry;

(*h*) As a raw material in the manufacture of school chalk;

(*i*) As orthopaedic plaster for surgical casts;

(*j*) As dental plaster for platework.

Gypsum plaster

Plaster of Paris or hemihydrate gypsum is produced by heating the gypsum rock to a temperature of about 160°C, at which point three fourths of the crystallization water escapes. If the temperature is increased to 220°C, the remaining water is expelled and a product known as "second-settle" stucco is obtained.

The dehydration or heating can be done in three different ways:

(*a*) The rock is fired in a simple pit dug in the earth or in a pot kiln, also called a field kiln;

(*b*) The crushed rock is heated in a rotary kiln;

(*c*) The powdered rock is heated in a kettle.

The field kiln. This method, still in use in North Africa and Spain, is the most ancient one. In Mizda, Libya, for example, the inhabitants of the village dig out gypsum rock from a nearby hill, crush it, and calcine it in holes in the ground using desert weeds as fuel.

The field kiln has the advantage that the investment cost is practically nil, since the wall can be built with any rock, and wood can be used as fuel. The only piece of machinery is a mill for pulverizing the burnt rock. The disadvantage is the low and varying quality of the finished product. In more industrialized countries the method is not used.

The rotary kiln. The second method, based on the rotary kiln, is used in large-scale production. The rock is dumped into a crusher and is then fed through a silo to a rotary kiln fired with gas or fuel oil. The calcined product is left in a "hot-pit" to cool off, then conveyed to a silo and from there to a pulverizer, then again to silos for storage and ultimately for bagging. The rotary kiln has the advantage that it is a continuous process and the rock is crushed to feed size in one stage.

The cost of a 50 t/d rotary calcining plant, including feeders, elevators, an impact crusher of 50 hp, a rotary kiln of 18 x 1.1 m, an oil burning installation, a hammermill of 15 hp, an air separator, and a bagging machine, would be approximately $100,000, plus freight and installation. The utilities required would be 30 kg of fuel oil per tonne of production and 16 kWh/t. Twelve people could operate such a plant.

The kettle. The third method involves the use of a kettle consisting of a vertical steel cylinder with a heavy convex bottom and horizontal flues to allow the combustion gases to pass through the body of the charge. The kettle is fired with coal or fuel oil. A vertical shaft carries strong vibrating arms. The lower ones drag heavy chains that sweep the heated bottom of the kettle. The capacity of the kettle can be very small or up to 25 tonnes per batch. It is fed with powdered gypsum having a maximum size of 2 mm.

In the kettle process the gypsum rock is fed to a jaw crusher and then conveyed to a silo via a bucket elevator. A vibrating feeder draws the crushed rock and feeds it to a hammer mill where it is reduced to 0–2 mm. This is then fed to a silo and from there to the kettle. The calcined product is conveyed to a hot-pit where it is left to cool off and then passes through an air separator. The coarse material is put through a fine grinder, after which the entire batch is conveyed to the storage bins and bagging machines. A kettle with a diameter of 1.5 m and a total height of 3.35 m will take 900 kg per batch and have a total capacity of 12 t/d. The simultaneous operation of all the machines will require a top load of 40 kWh. The consumption of fuel oil is approximately 20 kg/h. Two persons per shift can operate the plant, but more will be required for the bagging and loading sections. Moreover, a mechanic should be available for plant maintenance.

Plaster board

Plaster board or gypsum wall-board refers to panels made of plaster, the surface and longitudinal edges being sheeted in a closely adhering special cardboard, which has the double function of exterior reinforcing and surface finishing. It is produced in large, fully automatic plants where the plaster mix is discharged continuously between a lower and an upper endless cardboard web which passes at production speed over a forming table through a combined convection-radiation drier followed by a cooler and a cutting and trimming station.

The capacities of plaster board plants are generally 1,000 to 2,000 m²/h, the smallest having an output of 250 m²/h producing 1.5 million m²/a. The investment cost for such a plant would be approximately $2.2 million.

While plaster board is used in vast quantities in industrialized countries, it may not find the same market in developing countries, and therefore such large plants may not be feasible. It is, of course possible to export surplus production, but even a country with vast gypsum resources may not be in a position to sell its product competitively in world markets. The basic reason is that the gypsum input in the total cost of production is less that 20 per cent, and even if a particular country were able to produce its plaster somewhat cheaper than another country, the other raw materials, wood pulp, adhesives, cardboard glass fibre, accelerators and retarders, which account for some 51 per cent of the total cost, might all have to be imported. Utilities, water, electricity and fuel could also be expensive. In addition, as plaster board plants are highly mechanized, labour costs only account for some 4 per cent of the total outlay.

Therefore it seems doubtful that plaster board manufacture can be an economical proposition for a country that will not consume the major part of the production domestically.

Cast gypsum products

The most common cast gypsum product is the panels used for partition walls. Their size is usually 50 x 66 cm, and they can easily be handled by one person. Density is about 950 kg/m³, but this can be lowered by incorporating a light-weight filler such as perlite or vermiculite. These panels can be easily cut to the required shape and size with a saw

A plant for producing such panels will consist of a silo for storage of the plaster. At the bottom of the silo is fixed a short screw conveyor serving to extract the plaster and convey it to the weighing bascule. Under the bascule is the mixer, moving on rails, into which water is fed through a meter. A vibrator is then started, and the plaster is added. A light-weight filler can also be added, such as flyash, sepiolite dust, pumice, or perlite. Sand is less suitable, as it would sink to the bottom in the very fluid mix.

The mix is emptied into the moulding machine, and when the gypsum has set, the motor of the hydraulic system is started, and the panels are pressed up and out of the mould. The panels are then taken by a lifting clamp and put down on a car which runs out to the storage place where they are left to dry. The moulding machine can be filled four times per hour, that is, 30 mouldings can be produced per eight-hour day. With a capacity of 24 panels of 50 x 66 x 6 cm per moulding and an eight-hour working day, six days per week, 250 days per year, annual output would be 62,500 m^2.

The machinery and equipment for the above plant would cost approximately $70,000 plus freight and installation. The labour force would consist of a foreman-mechanic and five other persons. The required raw materials and utilities would be 50 kg plaster per m^2, and 50 l of water. The daily consumption of electricity would be 40 kWh.

This type of plant can be very interesting for developing countries, even those that do not have their own deposits of raw gypsum. Output can be increased easily and the plants can be dispersed about the country to stimulate industrial activity.

Strategies for development of cement and allied industries in developing countries

*H. C. Visvesvaraya**

Analysis of expenditure in India under successive national plans shows that expenditure on construction has been some 50 per cent of total investment. Overall, some 65 per cent of this expenditure on construction is accounted for by the cost of construction materials. In fact, expenditure on construction materials in India's Fifth Five-Year Plan is expected to be over Rs 180 billion ($22.785 billion) a figure which far exceeds even the total outlay in the Third Five-Year plan. That shows how vital a role construction materials, in general, and cement and cement-based construction materials, in particular, play in development strategy.

I. GENERAL VIEW OF THE CEMENT AND ALLIED INDUSTRIES, WITH PARTICULAR REFERENCE TO INDIA

Raw materials

Limestone and clay deposits

The availability of all principal raw mix components in India is, on the whole, encouraging. There is a total reserve of some 50 billion tonnes of cement-grade limestone, although only a small quantity (about 8 billion tonnes) of it is proven; the rest is inferred or indicated. Reserves of cement-grade limestone are distributed in the country as indicated in table 1.

Although there has been no systematic delineation of clay deposits for cement manufacture, it is generally thought that availability of suitable clay does not pose any problem.

Availability of gypsum

At the present level of production the Indian cement industry consumes gypsum at the rate of about 1 million t. a. The total reserves of natural gypsum in India are placed at about 1.2 billion tonnes. The state of Rajasthan accounts for more than 90 per cent of these reserves. The total production of natural gypsum in the country is estimated to be about 1.1 million t/a.

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*Director General, Cement Research Institute of India, New Delhi, India.

TABLE 1. RESERVES OF CEMENT-GRADE LIMESTONE IN INDIA, BY STATE

(Millions of tonnes)

State	*Proved*	*Inferred or indicated*	*Total*
Andaman and Nicobar Islands	–	1	1
Andhra Pradesh	3 872	11 663	15 535
Assam, Meghalaya, Manipur, Nagaland and Tripura	194	4 088	4 282
Bihar	61	849	910
Gujarat	215	1 070	1 285
Haryana	40	18	58
Himachal Pradesh	537	218	755
Jammu and Kashmir	81	125	206
Karnataka	157	18 326	18 483
Kerala	25	–	25
Madhya Pradesh	1 553	572	2 126
Maharashtra	88	1 988	2 076
Orissa	162	269	432
Rajasthan	694	11 663	12 357
Tamil Nadu	104	179	283
Uttar Pradesh	93	696	789
West Bengal	1	2	3
Total	7 877	51 728	59 606

The total availability of by-product gypsum is about 1.5 million t/a. Phosphogypsum, a by-product from the phosphoric acid industry, accounts for more than 90 per cent of the total production. Of the rest, nearly 0.1 million t/a comes from the marine salt industry and the rest from the titania, boric acid, citric acid, and hydrofluoric acid production.

Availability of industrial and agricultural wastes

Some of the industrial wastes of possible interest to the cement industry, their sources and the estimated annual production are given in table 2. It is expected that the demand for cement is likely to be in excess of targets fixed for production, and utilization of industrial wastes will get further impetus to bridge the gap.

TABLE 2. AVAILABILITY OF INDUSTRIAL AND AGRICULTURAL WASTES FOR CEMENT PRODUCTION

(Million t/a)

Waste	*Source*	*Availability*
Blast-furnace slag	Iron and steel industry	6
Fly ash	Thermal power stations	8
Calcium carbonate sludge	Fertilizer industry	1.2
Lime sludge	Paper and sugar industries	2.5
By-product gypsum	Fertilizer, phosphoric acid, hydrofluoric acid industries	1.5
Red mud	Aluminium industry	0.6
Kiln dust	Cement industry	0.6
Rice husk	Agriculture	15

Status of cement production

Origin and early growth

Cement was first manufactured near Madras in 1904; by 1918 there were three factories producing some 85,000 t/a. In the 1930s there was rapid expansion; in 1947, there were 18 plants producing 1.47 million t/a.

Progress under the national plans

The progress of the Indian cement industry since 1950 is shown in table 3.

TABLE 3. GROWTH IN INDIAN CEMENT PRODUCTION CAPACITY, 1959–1979
(Million t/a)

Plan		*Target*	*Achievement*	*Shortfall*	*Average annual growth rate (%)*
First five-year plan,	1951–1956	5.31	5.02	0.29	8.9
Second five-year plan,	1956–1961	16.00	9.30	6.70	13.1
Third five-year plan,	1961–1966	15.00	12.00	3.00	5.2
Annual plans	1966–1969	Not fixed	14.96		7.6
Fourth five-year plan,	1969–1974	Not fixed	19.74		5.7
Fifth five-year plan,	1974–1979	24.50	22.45[a]	1.05	2.6

[a] Estimated.

Future prospects

The installed capacity in 1977/78 was 21.87 million t/a and was expected to increase to 32.34 million t/a by the end of 1980/81, which is only 0.76 million t/a lower than the capacity of 33.10 million t/a required to meet the projected demand of 28.13 t/a on the basis of 85 per cent utilization.

If the gap between demand and supply is not to increase further, it will be necessary to add about 3 million t/a in capacity every year to meet the projected annual increase of 8 per cent in demand.

That would mean annually setting up seven or eight plants of standard capacity (0.4 million t/a) at an investment cost of about Rs 2 billion ($0.25 billion) on the basis of Rs 650 ($82.28) per annual tonne, and involve corresponding investment in other allied sectors, e.g. coal power and rail transport.

Cement consumption and future demand

All cement production in India is used and there is no accumulation of stocks. The natural conclusion is that if more were produced it would also be consumed and that there is a considerable unsatisfied demand. Recently, in addition to stopping exports of cement, the Government has also permitted the importation of about 1 million t/a. All indications are that the potential demand for cement is much greater than is apparent, and the only conclusive answer to the situation is increased production. It would, therefore, be prudent to plan on the basis of a slightly higher rate of demand. Considered from these points of view, an annual growth rate of 8 per cent has been adopted for projecting future demand.

The trade of developing countries in cement

The most striking feature of world cement trade during the past 10 years is the predominant position taken by the developing countries in supplying each other's import requirements.

For example, a cement plant was built in the Bahamas with a view to exporting not only to the east coast of the United States of America but also to other Caribbean countries.

The Kenyan cement industry is export-oriented and supplies a large area of the Indian Ocean region through its own vessels and cement terminals.

Iraq and Lebanon have a long tradition as cement exporters. The expansion of production capacity in these countries during the past 10 years was mainly intended for the export market. Iraq's largest customers are Kuwait and the United Arab Emirates. Lebanon has recently found a large market in Algeria, in addition to its outlets in western Africa. Egypt is strongly oriented towards the export of cement, which is an important source of foreign exchange.

Some developing countries, such as Algeria, Argentina, Brazil, Ghana, Indonesia, Kuwait, Saudi Arabia and Syria, have access to financial and technical resources which will enable them to become self-sufficient in the near future. Others such as Colombia, India, Mexico and Venezuela are already in a position to satisfy their own cement requirements.

It seems likely that the developing countries–especially those that are far from self-sufficient–will increase their production facilities. Many of these countries will install larger capacities than are actually needed in order to benefit from the economies of scale. The resulting surplus will be available to other countries, thus offering possibilities of inter-regional co-operation. As a consequence of these trends, the share of the developing countries in world cement trade should continue to grow.

Cement machinery in India

At present, there are eight manufacturers of cement machinery in India; they have so far supplied 37 complete cement plants of various capacities, the majority being 600 t/d, for a total of about 8 million t/a. The capability for the manufacture of a 1,200 t/d cement plant has also been developed. This cement machinery-making capacity is considered adequate to meet anticipated capacity build-up, and the maufacturers are reported to be gearing up to manufacture plants up to 3,000 t/d, with pre-calcinators.

The Heavy Engineering Corporation at Ranchi (a public sector undertaking) is already supplying large-scale castings to the cement industry in addition to others which are relatively smaller.

Modern developments on cement technology

Crushing and grinding

In recent years there have been significant developments in the design of different types of crushing equipment, e.g. jaw, gyratory, impact and roll crushers.

The adoption of closed-circuit grinding in raw materials processing has paid dividends not only by reducing energy consumption, but also in improved performance of rotary kilns and the quality of cement.

Roller mills operating in conjunction with large pre-heater kilns are also of interest to the cement industry, and are hailed as the mills of the future for dry process cement plants. With high efficiency and good capacity, they also combine drying, grinding and classification with a potential energy saving of 20 to 30 per cent. They can cope with increased moisture conditions, are extremely suitable for automatic operation and they have a lower noise level. Roller mills for kilns up to 3,000 t/d are already in operation; however, it is felt that these mills may not be readily suitable for limestones that are hard and have a high silica content, as these may cause high rates of wear in the grinding elements. Grinding aids are also being more widely used. These are mainly surface-active chemicals that reduce agglomeration of fine particles and the sticking of particles to the mill lining and grinding media, thus increasing overall grinding efficiency and decreasing energy consumption.

Suspension pre-heater kilns

The dry process has the twin advantage of economy and a reduced volume of exit gases to be cleaned for dust control. Today the most popular is the short dry-process kiln with a four-stage cyclone suspension pre-heater, which increases meal feed temperature from about 70°C to 750°C and effects an apparent calcination of about 40 per cent when feed enters the kiln.

Pre-calcination

Calcination in the cement clinker burning process is a highly endothermic reaction, and the amount of heat required for normal raw materials and mixing proportions is about 500-520 kcal/kg (2.1–2.2 MJ/kg) of clinker.

The advantages of pre-calcination are:

(a) It increases production 2–2.5 times without enlarging the kiln size;

(b) The reduced size of kiln and reduction in thermal loading improve the life of refractory brick and reduce downtime and operational costs.

Clinker coolers

In addition to the well known grate, planetary, rotary and shaft coolers, a 2,000 t/d tubular cooler has recently been developed in Austria with a clinker exit temperature of 160°C. There are shaft coolers with few moving parts and good overall thermal recovery; an additional advantage is that there is no excess cooling air to be vented.

Dust collectors

The dust collectors commonly used in cement plants include bag filters, multicyclones and electrostatic precipitators. The electrostatic precipitator requires the least energy amongst the high-efficiency collectors; its maintenance cost is low because it is constructed of steel and operates dry, above the dew point. Its major disadvantages are high installation cost, unpredictable collection efficiency with certain high resistivity dusts and the expense of the instrumentation and controls. A decision on the type of dust collection system to be adopted in a particular situation will depend on optimization between the norms of the pollution control required and the increase in production as a result of recovery of dust.

Instrumentation

Sophisticated instrumentation and control systems are now installed in large cement plants to record and control operating conditions. On-line X-ray analysers for quick analysis of raw materials are used and systems for automatic centralized process control, comprising control-panel equipment, analog controllers, television, computers and mini computers are also being employed increasingly in modern cement works.

In India, off-line X-ray analysers might be more appropriate as they would be adequate for keeping track of the raw material composition without being as expensive as the on-line equipment, while at the same time permitting a good part of the work to be done manually.

Other developments

Other developments include the cold process of cement manufacture, methods for laying the refractory lining without stopping the kiln, a gearless drive for cement mills, the combined manufacture of cement and sulphuric acid and fluidized-bed sintering based on the total energy concept.

Size of plants

The Indian cement industry employs about 80,000 persons, i.e. about one ranging from 20 to 3,000 t/d. There are seven cement plants having capacities of more than 2,000 t/d, but all are based on multiple kilns.

Employment

The Indian cement industry employs about 80,000 persons, i. e. about one employee per tonne of daily production. By 1983 it is expected that a further 55,000 persons will be employed; the relationship between plant size and employment potential is shown in table 4.

TABLE 4. EMPLOYMENT-CAPACITY RATIOS IN THE INDIAN CEMENT INDUSTRY

Capacity (t/d)	*Number of plants*	*Employment-capacity ratio (persons per annual tonne)*
Mini, < 100	3	4–5.5
Small, 101–300	5	1–4.5
Medium, 301–1 000	16	0.29–2.32
Large, > 1 000	32	0.18–2.26

As might be expected, the ratio is highest in small cement plants. Interestingly, the existing three mini plants in India are each based on different processes, namely, vertical shaft kiln, sinter grate and rotary kiln.

II. ALTERNATIVE TECHNOLOGIES

Wet and dry process plants

In the past most cement was manufactured by the wet process, but today the global trend is towards the dry process. The most decisive factors are fuel and power consumption which account for about 40 per cent of the cost of production.

Although development of long wet process kilns with internal heat exchange systems brought fuel consumption down to as low as 1,300 kcal/kg (5,400 kJ/kg) of clinker, more recent developments in the dry process kiln have reduced fuel consumption to as low as 700 kcal/kg (2,900 kJ/kg) of clinker and this appears to have tilted the balance in favour of the dry process. The energy requirement per unit of cement is 110–120 kWh/t for the wet process and 130–140 kWh/t for the dry process. Water requirements depend mainly on the process used. A dry process plant uses up to approximately 810 l/t and an average wet process plant requires approximately 1,620 l/t.

As the dry preparation of such materials presents difficulties, the wet process is preferable for dealing with moist raw materials, such as chalk or plastic clay. The wet process will generally be employed in cases where the raw materials contain harmful admixtures which have to be removed by washing or wet benefication.

Adoption of the dry process can save as much as Rs 8.80 ($1.11) per tonne of clinker on account of fuel, assuming that the dry process requires 0.18 t of coal (at 5 Mcal/kg or 21 MJ/kg) per tonne of clinker as against 0.29 t for the wet process, the price of coal being taken as Rs 80 ($10.13) per tonne. Both the consumption of fuel and the unit cost of fuel are much higher in many wet process plants.

Although energy consumption in the dry process is more by about 20 kWh/t, costing approximately Rs 2.00 ($0.25) per tonne, the latter can be balanced by utilizing exit gases in drying raw materials while grinding. In addition, adoption of the dry process saves about 810 l/t. In other words, there is a strong case for adoption of the dry process wherever possible and when the quality of raw materials is not a problem.

Large and small cement plants

Table 5 projects the capital investment and investment per tonne of installed capacity for a 50 t/d and a 1,200 t/d plant according to calculations by the Cement Research Institute of India (CRI).

TABLE 5. INVESTMENT FOR 50 AND 1,200 T/D PLANTS

Type of investment	*1 200 t/d*	*50 t/d*
Capital investment	*(Thousands of rupees)*	
Fixed capital	284 000	9 490
Working capital	12 500	661
Total	296 500	10 151
Investment per tonne of installed capacity	*(Rupees)*	
Fixed capital	710.00	558.40
Working capital	31.25	38.89
Total	741.25	597.29

The size of 1,200 t/d has been chosen as it is the present standard size, though projects as large as 3,000 or 3,200 t/d are now to hand.

The CRI mini cement plant in Tamil Nadu is based on a vertical-shaft kiln which was redesigned and restructured at a 20 t/d capacity (see figure I).[1] First trial runs were carried out in 1975/76 and proved that satisfactory quality could be produced in a vertical-shaft kiln mini-plant on a sustained basis under Indian conditions. Encouraged by the above findings, the Committee of Direction for Cement Research, set up by the Indian Ministry of Industry, sponsored the CRI project in 1976 with the objective of running the plant on a continuous basis and collecting the data relating to output performance, consumption factors, process parameters, clinker and cement quality and related economic factors.

The plant was operated intermittently for a total of 178 days in 1976/77 on a one-, two- and three-shift basis, and produced cement conforming to Indian Standards Specifications, the longest continuous run on a three-shift basis being for 45 days. During 1977/78, the plant was run continuously for 171 days on a three-shift basis in two stages.

The plant has now been in continuous operation since April 1978.

Indigenous precalcinators

CRI has developed a pre-calcinator which emphasizes the importance of partial precalcination. The first such precalcinator is now being erected for an Indian cement plant (300 t/d capacity kiln). Some of its important characteristics are:

(*a*) There is a minimum 30 per cent increase in the rated capacity of the kiln in clinker production;

(*b*) The precalcinator suits Indian coals;

(*c*) A 20 per cent increase in the life of refractory lining in the burning zone of the kiln is achieved;

(*d*) There is a heat saving of 25–35 kcal/kg clinker compared with the existing pre-heater kiln.

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[1] The complete techno-economic details of mini cement plants are covered in a recent publication of the Cement Research Institute of India (No. SP-13-78) entitled "Techno-Economic Viability of Mini Cement Plants".

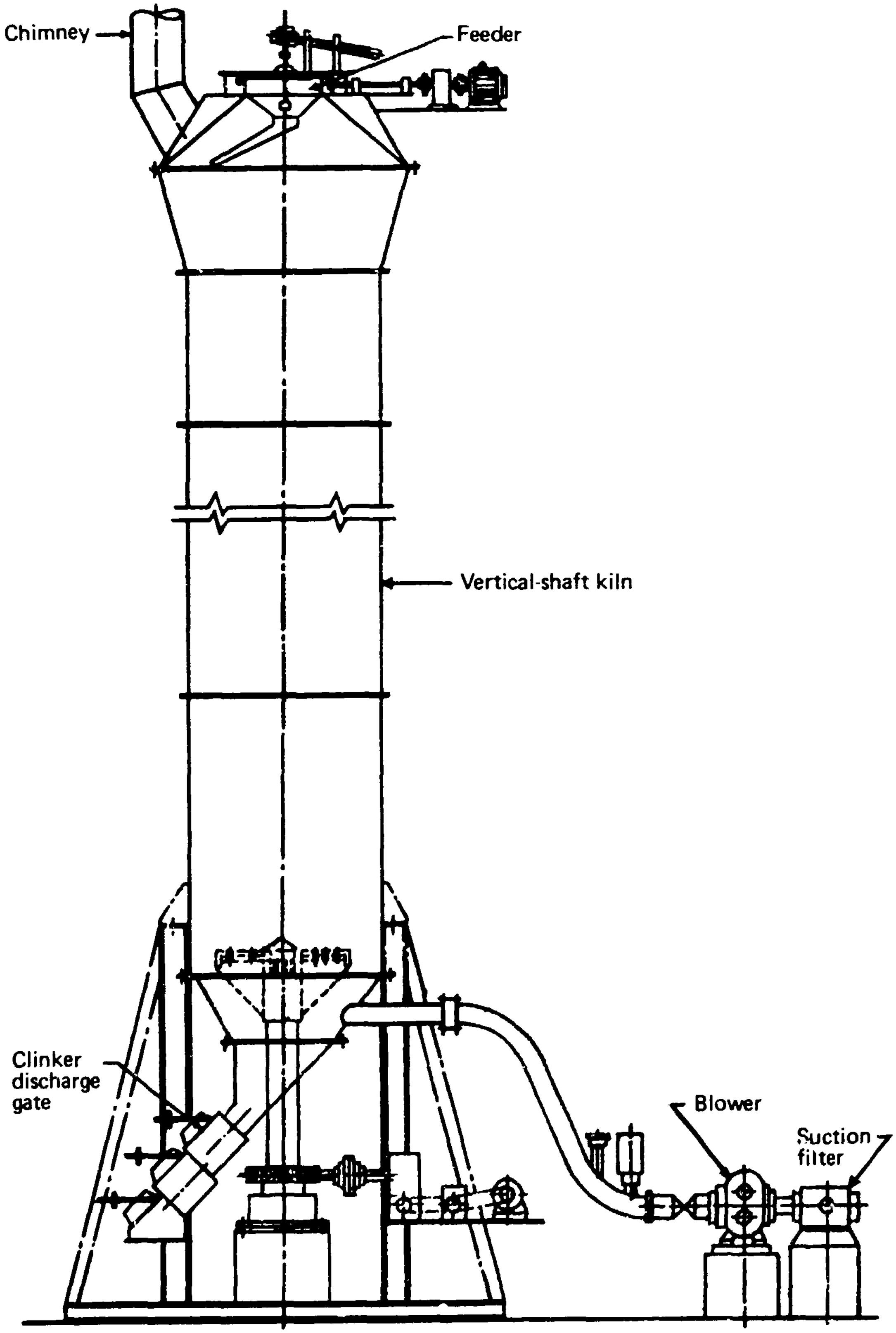


Figure I. General arrangement of CRI type vertical shaft kiln for Visvakarma mini cement plants

Rapid quality-control systems with simple facilities

Developing countries generally find on-line instrumentation controls used by the advanced industrialized countries to be too expensive, but must nevertheless have an alternative system of quality control. CRI has worked for several years on rapid methods of testing–both chemical as well as simple instrumental methods. A comparison of these is given in table 6, and a summary of savings in direct costs for the rapid methods used with conventional analytical chemistry laboratory facilities, colorimetric instrumentation facility, and ethylenediaminetetraacetic acid is given in table 7.

Improved cement packing

By 1980 India may need as many as 600 million bags (new and used) per year for packing cement. More bags are also required for export. Many other developing countries face a similar problem.

In addition, the loss of cement due to seepage from the plain jute bags in general use has been estimated to cost as much as Rs 100 million ($12,658 million) every year. CRI was therefore asked jointly by interests representing manufacturers, consumers, and the Government to solve this problem in an appropriate manner.

The basic requirements for packing cement were formulated as follows:

(a) The bag should be sufficiently proofed against water or dampness and against leakage or seepage of cement;

(b) The bag should be strong enough to withstand the stresses and strains of handling. Either a provision should exist for hooking it, or it should be possible to eliminate hooking in industrial practice without any adverse effects on productivity;

(c) The bag should not present difficulties in filling, either qualitatively or quantitatively, with the present packing machines;

(d) The bag's construction material should be able to withstand the high temperature of cement–which could be of the order of 90–100°C at the time of packing;

(e) The total cost of the bag should be economical, taking into account possible reuse;

(f) The material used and the processes adopted for the manufacture of the bags should be such as to ensure continuity in the supply of bags;

(g) The material used should have good frictional characteristics to avoid slippage on conveyors.

Investigations then began of the relative properties, availability, and techno-economics of the three packaging materials used world-wide, i.e. jute, paper and plastics. As a result it became overwhelmingly clear that any large-scale use in India would require the bags and therefore the technology to be jute-based.

TABLE 6. COMPARATIVE STUDY OF THE VARIOUS INSTRUMENTAL ANALYTICAL TECHNIQUES USED BY CRI

Technique	*Instrument*	*Approximate capital investment (thousands of rupees)*	*Relative servicing and maintenance cost*	*Type of specialist needed*	*Availability of specialist*
Electron microscopy	Electron microscope	1 800	High	Specially trained physicist or chemist	Very difficult
Electron probe study	Electron probe micro-analyser	800	High		Very difficult
Infrared studies	Infrared spectrophotometer	800	High		Not difficult
X-ray techniques	X-ray fluocrescence spectrometer	400	High	X-ray mineralogist	Difficult
Petrographic analysis	Petrographic microscope, microhardness tester Reflectivy measurement device Point counter universal stage	150	Low	Geologist petrographer	Easy
Thermal analysis	DTA apparatus, TG apparatus	120	Moderate	Specially trained chemist	Easy
Colorimetry	Colorimeter	20	Low	Specially trained chemist	Easy

TABLE 7. COMPARISON OF DIRECT COSTS OF GRAVIMETRIC, COLORIMETRIC AND EDTA METHODS *(Rupees)*

	Expendable items			*Energy*			*Labour*		
Determination	*G*	*C*	*E*	*G*	*C*	*E*	*G*	*C*	*E*
SiO_2	5.90	1.00		1.50	0.05		8.50	2.40	
CaO	4.90	0.35	1.95	1.50	0.05		14.25	0.60	2.40
MgO	2.90	0.40	1.40	1.50	0.05		7.15	0.60	2.40
Fe_2O_3	2.50	0.40	0.34	0.20	0.05		2.40	0.70	2.40
Al_2O_3	4.30	0.35	1.51	1.50	0.05	0.10	4.75	1.90	2.40
Total	20.50	2.50	5.20	6.20	0.25	0.10	37.05	6.20	9.60
				Total			63.75	8.95	14.90
				Time (man-hours)			8	1.5	2

Notes: G = gravimetric; C = colorimetric; E = EDTA method. Gravimetric method as per IS: 4032–1968.

After the laboratory tests were completed, CRI scientists were sent to three cement works to test the bags in the plants. A bundle of 41 bags was sent to each of 58 cement manufacturers throughout the country, with detailed instructions for testing. On the basis of the results received, and a study of the bags tested and returned to CRI, the technical feasibility of the improved bags was proved.

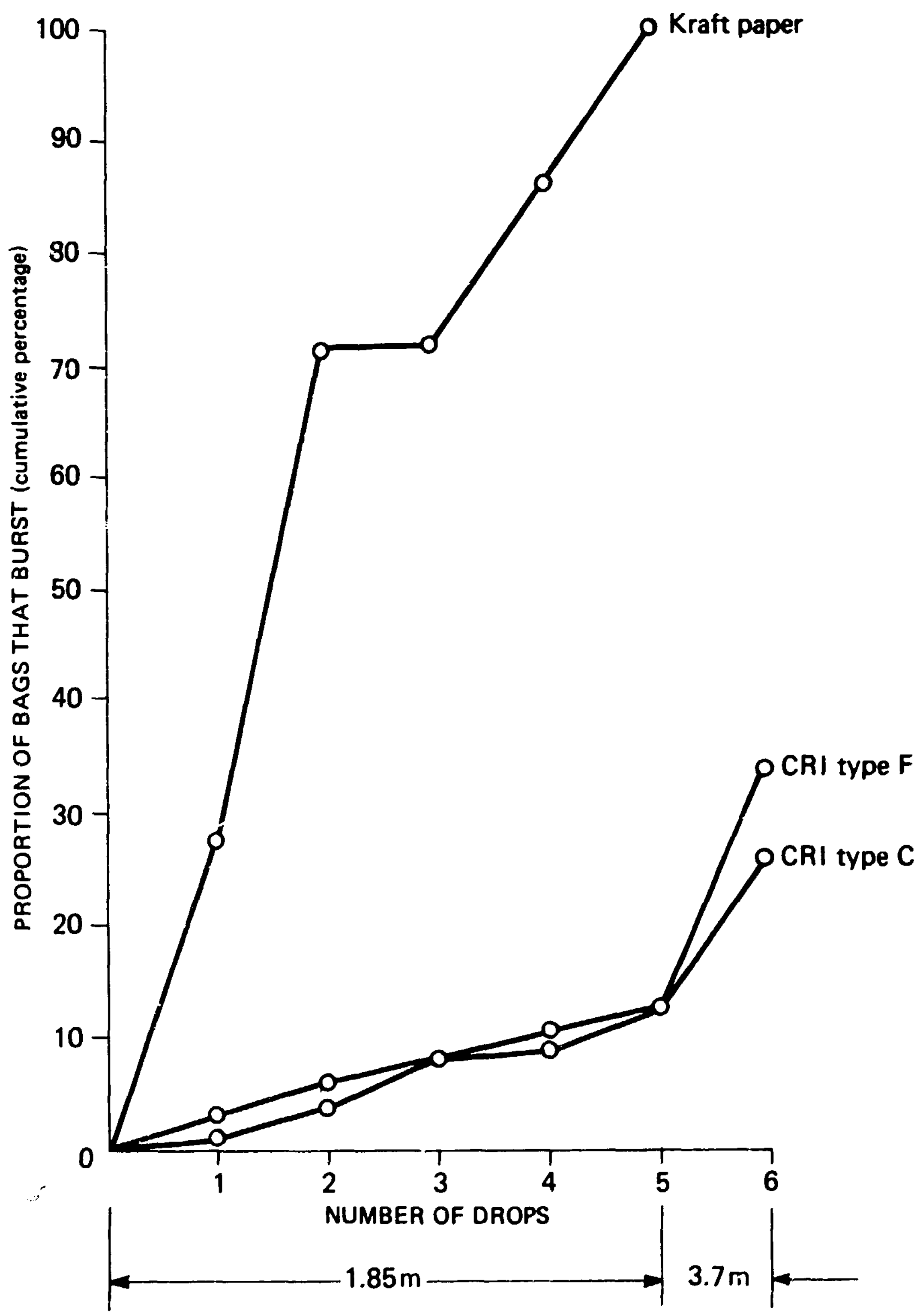


Figure II. Comparative performance of CRI and kraft paper bags of approximately the same cost

Industrial commercial trials with 5,000 and 10,000 bags were then made.

A techno-economic assessment of improved performance vis-à-vis the additional cost involved in the packaging was then carried out in the context of overall savings that would accrue with reference to conventional heavy jute bags, as well as to kraft paper bags used in many other countries. The results are summarized in figure II and tables 8 and 9.

TABLE 8. COMPARISON OF CRI AND CONVENTIONAL HEAVY JUTE BAGS

Property	*CRI compared to jute*
Improvement in strength	55% more
Seepage loss	94% less
Loss due to entry of moisture	83% less
Possible number of reuses	33% more
Initial cost of bag	28% more
Equivalent cost of bag	47% less

TABLE 9. COMPARISON OF LABOUR CONTENT OF BAGS

	Labour content per 1 000 bags	
Type of bag	*(man-hours)*	*(Rupees)*
Kraft paper	0.5	2
Heavy jute	12	30
CRI	16	40

The appropriateness of the technology developed was thus established, and industrial usage of the CRI bags is constantly increasing.

Ready-mixe[illegible] without using agitators or truck-mixers

Two thirds [illegible]crete produced in most developed countries is ready-mixed, bu[illegible] in developing countries is far less extensive. Appropriate technology of ready-mixed concrete (RMC) for developing countries, with particular reference to India, was thus studied.

Nearly 120 million tonnes of concrete are produced annually in India, and the ability to develop new technologies is available within the country. If some of the recent developments in construction technology, as practised in developed countries, have not yet been adopted in India, it is because of the techno-socio-economic considerations which have led to the adoption of an appropriate technology instead. RMC is a case in point.

There are two basic reasons why RMC is not yet established as an industry in India:

(*a*) RMC is capital-intensive and a major portion of the capital outlay is for the transportation fleet of agitators or truck-mixers. A recent study conducted by CRI shows that 62 to 70 per cent of the fixed capital cost for a 125–250 m^3/d RMC plant goes to pay for this fleet;

(b) There is no matching infrastructure for proper handling, placing and compaction at the site of placement. RMC becomes competitive with site-mixed concrete only when the demand poured per day exceeds a certain level–in industrialized countries, some 500 m^3 per week. The CRI study shows that the optimum size of a RMC plant in India should be about the same. However, in India and in most other developing countries, the concrete is usually placed manually. Placers or pumps are used in large construction projects only when a central batching and mixing plant can be afforded near the construction site itself. For an average construction job in most developing countries, handling 3 m^3 of concrete per trip in a truck-mixer or agitator poses large problems.

Therefore, an appropriate technology for RMC in developing countries must enable concrete from the central batching/mixing plant to be transported without agitation. This technology comprises a central batching/mixing plant, a transportation fleet of non-agitating vehicles of appropriate sizes (which are lower in cost than agitating types) and a concrete mixer at the site for re-mixing.

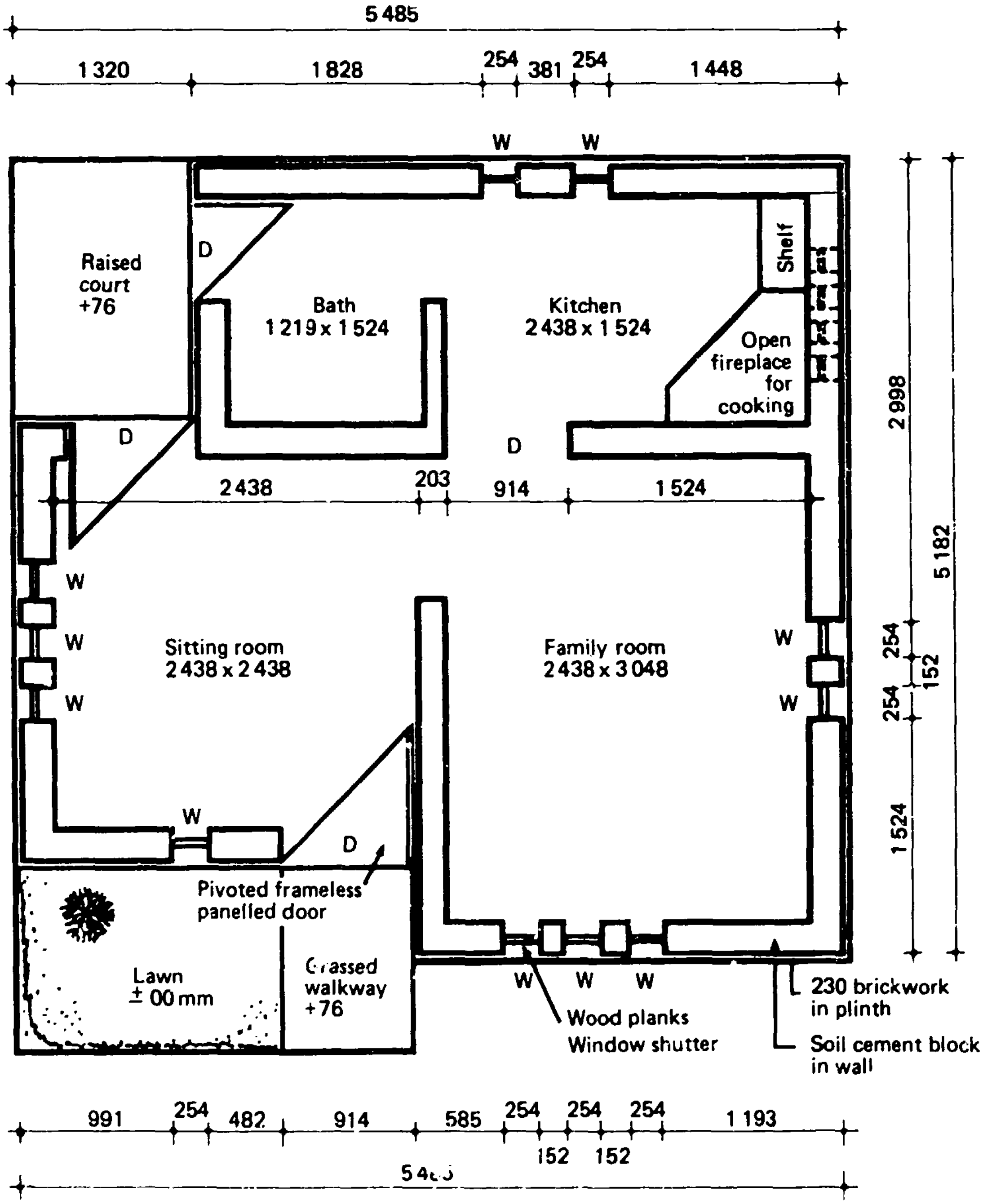
As is well known, a high slump (50–100 mm) concrete from the central batching/mixing plant, if delivered without agitation, would pose problems of serious loss of workability and even "stiffening" during transportation, and will call for retempering at the site. Depending upon climate and transport difficulties, the hauling distance would also be severely restricted. If, on the other hand, dry concrete materials after batching were to be transported in open trucks, most of the cement and other fine particles might be blown away and segregation would also take place in the dry mix. Between these two extremes is the alternative of transporting concrete in a "semi-dry" state from the batching/mixing plant, with only sufficient water added to keep the concrete in a cohesive mass, the balance of water being added prior to final placing. Although this solution might sound simple, it calls for a thorough study of all aspects of the choice of materials, particularly the grading of aggregates and the percentage of fines, proper mix designs, tendency to segregate during transport, loss of water due to evaporation during transport, the state of dehydration of cement during transport and its effect on the final workability of the concrete. CRI research developed a technology which enabled concrete to be transported for periods up to 1–1½ hours in non-agitating vehicles.

Ideally the transport fleet should consist of a large number of ordinary, non-agitating vehicles of smaller capacity (0.5–1 m^3) rather than a small number of larger capacity vehicles. Generally, overall transport costs would be lower with an increase in the unit size of the payload. It must be borne in mind that the ultimate advantage of RMC is derived by guaranteeing the quality of the concrete for both large and small jobs alike. While in large construction projects, adequate infrastructures to produce quality concrete may be provided economically, it is in the small construction projects that RMC has to fulfil equivalent purposes. The minimum facilities for testing concrete materials, mix designs and proper batching and mixing to produce quality concrete for small projects entail uneconomical overhead costs and thus nominal concrete mixes are widely used rather than controlled concrete. Keeping such small jobs in mind, smaller trucks ensure fuller utilization of transport capacity, and overall they may even be more economical.

The size of the central batching/mixing plant must match the capacity of the transportation fleet; therefore, smaller size (10 30 m^3/h), largely manually/controlled batching plants are called for.

The advantages of the CRI system are that:

(a) It enables the use of controlled concrete for small or medium construction jobs; this is important since in most of the developing countries the cost of the necessary infrastructure for producing controlled concrete by conventional methods for smaller jobs has been found uneconomic;



(Dimensions in mm)

Figure III. CRI rural house

(b) It enables industrial wastes, such as fly-ash, to be used on a large scale;

(c) It enables non-agitating, ordinary trucks to be gainfully utilized for carrying loads on return trips, whereas conventional RMC truck-mixers and agitators always return empty;

(d) It enables a balance to be maintained between the utilization of labour and the mechanization appropriate to relevant areas in developing countries.

Concrete poles for rural electrification

The present demand for line support required for rural electrification in India is estimated at over 4 million poles per year. A large portion of this demand may be met by pre-stressed concrete poles, and economical designs which are consistent with functional requirements, would result in considerable savings.

The CRI R and D project on concrete transmission-line poles for use in rural areas has led to the revision of Indian Standard IS: 1678–1960, and the Rural Electrification Corporation is bringing out a manual for production of transmission-line poles incorporating CRI design and development work.

Low-cost materials for low-cost houses

CRI has developed a design for a rural house and a small storage bin eliminating the use of costly conventional construction material by exploiting such locally available materials as natural soils, rice husks, secondary species of timber and sandstone slabs.

The soil stabilization technique requires only a small quantity of cement as a stabilizing agent. Block-making is simple, and the services of skilled labourers are not required.

Locally available sandstone tiles are used for the roof and broken tiles are used for the floor. Window frames and door panels are made of wood, and lime and *surkhi* are used for the foundations.

If required, inside walls can be plastered with a 15-mm thick layer of clay putty. The proportion of the mix is normally 12:1.

The external joints of block masonry are pointed with cement mortar (1:4) to protect them from weathering. A plan of the house is given in figure III.

Materials for the house cost Rs 1,700 ($215), and the total cost of skilled and unskilled labour comes to about Rs 1,000 ($125), which puts the house well within the reach of the poor.

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Appropriate technologies for small-scale production of cement and cementitious materials

*R. J. S. Spence**

Summary and recommendations

Small-scale Portland cement plants

There are economic advantages to be gained, in certain circumstances, from producing Portland cement in much smaller plants than are currently used. Such plants could:

(a) Be located wherever local demand for cement was large enough, in relation to the capacity of the plant, and suitable raw materials existed;

(b) Be locally manufactured and assembled, avoiding the need for imports and reducing dependence on foreign firms;

(c) Be erected and brought into production quickly;

(d) Make only a small localized additional burden on the existing infrastructure.

At present the smallest available plants made by cement machinery manufacturers in industrialized countries are vertical shaft kilns with outputs of 180–200 t/d. Plants of this size could be manufactured partly in local workshops. Much smaller mini-plants of 20–50-t/d capacity have been developed in India. Plants of this size could be manufactured completely independently of companies in industrialized countries, and would reduce capital costs per unit of output. But technical and institutional problems have so far prevented the designs for these plants becoming available for commercial production.

Lime-based cementing materials

Much of the production of Portland cement could be replaced by lime and lime-pozzolana mixtures. Technology for producing these materials is relatively simple, and can be utilized at a very small scale. Capital costs for the equivalent

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*Lecturer, Department of Architecture, University of Cambridge, United Kingdom of Great Britain and Northern Ireland, and Chairman of the Cementitious Materials Panel of Intermediate Technology Development Group Ltd, on behalf of which this paper was prepared.

output are significantly lower than for Portland cement production and employment potential is considerable. Construction of plants could be entirely local. An extensive range of raw materials can be used; many of which are of widespread occurrence.

Other cementing materials

Other raw materials, gypsum, impure limestones and dolomites can be used to make different forms of cement. These processes could, in appropriate circumstances, be cheaper to establish and produce cheaper materials than Portland cement. Further processes for small-scale production of cement are also being developed.

Recommendations on institutional support needed to promote alternative cement manufacture

To promote the development of small-scale Portland cement plants:

(a) Capital to establish plants should be made available on generous terms;

(b) There should be no freight equalization charge or other distortion of the real cost of transporting cement throughout the country;

(c) A range of standards for cement should be instituted, rather than one single standard, to allow for different levels of manufacturing expertise;

(d) The development of these plants should be the responsibility of an institution entirely independent of large-scale cement manufacturers.

To promote the development of lime and alternative cement:

(a) The development of the materials should be the responsibility of a government-financed small industry development organization, whose responsibility will not only be the development of appropriate techniques for manufacture and establishing manufacturing units, but also the promotion of the material to potential users;

(b) New raw material surveys should be conducted to locate likely small-scale deposits of suitable materials;

(c) Some means should be found to encourage technically qualified people to work in industries in rural areas;

(d) The properties of alternative cements should form a part of all courses in building and civil engineering.

INTRODUCTION

The place of cement in development

Cement, or at least some form of cementing material, is an essential ingredient of virtually every type of construction in developing countries and hence a continuing and expanding supply of cement is essential to provide the infrastructure for development. A temporary shortage of cement in a developing country can, and frequently does, completely halt crucial construction programmes. Throughout the developing world precious resources are wasted on half-completed projects which cannot be finished because cement is not available.

Thus cement must be counted among the basic commodities on which development programmes rely, with an importance comparable to that of water, energy and fertilizer supply; consequently self-sufficiency in cement production is always given a high priority in development planning.

Until recently, the means by which most developing country planners sought to achieve an increase in the supply of indigenously produced cement had been the establishment of comparatively large-scale factories, on the model of those in the industrialized countries. These factories produce Portland cement and an associated range of products satisfying ISO standards. The factories have been either entirely imported, or, in the countries with a more highly developed industrial sector (e.g. India), locally manufactured in association with manufacturers from industrialized countries. This approach has certain undesirable consequences for the economies of the poorer countries, and it is being increasingly asked whether there are not alternative approaches by which a greater degree of local self-reliance, not only in the manufacture of cement, but also in the establishment of cement plants, could be achieved.

Two alternative approaches are being widely considered. The first is the manufacture of Portland cement, or a cementing material of comparable quality, in much smaller, locally made kilns which could be widely dispersed. This approach, already successfully adopted in China is under active consideration in India.

The second approach is the upgrading of village-scale technology based on lime and pozzolanas in order to produce a standardized, though comparatively low-grade cementing material that could serve as a partial or complete replacement for cement in a wide range of applications.

In addition to these two approaches, which depend on essentially the same raw materials as does Portland cement and are thus of similar general applicability, there are a range of other materials or techniques by which cement could be made under particular local circumstances. Some of these are little known, and could be profitably more widely used than at present in developing countries.

The introduction of new materials and techniques is always accompanied by unexpected problems of a socio-economic as well as a technical nature; that is particularly likely to be true in the case of a material with such a powerful developmental role to play as cement. Some of the social, economic and institutional problems that have been encountered or are likely to be encountered in introducing new or different cement-making technologies are also considered in this paper.

Existing cement production

The consumption of cement by developing countries has risen rapidly in the last 20 years as development expenditure has increased. Even more impressive has been the increase in levels of domestic production (see table 1).

TABLE 1. GROWTH OF DOMESTIC CEMENT PRODUCTION IN THE MACRO REGIONS OF THE WORLD AND IN CHINA AND INDIA, 1966–1975

Region or country	*1966*	*1975*	*Increase*
	(Million tonnes)		(Percentage)
Africa	12	23	92
North America	85	90	6
South America	17	34	100
Asia	82	168	105
Europe	176	248	41
Oceania	5	6	20
USSR	80	122	53
World	457	691	51
China	11	30	173
India	11	16	46

Source: United Nations Statistical Yearbook 1976.

In all the developing regions, cement production doubled during this period, while much smaller increases were recorded in the developed regions. The increase in cement production in the developing regions has, in fact, been a great deal faster than that of the average *per capita* income, reflecting perhaps the predominance of capital projects in the market for cement. Some particularly remarkable increases were those of China (from 11 million to 30 million t/a), the Philippines (from 1.6 million to 4.4 million t/a) and Sri Lanka (from 80,000 to 393,000 t/a).

Correspondingly, imports of cement by developing countries have declined. A considerable number of developing countries are already, or soon will be, self-sufficient in cement.

The trend to large-scale plants

Details of the sizes and types of cement plants that have been established are not readily available on a world-wide basis. However, recent reports on the Indian cement industry [1] suggests that whereas the majority of the kilns established in the 1950s and 1960s were of 300–500 t/d capacity, those established more recently are of 600 t/d capacity and larger. However, in 1975 there was no kiln in India larger than 1,000 t/d capacity. In the same year the National Committee on Science and Technology in India was in an advanced stage of completing an exercise for single units of larger capacities – 2,000 t/d and above.

It would appear that the current trend in conventional cement manufacture in developing countries, as elsewhere, is towards larger and larger kilns. Indeed, the present dependence of so many developing countries on just a few cement-plant manufacturers in industrialized countries makes it inevitable that technological trends in the industrialized countries will be followed in the developing countries and, at first glance, the savings in capital cost and energy costs resulting from an increase in size of plant seem to present a good case for this trend.

Whatever the advantages of the use of large-scale cement plants in the industrialized countries (and these advantages are by no means undisputed),[1] their appropriateness for all situations in developing countries is being seriously questioned.

Problems

The problems associated with large-scale plants are:

High capital cost per unit of output
Long time-lag in construction
Difficulties in satisfying infrastructure requirements
High cost of transportation to outlying areas
Dependence on imported machinery
Low capacity utilization
Limited number of locations where raw materials are adequate
Difficulty in obtaining capital for new plants

Some of the problems are directly associated with the scale of production. The reserves of raw materials required to keep a plant in operation for a period of 30 to 40 years are considerable, and the number of locations where reserves of sufficient quantity and quality are found is limited. In India, a high proportion of cement is produced in the south of the country, while the largest markets are in the north. The scale of the machinery required to be manufactured, transported and installed creates further problems. The larger the plant needed, the smaller the number of workshops capable of producing it. For most countries, this means the entire plant must be imported. But even in the countries that have their own heavy workshop capability, the unit cost of machinery increases as the scale increases.

For smaller items which can be produced in many workshops there is keen competition leading to a lowering of price. The size of the infrastructural requirements, e.g. power, maintenance workshops, railways, and the specialized skills needed for a large plant, create further problems. Shortages or breakdowns can frequently result in plant shutdowns. In India, capacity utilization has been usually high, above 80 per cent, because of the large demand, but over recent years has been severely hit by shortages of coal, power

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[1] A recent report (unpublished) from a large cement manufacturer in the Federal Republic of Germany states that neither fuel nor capital costs have been substantially reduced by the installation of larger units. Greater expenditure on servicing personnel and reduced competition among machinery manufacturers are additional factors which in practice weigh against the larger plants.

and freight cars, causing a drop to 72 per cent capacity utilization in 1974. In other countries, with a less well-developed infrastructure, capacity utilization is frequently much lower. If low capacity utilization in large plants were calculated for at the planning stage, their economics would look far less attractive.

Because of the large-scale, high capital cost and long time-lag in construction (three to five years), the financial commitment in a large cement plant is immense. In developing countries there are few if any investors who have the resources for such an undertaking, leaving the expansion of the cement industry either to government or to foreign investors. This is one of the main reasons why expansion in production so frequently lags far behind, causing an almost universal scarcity of cement.

Another problem of growing importance associated with large-scale plants is that of transportation and distribution of the product. The level of demand for cement in developing countries is typically such that any large-scale plant must serve a large geographical region. India's area of 3.2 million km² is served by 53 cement plants, approximately the same number as in the much smaller area, 230,000 km², of the United Kingdom of Great Britain and Northern Ireland. Africa south of the Sahara (excluding South Africa), an area of more than 16 million km², is served by no more than 25 plants. Thus transportation costs must represent a substantial proportion of the price buyers pay for cement. In India, where most of the cement is transported to district distribution centres by rail, distribution costs are equalized throughout the country, with a freight equalization charge of approximately 15 per cent of the consumer price. This arrangement, though advantageous to the consumer, reduces the incentive for new cement plants to be located near large markets so that transportation costs would be lower.

In many other countries, where rail networks are less developed and cement must be transported by truck, bullock cart, boat or even by air, transportation costs are much higher, particularly where these have to account for numerous handlings and for the inevitable loss and deterioration in transit. Thus, throughout Indonesia the price of cement is above $100 per tonne; in parts of Sumatra it is as high as $500 per tonne; and the price of cement in the interior of the United Republic of Tanzania can be as much as two or three times that in Dar es Salaam, where the factory is situated.

Finally, the centralization of production resulting from the use of large-scale cement plants is entirely inconsistent with a policy of regional self-sufficiency.

Because of the problems, there is now considerable interest in the possibility of smaller-scale cement plants which could be:

(a) Widely distributed wherever there is a demand for cement and suitable raw materials are found;

(b) Manufactured and assembled locally, avoiding the need for imports and reducing technological dependence on foreign firms;

(c) Erected and brought into production quickly;

(d) Cheap enough to be financed locally;

(e) Only a small localized additional burden on existing power and transportation infrastructure.

Such smaller plants would also need to be of low capital cost per unit of output, and economical in their use of energy; otherwise the cost of the cement produced in them would not compete with that produced in large-scale plants. The straightforward scaling down of existing technology used in large rotary plants is unlikely to meet this requirement because of the economies of scale in rotary plants. Different technologies, more appropriate to the specific requirements of a small plant, are therefore needed.

I. SMALL-SCALE PORTLAND CEMENT PLANTS

Background

The earliest Portland cement kilns were like lime kilns. They consisted of a conical or bottle-shaped shaft and were operated intermittently. One of the reasons why shaft kilns were susperseded, early in the twentieth century, by rotary kilns, is that the rotary kiln could be operated continuously, thus considerably improving fuel efficiency, and making it possible for a more uniform product to be produced. As demand grew, so longer and larger kilns came into use, and with each increase in scale came a reduction in fuel consumption and in capital costs. Shaft kilns could not be scaled up in this way, and so they ceased to be economical for situations where there was a large concentrated demand.

The reasons for this can be explained as follows:

"The main difference between the vertical shaft and rotary types of kiln is that the principle of heat transfer by conduction plays a more important role in the vertical shaft kiln than radiation, whereas in the rotary kiln radiation is more important than conduction. Heat transfer by conduction can be efficient in a relatively small space; beyond a certain size heat transfer efficiency drops due to high radiation losses. On the other hand, heat transfer by radiation is progressively more efficient in a larger space due to lower heat losses. This basic fact led to the development of larger and larger plants based on rotary kilns. The vertical shaft kiln can be efficient with a capacity of as low as 1 t/d, and has a maximum efficient capacity of 200 t/d. The rotary kiln, however, has a minimum efficient capacity of 300 t/d and nowadays capacities of 3,000 t/d and more are preferred." [2]

In fact, vertical shaft kilns virtually went out of use until the 1930s when new designs with continuous, as opposed to batch operation, were developed. Such continuous operation vertical shaft kilns continue to be used in some European countries for a small proportion of their cement production. Overall, some 5 per cent of world output today is still being produced in vertical shaft kilns.

Because of the heat-transfer principle used, shaft kilns tend to have lower fuel consumption than rotary kilns. A recent report on the European cement industry [3] gives an average fuel consumption for the main processes used (see table 2).

TABLE 2. REPRESENTATIVE ENERGY CONSUMPTION OF COMMON PROCESSES OF CEMENT MANUFACTURE IN EUROPE

	Energy consumption per kilogram of cement [a]	
Process	*(kcal)*	*(kJ)*
Dry (long kiln)	860	3 600
Wet (long kiln)	1 300	5 400
Semi-dry (great pre-heater, Lepol type)	850	3 600
Dry (suspension pre-heater)	790	3 300
Shaft kiln	750	3 100

Source: [3].

[a] Not including the electrical energy consumed, which amounts to 0.1 kWh, or 86 kcal (360 kJ).

Lower fuel consumption enables vertical shaft kilns to remain competitive with rotary kilns in spite of the difference in scale of operation. However, there are differing views both on the scale and on the technology best suited to small Portland cement plants in developing countries. Some recent work is summarized below.

Indian development work on small-scale vertical shaft kilns

Between 1965 and 1970 the Regional Research Laboratory, Jorhat, India developed designs for small shaft kilns with capacities of 2, 30 and 100 t/d. Pilot kilns of 2 and 30 t/d were installed.

In 1965, the Uttar Pradesh State Planning and Action Research Institute decided to design, build and operate a 25 t/d plant in India, on which the design of future commercial plants could be based. The design was in many respects similar to the Jorhat design, based on a disc nodulizer feeding a vertical shaft kiln. The kiln was designed to use as raw material a mixture of kankar (impure secondary limestone found in the plains of northern India) and rock limestone. The fuel was coke breeze with some coal added. Production trials took place in 1970/71 during which 10,000 tonnes of cement were produced, most of which satisfied the Indian Standards Institution specification for Portland cement, except for the expansion ratio, which was somewhat high. Further work to develop this design was initiated in 1978 by the Appropriate Technology Development Association, Lucknow, India.[2]

A similar project is that of the Cement Research Institute of India (CRI), New Delhi, at its Tamil Nadu centre where a 25 t/d plant has been developed and is working on an industrialized commercial basis.[3]

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[2] See "Proposal and Feasibility Study for a 25 t/d Mini Cement Plant" in this monograph.

[3] Several research reports on mini cement plants are available from CRI. See, too, the paper prepared by CRI contained in this monograph.

Medium-scale vertical shaft kilns

During 1976, a mission for UNIDO was undertaken by a cement consultant whose main aims were:

To organize and undertake an exploratory mission to producers of equipment for shaft kilns and cement manufacturers experimenting or working with shaft installations;

To make observations and recommendations on the requirements for the establishment of shaft kiln pilot plant installations [4].

The consultant recommended the use of vertical shaft kilns of a size considerably larger than the Indian designs and proposed a plant with an annual output of 80,000–120,000 t, from two conventional shaft kilns of 180–200 t/d or, alternatively, one kiln working on the newly developed Reba process. Such a plant would be large enough to take advantage of highly developed existing kiln designs yet small enough to be fabricated locally and to make substantial savings through standardization. The advantages of a vertical shaft kiln installation are:

Substantial savings in space
Simple construction with no heavy castings
Fewer problems with starting and stopping
High degree of reliability due to the durability of refractory bricks
Kiln and cooler form an integrated unit
Production of low-alkali clinker possible
Possibility of low-cost do-it-yourself construction

The consultant pointed out that conventional shaft kilns might not be suitable for all raw materials as they require the use of high strength pellets and low-volatile fossil fuel. The Reba process, however, would enable shaft kilns to be oil-fired.

The compact cement plant

A different approach was suggested in a recent article in *World Cement Technology* [5]. The author underlined the need for small cement plants in developing countries in order to achieve dispersal of industrial activity for local economic development. He argued, moreover, that the smaller the plant, the lower the unit cost, because of the increased competition among the much larger number of workshops able to produce it.

He did not, however, accept the vertical shaft kiln as the answer, except at the mini-plant level of 10–50 t/d. Above 100 t/d, he argued, the vertical shaft kiln had major disadvantages because:

"Nodulisation of cement raw mix and fuel (coke breeze only can be used and this normally has to be brought from steel plants at comparatively high cost, when compared to low/medium grade coals normally used in the cement making process) in the correct proportion is necessary for charging the nodules to the vertical kiln. This process requires additional equipment and auxiliaries which increase costs. Adequate control of the burning process, once the nodules are charged to the kiln (to achieve uniformly burnt clinker) is difficult to achieve in a shaft kiln and results in an uneven quality of clinker which after selective screening does not produce a good quality clinker cement. In view of the additional equipment necessary in a shaft kiln plant the operational costs are also relatively higher when compared with an SP kiln system."

He therefore proposed a "compact" plant of 150 t/d capacity, with a rotary suspension pre-heater kiln, using the dry process of manufacture. The kiln would be fired by pulverized coal.

Cement production in China

According to a 1977 report [6] more than half of China's cement production comes from small-scale plants. The standard plant has an annual production of 32,000 t, approximately 100 t/d. The technology is described as follows:

(a) The feed is uniform nodules obtained from a simple disc nodulizer;

(b) The kiln is fed more or less continuously by a team working on the top of the kiln;

(c) Clinker formation is confined to the upper portion of the kiln;

(d) Draught is usually induced and heat exchange takes place in the lower portion of the kiln;

(e) Clinker discharge is usually discontinuous;

(f) Fuel economy is good because:

- (i) Fuel is being interground into the nodules;
- (ii) There is sufficient heat exchange within the kiln;
- (iii) There are porous clinkers, which need less energy for grinding.

Comparison of small- and large-scale plants

The information available on operating costs of small plants in developing countries based on long-term production experience is generally scanty.[4] However, production costs are such that, with an equivalent selling price (including packing and transport), the return on capital for two plants, one 25 t/d vertical shaft and one 1,200 t/d rotary, would be approximately the same. In practice, however, it is envisaged that cement from the 25 t/d plant would be bought unbagged straight from the silo with customers providing their own transport, and consequently the selling price would be some 25 per cent lower than bagged cement from the large plant.

The economic advantages, under Indian conditions, of a small plant, compared with a large rotary kiln plant, can be summarized as follows:

(a) Lower (40–50 per cent) capital investment per unit of annual cement production. This is an important factor, as capital costs account for about 50 per cent of the cost of production in a large rotary plant;

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[4] CRI has however, published some information in its recent publications.

(b) Lower fuel cost per unit of cement produced, due to utilization of cheaper quality coal or coke and slightly lower fuel consumption;

(c) Electric power consumption no greater;

(d) Lower consumption of grinding media and kiln refractories;

(e) Lower transport and distributive costs due to proximity of consumer market and possibility of selling unpacked cement to local consumers. Packing, transport and distribution account for about 25 per cent of the cost of cement to the consumer;

(f) Simpler machinery, allowing faster development of machinery manufacturing capacity due to possibility of using less sophisticated, less capital-intensive workshops;

(g) Simpler operation, allowing quicker spread of know-how among less skilled personnel;

(h) Lower spares and maintenance costs due to simpler machinery and smaller inventory of spare parts;

(i) Greater flexibility in rate of production to meet fluctuating demand due to lower costs of shutting down and starting up and possibility of operating several kilns at the same time;

(j) Capability of producing from the same kiln a variety of different cementitious products to suit local needs;

(k) Quicker installation and running-in of new plants (one year as against five years), which improves cash flow and makes faster build-up production possible;

(l) Utilization of small of calcareous materials that are widely scattered throughout many countries but cannot be utilized economically by large plants;

(m) Possibility of dispersal of production in rural areas, creating better balance of regional development;

(n) Creation of more employment per unit of investment–an important consideration in developing countries.

Comparison of experiences in China and India

During 1965–1975 cement production in China more than tripled, from 15 million to 48 million tonnes. More than half of this total was produced in small shaft kilns dispersed in rural areas. The number of these kilns increased from 200 in 1965 to 2,800 in 1975. Their average capacity was approximately 10,000 t/a.

Over the same period, cement production in India increased from 11 million to only 16 million tonnes. Although during this period there were a number of experiments with small-scale production using shaft kilns, the whole of India's production continued to come from rotary kiln plants, ranging in size from the rather small 20,000 t/a capacity plant at Srinagar to the giant 1,080,000 t/a plant at Jamul.

There are at least four reasons for the differences between the two countries in their choice of technology.

First, it is probable that small-scale plants have been used in China primarily for reasons of development policy rather than of production economics. The policy is to decentralize production and to create rural self-sufficiency wherever possible. Such a policy favours small cement plants in rural agricultural areas, financed by capital raised at country or commune level, with equipment built in local workshops and with a locally trained work-force. Large plants are still used for the larger demand in cities.

Secondly, China's policy of decentralized production is encouraged because of the nature of its transportation network. In order to reach district centres, cement from large centralized plants frequently has to be transported by road, and the cost of this would add considerably to the price of the cement. In India, on the other hand, an extensive railway system enables cement to be transported cheaply.

Thirdly, India's freight equalization system reduces the economic benefit from the establishment of small plants. One of the strongest arguments in favour of small plants is that they enable raw materials near to markets to be exploited, thus reducing transportation costs. A national freight equalization system eliminates this potential advantage.

The fourth difference is in the standards adopted for cement quality. In China, there are six classes of cement, with compressive strengths ranging from 200 to 600 kg/cm^2 (20 to 60 N/mm^2). For different types of construction, different cements may be used. Most small plants are said to produce cement class 400 (400 kg/cm^2), which could be used for most rural construction (though it has been suggested that these claims may be overstated [6]. But, in any case, the range of standards available ensures that whatever cement is produced, it can find some use. Obviously, for projects requiring higher quality cement than the local plant could produce, cement would have to be imported from plants elsewhere. In India, by contrast, there is only a single standard for Portland cement, and if a plant does not produce cement fully satisfying this standard, the cement cannot be sold for general use. A major problem with the Lucknow plant was that, although it produced a cement acceptable for most purposes, the cement sometimes failed to satisfy the expansion-ratio test specified by the standard. Thus national control of distribution and rigid insistence on a single standard (following the practice of the industrialized nations) has greatly inhibited the development of the small cement plant in India.

The precise conditions in China and India are not found in other countries, whose experience will probably be different. Local conditions must be carefully considered by policy makers if small-scale cement plants are to be succesfully established in developing countries.

II. LIME-BASED CEMENTING MATERIALS

Background

Before the development of modern cements, lime was used in many of the situations where cement is used today. For several centuries, virtually all permanent buildings were of masonry construction, and the masonry units, whether brick or stone, were usually laid up in lime mortar. Plastering, both internally and externally, was also done with lime plaster (usually with some fibrous binding material such as horsehair to hold the plaster together and to prevent the formation of cracks). Such concrete as was used, for example in foundations, was also made with lime [7].

The replacement of lime by cement resulted in much more quick-setting mortars and plasters, and the consistency of the material gave the builder more confidence. At the same time, the messy lime-slaking operations which were needed to produce the best lime mortars were eliminated. Consequently, wherever Portland cement was available at a reasonable price, it tended to replace lime altogether.

But mortars made with Portland cement and sand alone, without lime, tend to be harsh and difficult to work with, and when they have reached their full strength, tend to be much stronger than the bricks that they bond. This is undesirable as it can cause cracking in the masonry. A much better mortar is one based on lime, to give the workability required, but with just enough cement added to provide adequate strength and a fast enough set to allow the work to proceed quickly. This is the standard mortar used in industrialized countries today. The availability of bagged hydrated (slaked) lime enables such mortars to be made on the site just as readily as cement mortars.

An alternative method of achieving the strength necessary for lime mortars and plasters is by the addition of pozzolanas. Pozzolanas are materials which are not cementitious in themselves, but which when mixed with lime will cause the mixture to set and harden in the presence of water-like cement. These materials are of ancient origin, and were used by the Romans to make the concrete for many of their most magnificent durable structures. The massive 42-m dome of the Pantheon in Rome, for example, which has survived nearly 2,000 years, is made from lime-pozzolana concrete.

The significance of lime and lime-pozzolana mixture as alternatives to Portland cement in developing countries is that both can be manufactured by very simple processes suitable for village-scale technology. Lime is made by age-old technologically unsophisticated processes in most countries where limestone is available, in lime kilns of an enormous variety of shapes and sizes. However, most of these processes are highly inefficient, being based on intermittent or batch production of lime. Because of the inefficiency of the process, the price of lime is often as high or even higher, per unit weight, as cement, and it is cheaper and more reliable to use cement alone in mortars and plasters. A 1:6 cement/sand mortar is common in many developing countries. Locally produced lime is frequently used only for lime washes. But with improved manufacturing techniques, it is possible to produce lime of a consistent and satisfactory quality at a price which will usually be competitive with Portland cement.

Pozzolanas are currently used in many developing countries. In Indonesia, huge deposits of volcanic ash or tuff provide one source of pozzolana which is used for mortars and for block-making. A pozzolana commonly used in mortars in India and Indonesia is pulverized fired clay, sometimes made by grinding up reject bricks and tiles from the brick and tile kilns; another is the ash from agricultural wastes such as rice husks. But a lack of scientific understanding of pozzolanas, and a lack of quality control in their manufacture has often meant that these potentially valuable but inexpensive, locally produced building materials are rejected in favour of modern factory-produced materials, although recently developed manufacturing techniques and know-how make it possible for local pozzolanas to be used much more widely than at present.

The capital cost of the equipment to manufacture these alternative materials is very much less than that needed to set up the equivalent cement-making capacity, even using small-scale plants. The equipment could be built locally or manufactured in small- or medium-sized workshops.

A further way of reducing the need for Portland cement and replacing it with more appropriate materials would be to design buildings in such a way that reinforced concrete is not needed, or the amount of cement needed in the reinforced concrete is reduced. Many techniques of this sort are available [8].

By adopting such alternative strategies developing countries could reserve much of their supplies of Portland cement for the construction of dams, highway bridges and other reinforced concrete work for which no alternative material is available.

Lime

Raw materials

Lime is made from limestone, a rock containing mainly calcium carbonate and up to 50 per cent magnesium carbonate. There are few places in the world where some form of limestone suitable for lime production is not available. Limestone occurrences of any size are usually noted and mapped by geological surveys because of the mineral's importance as a raw material in cement production and other industries. But localized deposits of little economic significance, but too small to be marked on available geological maps, may nevertheless yield a sufficient quantity of material to supply a village-scale industry for many years.

Production process

Lime is produced by a two-stage process. First, limestone is burnt, or calcined, in a kiln at a temperature in excess of 900°C, driving off carbon dioxide, and producing quicklime (calcium oxide).

The second stage is called slaking or hydration. Quicklime reacts rapidly with water, evolving heat and expanding, so that the lumps of quicklime break down to a fine powder. This powder is slaked, or hydrated, lime (calcium hydroxide).[5]

The type of kiln used depends largely on the fuel available. In many ways the ideal fuel for lime-burning is firewood, because the length and low temperature of the flame make for much more even burning of the stone than with other fuels. But fossil fuels and even charcoal can be employed.

Batch kilns are by far the most common types of small kiln in use in developing countries today. The are cheaper to build and easier to control, and

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[5] In certain circumstances, the lime leaves the kiln as quicklime to be slaked at the site or used for some other purpose. This can save weight in transportation, but quicklime exposed to the air gradually becomes "air-slaked" lime, which is useless.

they fit the pattern of intermittent production and demand typical of small rural industries. The design and size of batch kilns varies greatly in different parts of the world; studies exist on developing country kilns overall [9] as well as on kilns used specifically in Ghana [10] and India [11]. Volunteers for International Technical Assistance (VITA) has developed a new type of small batch kiln for use in Honduras [12]. But fuel efficiency is low by comparison with continuous kilns, and because of the length of the cycle of operations (20 days in the case of rural-type lime kilns in India), average production is low even from a large kiln. However, if firewood is the only available fuel, a batch kiln must be used.

Continuous kilns can be used where coke, coal or oil are available. The kiln typically consists of a cylindrical shaft made of some local material (e.g. stone or brick). At its simplest, the kiln is open at the top for the feeding of raw materials and has one or more openings at the base for removal of the burnt limestone. If coal or coke is used as fuel it is fed with the sized pieces of stone at the top of the kiln; the stone and fuel fall gradually into the firing zone of the kiln, which is in the middle, insulated by a zone of unburnt stone above and a layer of burnt stone below. An efficient heat exchange process between stone and gases takes place. The shaft may also be insulated. Consequently, fuel efficiency is much higher than that of batch kilns, and if the kiln is well controlled, greater evenness of burning results. If oil is to be used as a fuel one or more oil burners are located at appropriate positions around the shaft.

The Khadi and Village Industries Commission (KVIC), India, studied the performance of small continuous shaft kilns, and a design for a small coal- or coke-fired kiln is available from the Commission with details of its expected performance characteristics [13]. The same type of kiln can also be operated intermittently if firewood is to be used as fuel. Naturally, fuel efficiency and average output will be lower.

The Directorate of Building Research, Bandung, Indonesia, has developed a new type of small oil-fired kiln, although its sophisticated burner design makes it too expensive for widespread rural use [14].

The simplest technique for hydration is known as platform slaking. The pieces of quicklime are spread out in a layer not more than 300 mm deep, and water is sprinkled on it to break the lumps down into powder; water is added until no more can be absorbed. The layer is turned occasionally during the process. The lime is then sieved through a fine screen to remove coarse material which is either unburned or unhydrated. Inevitably some finer pieces of unburned material will pass the screen, and lime made this way is not the best material for mortars and plasters unless it is subsequently ground in a mortar mill. But it is perfectly adequate for many other uses–block-making, soil stabilization and agricultural applications. Slaking can also be done in a tank or pit in an excess of water to form lime putty [15].

The best quality dry hydrated lime can only be achieved by using a mechanized hydration plant with an air separator, so that all coarse material is removed [9]. Hydration plants are commercially available with nominal outputs ranging from 40 to 400 t/d, the smallest being considerably larger than the smallest kilns. The Central Building Research Institute (CBRI), India, has developed a much smaller hydration plant which could be fabricated in a local workshop.

Special care needs to be taken in the hydration of a lime containing a substantial proportion of magnesium oxide; for these limes platform slaking cannot be used.

Production requirements

The simplest process of lime manufacture using batch kilns built from local materials and including entirely manual quarrying, loading and unloading and slaking methods would involve little capital cost, probably less than $1.91 per tonne [9]. In Honduras, labour for making quicklime, including quarrying, was found to be 25–40 man-h/t. Shell lime in south India made in small batch kilns, requires 15–20 man-h/t including slaking, excluding the collection of shells. The capital cost of establishing the small lime kiln designed by the KVIC including storage, is Rs 25,000 ($3,220) at 1970 prices. If production were achieved 300 days a year, this would work out at Rs 60 ($7.80) per annual tonne. Labour for kiln operations and slaking only is about 35 man-h/t.

The same kiln recently established in the north of the United Republic of Tanzania as an intermittent wood-fired kiln costs about $3,900, including a storage shed. Because of the intermittent operation, the maximum annual production would be about 200 t, giving a capital cost of $19.50 per annual tonne. Labour requirement would be 30–40 man-h/t.

Fuel requirements depend on the efficiency of the kiln and can be approximately calculated [9]. By comparison, a medium-sized oil-fired plant exported from the United Kingdom, with a production capacity of 60 t/d (20,000 t/a) would cost $1,170,000 to $1,950,000 or $58–$97 per annual tonne.

Pozzolanas

A wide variety of siliceous or aluminous materials may be pozzolanic; volcanic ash, a natural pozzolana; pulverized burnt clay [16] and ash from agricultural wastes [17, 18], are classed as artificial pozzolanas.

However, the possible employment of diatomite [19], bauxite, and many of the lateritic soils found in tropical countries [20] as pozzolanas must also be mentioned. A process (called Latorex) exists for using such lateritic soil in block-making [21].

Processing and uses

The processing and use of pozzolanas depends to a great extent on the type of pozzolana in question.

Volcanic pozzolana in Indonesia

Indonesian Lembang volcanic trass is a course-grained material; it is loosely cemented and easily quarried. For block-making it is mixed with 20 per cent dry hydrated lime–produced in small-scale traditional kilns about 50 km apart, and sufficient water is added to facilitate compaction. Moulding and compaction is traditionally carried out manually; but for larger scale production of better quality blocks the Directorate of Building Research has introduced a vibrating compaction machine [22]. The blocks are cured at ambient temperature for 28 days before being sold. The blocks are extensively used in the city of Bandung where they are cheaper to use than burnt clay bricks. However, shrinkage cracking in walls built with them is common, possibly because they are sold before the full curing period has elapsed.

Volcanic pozzolana in East Africa

The Arusha-Moshi region in the north of the United Republic of Tanzania is volcanic and has huge deposits of yellow fine-grained tuff. The Small Industry Development Organization in Dar es Salaam has begun recently to use this tuff to make lime-pozzolana mixtures, which are mixed either with sand for mortars and plasters or with coarse aggregate to make blocks. Compaction of the blocks is by a hand-operated block press [23].

Burnt clay pozzolana in India and Indonesia

Traditional *surkhi* in India is made by grinding reject bricks or tiles in a ball mill or hammer mill. It is somewhat coarse but sufficiently reactive to enable masonry mortars to set and harden. In Jaipur, Rajasthan, a form of *surkhi* is made from a soil which contains too little clay and too much sand to be of any use for brick-making. The soil is cut and removed in blocks, forming circular pits. The blocks of soil are then replaced in the pit with alternative stacks of firewood and the whole mass is fired through. The resulting burnt soil is friable and needs no pulverizing. Mortar is made by adding it to lime putty and mixing with a hoe. Neither sand nor cement is used. The mortar has been used by the Rajasthan Housing Board for all masonry work throughout a large housing scheme [11].

In Kerala, plastic clays suitable for tile manufacture are found, and the Mangalore tile industry, though now declining, has been flourishing for more than a century. Because the Mangalore pattern tile is liable to crack during drying, a high proportion (up to 15 per cent) of rejects are produced. When pulverized in a hammer mill these tile rejects give a *surkhi* which is being used in conjunction with lime for masonry mortars, and in the warm humid climate of Kerala sets and hardens rapidly.

A similar coarse pozzolana is made in Java. A clay-like soil is mixed with water, moulded into blocks and dried in the sun. The blocks are built into a clamp, fired with firewood, then disintegrated using wooden flails. The coarse particles are then screened out. The resulting red powder, *cemen mera*, is used in conjunction with lime, sand, and sometimes cement in masonry mortars.

Improved burnt clay pozzolana in India

During the 1960s, the Central Road Research Institute, Delhi, carried out extensive investigations on burnt clay pozzolana [24]. They located suitable clay deposits throughout India, established procedures for firing and grinding to obtain maximum reactivity, and set up pilot small-scale manufacturing plants using down-draught and rotary kilns. These plants were able to produce a pozzolana of very much higher quality and uniformity than the traditional *surkhi*, which could be used either in lime-pozzolana mixtures for mortars and plasters or for the production of Portland-pozzolana cement by intergrinding cement with the burnt clay.

To improve the fuel efficiency of burnt clay pozzolana production, the Sri-Ram Institute, in conjunction with the National Buildings Organisation, has developed a fluidized bed calciner with a capacity of 20 t/d [25].

KVIC Bombay has developed an alternative lime-pozzolana material, known as Lympo. The pozzolana is obtained from underfired bricks from rural brick clamps. These are pre-crushed and then interground with lime using a hammer mill; a small proportion of mineral gypsum is also added to control the setting and initial rate of hardening [26]. India has developed standards both for burnt clay pozzolana and lime-pozzolana mixture [27]. Three grades of lime-pozzolana mixture are specified for different uses.

Rice husk ash

Ashmoh is a rice-husk cement developed at the Indian Institute of Technology, Kanpur. Rice husk-ash from rice mills and hydrated lime are ground together in a small ball mill. Ashmoh is a fine powder of light to grey colour with a bulk density about half that of Portland cement. It is recommended for use in mortars, plasters, sand-cement blocks, well rings and canal linings [28]. A small pilot plant has recently been set up at Aau in the Banda district of Uttar Pradesh [29].

An alternative way of using rice husk to make a pozzolana has been developed at the Nave Technical Institute, Shahahanpur [30]. Equal quantities of clay and rice husk are mixed with water and shaped into cakes. These are then dried in the sun and fired in an open clamp. No fuel is needed except for the initiation of the fire. The fired product is ground to a fine powder in a ball mill and then passed through a 200 mesh sieve. It is claimed that if the clay content of the soil were greater than 20 per cent, a highly reactive pozzolana would be produced.

Production economics

Little economic information based on commercial operating experience is available. Economics of production are also dependent on time, place, availability of raw material, fuels and other inputs. The economic data gives only an indication of likely performance. The production requirements for Lympo at three different scales of production are given in table 3.

TABLE 3. PRODUCTION REQUIREMENTS FOR LYMPO

		Capacity (t/d)		
Requirement	*Unit*	*2*	*5*	*10*
Investment[a]	Rs	20,000	45,000	80,000
	$	2,535	5,850	10,140
Working capital	Rs	10,000	15,000	30,000
	$	1,404	1,911	3,822
Power	hp	5	10	15
	kW	3.8	7.6	11.2
Labour	persons	5	10	15

Source: [26].

[a] Including cost of the kiln and all machinery but excluding cost of land and buildings.

In the United Republic of Tanzania, a unit producing 60 t/m of lime-pozzolana mixture using natural volcanic ash has a capital cost of $4,680 and employs approximately 10 persons. Thus the capital cost is approximately $6.80 per annual tonne, and labour is about 25 man-h/t (for kiln operation and mixing only).

The cost of the Ashmoh rice-husk cement plant at Aau is said to be $2,925 ([29], p. 178). This does not include the lime kiln. For an annual production of 250 t this works out at $11.70 per annual tonne.

III. OTHER CEMENTING MATERIALS

Hydraulic lime and natural cement

Limestone containing some clay will, if calcined at the appropriate temperature, produce hydraulic lime, which will set and harden without addition of pozzolana. One classification distinguishes feebly hydraulic (less than 12 per cent active clay), moderately hydraulic (12–18 per cent) and eminently hydraulic (18–25 per cent), limes.

Many of the limes produced before the advent of Portland cement were hydraulic, their rate of strength development making them superior to high calcium limes for mortars in large buildings or underwater structures. The processes for calcining and slaking a hydraulic lime are different from those for a high-calcium lime. Firing temperatures must be somewhat higher and slaking can be expected to take much longer. No detailed account of the process of manufacture of hydraulic limes appears to exist. Nevertheless excellent low-cost mortar and plaster material can be produced by simple technology from the right material, and hydraulic limes should not be overlooked.

In the construction of the Lloyd Barrage at Sukkur, India, the engineers produced an artificial hydraulic lime. The process has been described [31]. High calcium lime was calcined and slaked in the normal way, then ground wet for 20 minutes with 25 per cent of its volume in clay. The resulting slurry was then dried, cut into lumps and fired a second time in an intermittent kiln. The hydraulic lime, on removal from the kilns, consisted of lumps and powder; in about a week it had slaked to powder. The double calcining involved in this process is likely to make it uneconomic today except in special circumstances.

Natural or Roman cement is a material made by calcining certain very impure carbonate rocks. It was the forerunner of Portland cement, and widely used during the early industrial period in the United Kingdom. The best known raw material was septaria ("cement-stones") which were found washed out of the London clay at coastal outcrops. Their composition was 60–70 per cent carbonate, 30–40 per cent clay. Calcining at a temperature just below that required to cause fusion (approx. 1,100–1,200°C) and subsequent grinding produced a powdery material of cementitious properties. A recent laboratory study [32] has indicated that the strength achieved after 28 days would be no more than around one third to one half that of Portland cement. Natural cements are not made commercially today, but the process could be used in areas of cement scarcity where raw materials were suitable.

Gypsum

Some of the earliest plasters used in ancient Egypt were made from gypsum (calcium sulphate), an abundant mineral. As rock gypsum, it is often found in beds of substantial thickness. Calcination at about 165°C drives off about 75 per cent of the water, leaving the hemihydrate, a white powder called plaster of Paris. If water is added to plaster of Paris, the hydrate is reformed, setting hard in a very short time.

This quick-setting property of plaster of Paris makes it very useful for a variety of building purposes, but it is soluble in water, which makes it unsuitable for external use except in arid climates. For this reason its use in most industrialized countries today is limited to internal plasters and plasterboard, though in some countries it is used for block-making.

The low temperature required in calcination and the processing technique for producing the hemihydrate are very simple. Calcination can take place in a pan, kettle or kiln. Also, the process has an energy requirement less than one fifth that for producing Portland cement. Details of manufacturing techniques are available from UNIDO [33]. A survey of the global resources of gypsum and anhydrite and its uses has been published by the Institute of Geological Sciences [34].

Other cements and cement-making processes

In the Schifferle process [35], a cement is made by intergrinding lime with siliceous materials to a considerably greater fineness than that achieved in Portland cement production (area over 9,000 cm^2/gm against 2,500 cm^2/gm). A variety of raw materials may be suitable, among them volcanic ash, rice-husk ash, kaolinitic and montmorillonitic clay. Strengths at 28 days comparable with that achieved by Portland cement are claimed.

One advantage of the process is that no heat is used other than that used in manufacture of the lime. On the other hand, considerable grinding energy is needed. The process is said to be suitable for use on a limited scale.

Magnesium oxychloride or "sorel" cement is made from magnesium carbonate. It is a hard-wearing cement which was once used for floors in hospitals and other public buildings. However, only one occurrence of magnesium carbonate in India is known to the author, at Salem, Tamil Nadu. Recently, work at the CBRI has shown that magnesium oxide can be produced from half-burnt dolomite, and this could be used for making sorel cement.

In the recently developed Tetrosem process [36], the raw materials react together in falling through a plasma generated by a rotating electrical arc. The process offers opportunities for small-scale plants in which a wide range of different raw materials could be processed. At the present time the process is still under development and precise costs are not known.

IV. NON-TECHNICAL PROBLEMS IN IMPLEMENTING APPROPRIATE TECHNOLOGIES

The following general conclusions are based on experience in the development of small-scale cement plants in India. It is suggested that these factors apply not only to the cement industry, but also to other industrial sectors which produce essential commodities such as fertilizer, steel, or sugar.

(a) When technical problems are eventually overcome, the establishment of an alternative technology will be difficult if certain types of government support continue to be given to manufacturers of conventional technology;

(b) National controlled prices which do not allow the industry sufficient margin to finance its own expansion make it difficult for alternative technologies (which must find their own capital) to compete;

(c) National control of distribution, and freight equalization charges reduce the economic advantage of setting up small-scale plants near their markets, at some distance from large-scale plants;

(d) A single national standard which prevents an adequate but slightly below standard material from being sold and used makes the establishment of a different technology a high risk;

(e) Large-scale manufacturers might well regard it as in their interests to resist the proliferation of small-scale units.

Other problems are encountered when it is proposed to replace a product now produced in large-scale modern industry with a village-produced alternative, of rather different properties, for example, if cement is replaced by lime-pozzolana mixture. Unfamiliarity with the product will initially make users suspicious of it, and unwilling to take the risk of using it in preference to a well-known and reliable existing product. The fact that it is made at a village level, with less quality control than can be expected in a factory, and not subject to any recognized standard or specification, will increase the lack of confidence. The techniques for using it will be different from those for using cement, and any incorrect use leading to failure will have a damaging effect on the reputation of the material, emphasizing the lack of confidence.

There will also be considerable production difficulties, at least in the early stages. Each new raw material presents its own production problems which must first be solved. Subsequently, adequate quality will depend on accurate, responsible and methodical work by people who are likely to be unfamiliar with the industrial method of production. Any sub-standard material which finds its way on to the market, particularly in the early stages of production, when users are unfamiliar with the product, will increase the potential users' lack of confidence. In addition, demand is likely to be low in the initial stages.

To counteract the market distortions as well as to overcome other obstacles to the establishment of small-scale production of cementitious materials, a strong commitment by Governments, backed where necessary by legislation is needed. Some proposals for consideration are:

(a) Capital for those intending to establish plants should be made available on terms at least as generous as those extended to large-scale manufacturers;

(b) In order to create an incentive for the establishment of small plants at a

distance from existing factories, there should be no freight equalization charge or other distortion of the real transportation cost of cement throughout the country;

(c) To assist in the introduction of small-scale technology and its gradual improvement, a range of standards for cement should be instituted, as in China, rather than the one single standard set by the International Organization for Standards (ISO). The new standards should permit different grades of cement to be used for different purposes. A national system of quality control to ensure that all cement produced was correctly classified would also be needed. An examination of how the Chinese system works would provide valuable background for such a policy;

(d) Since the interests of large-scale cement manufacturers might conflict with the national interest over this issue, the development of small-scale Portland cement plants should be the responsibility of an institution entirely independent of the large-scale cement manufacturers. It will be responsible for the technical work leading to the design of satisfactory plants, and also for the promotional work needed to establish these plants as commercially successful alternatives to existing technology. Its responsibilities should therefore include:

Supply of drawings and designs and of financial data

Technical guidance and supervision during installation of new plants including training of personnel

Preparation of simplified technical manuals

Standardization of manufacture of plant and machinery and supervision of manufacture of plant

Organization of technical seminars and meetings

Small industry development organizations already exist in many countries, and the development and promotion of lime-pozzolana or other alternative village-scale technologies for producing cementing materials should also be included among their responsibilities. They should promote new products of small plants by:

Preparing descriptive leaflets showing corrects uses of the material and warning against incorrect uses

Organizing training courses for potential users

Showing the proper use of the material through demonstration buildings

Preparing national quality control standards and establishing test facilities to check that these standards are met

The lack of information on raw materials resources for small-scale industry should be rectified by conducting a survey of potential raw materials resources, initially from existing geological maps and records, and subsequently by field surveys in promising areas. The work of the National Building Research Unit of the United Republic of Tanzania is a good example of how this work can be started [37].

Means must be found to rectify the shortage of technically qualified or trained people willing to work in industries in rural areas. The policy of some countries (e.g. the United Republic of Tanzania and Zambia, requiring two years of directed compulsory government service after graduation from university or technical college) is worth considering. In order to overcome the prejudices on the part of technically qualified builders and engineers against village-produced cementing materials, the properties and use of these materials should be taught as an essential part of all courses in building and civil engineering. To facilitate this, suitable course material needs to be prepared. The economic benefit to the national economy of using these materials in place of conventional factory-produced products should be clearly illustrated.

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Proposal and feasibility study for a 25 t/d mini cement plant

†*R. Bruce** and *M. K. Garg**

Portland cement is used in building activities to the virtual exclusion of lime mortar or natural cement because the latter fail to meet present-day building requirements, and they cannot be improved in such a way as to ensure the advantages of low cost, simplicity of use and adaptability to remote rural areas. The large-scale production of Portland cement appears, therefore, to be the only choice left for the planners. The question is whether to use large plants located near the limestone deposits, involving heavy transport costs to consumer markets, requiring substantial capital, and taking considerable time to reach required production levels; or to use decentralized mini cement plants that would:

- Utilize local deposits of calcareous materials
- Require much lower capital investment
- Come on-stream more quickly
- Create rural employment
- Sharply reduce transport and packaging charges

Technology of Portland cement

The production of Portland cement involves the following steps:

- Mixing of raw material under rigid analytical control
- Fine grinding of the mix (either wet or dry)
- Firing (calcining) the mix to a temperature of 1,400–1,450°C
- Fine grinding of the fired clinker with addition of a small amount of gypsum

The minimum efficient capacity of the rotary kiln is estimated at 300 t/d, and capacities of 3,000 t/d and above are preferred because they have the following advantages:

- Lower radiation heat losses in the kiln area
- Lower capital investment per tonne produced
- Savings in personnel costs
- A general reduction in overhead costs (spare parts, lubrication and maintenance)

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*On behalf of the Appropriate Technology Development Association (ATDA), Lucknow, Uttar Pradesh, India.

Despite the economic advantages of such large-scale plants, they have not been coming on-stream in India at the rate required to fill the gap reflected in the following statistics:

Period	*Installed capacity*	*Production*
	(millions of tonnes)	
1977–1978	21.9	19.2
1982–1983 (projected)	35	30

Vertical-shaft kilns, on the other hand, can be operated with a capacity as low as 1 t/d and have a maximum capacity of about 200 t/d. The techno-economic feasibility of setting up mini vertical-shaft cement plants, particularly in locations far removed from cement production centres, is therefore under consideration.

Details of development work done in India

With the successful utilization of vertical-shaft kiln technology for cement production in a number of countries, particularly in Europe and China, it may be asked why this technology has not yet been applied in India. This idea was taken up as early as 1949, and quite substantial development work has been carried out, but as yet no commercial production has begun. The reasons may be summarized as follows:

(a) In Europe vertical-shaft kiln technology has been developed on the basis of a kiln design with a capacity of 180–200 t/d. Four to six kilns of the above capacity are installed in one unit. The unit thus becomes not a mini cement plant but a large-scale cement plant. The only difference is that in place of a rotary kiln a number of vertical-shaft kilns are used. This model and design of kiln could not be used for decentralized mini cement technology required under Indian conditions;

(b) The vertical-shaft kiln used in China has a capacity of 25–30 t/d, which is also the requirement in India. But the quality of cement produced in China with such kilns is not the same as that of Portland cement and cannot meet Indian standard specifications. In China, the development and use of technology and the consumption of its products are all the responsibility of bodies which can exercise quality control, absorb non-commercial production costs, and operate small-scale plants even when they do not produce cement fully meeting Portland cement specifications;

Conditions in India are different. Government agencies are disinclined to promote any technique about which there is the slightest doubt. Private entrepreneurs and business organizations will not accept new technologies developed by government research agencies without some form of guarantee and technical assistance, which has never been offered in the case of mini cement plants. Furthermore, the majority of consumers are not prepared to accept a lower quality product, even at a lower price, when Portland cement is available.

Over the past 20 years efforts have been made to establish mini cement plants in India despite the problems presented by the above-mentioned conditions. Various projects have involved the Deccan Cement Company, the Defence Department, the Indian Cement Research Institute, the Jorhat Regional Research Laboratory at Assam, the Planning Research and Action Institute (PRAI) of the Uttar Pradesh state government at Lucknow, the National Research Development Corporation, and the Tamil Nadu state government. But none of these project plants managed to produce cement up to Portland cement specifications. In the case of the PRAI project plan at Mohanlalganj, the expansion ratio of the cement produced was rather high, making its use for structural and load-bearing purposes of doubtful safety.

The Intermediate Technology Development Group (ITDG), London, became interested in the efforts made in Mohanlalganj to develop appropriate technology for a mini cement plant. One of the authors (R. Bruce), an associate of ITDG, was therefore sent to India to make a detailed report on the Mohanlalganj cement plant.

On the basis of economic and production data from the Mohanlalganj plant, and data supplied by the Cement Corporation of India on the 1,200 t/d rotary kiln plants currently being installed in India, it was concluded that a 25 t/d vertical-shaft plant could successfully compete with the large plants, providing it consistently produced standard Portland cement. To achieve this, it would be necessary to seek expert technical advice.

It was further recommended that to achieve the widespread use of this technology in India, it would be necessary for a non-government agency to build and operate a new 25 t/d plant in co-operation with a business establishment or autonomous development agency. Its design should be based on that of the Mohanlalganj plant, which seems to be the most sophisticated available model. However, technical experts will be needed to establish plant specifications, to make design changes where necessary, and to provide on-the-spot assistance in India during the first year of the plant's operation. Such expert services should remove any remaining doubts about the feasibility of the technology and create the atmosphere of confidence required to attract investors.

In May 1977, ITDG arranged for the other author (M. K. Garg) to visit Kenya and Europe with complete plans and specifications of the Mohanlalganj pilot plant, which were examined by independent experts in the Federal Republic of Germany.

It was found that the high free-lime content of the cement produced at Mohanlalganj, which was the cause of the high expansion ratio, was largely the result of failure to reach and maintain a high enough temperature (1,400–1,450°C) in the kiln. Various simple procedures were recommended to solve the problem:

(a) The "mixed meal" rather than the inter-grinding process should be used;

(b) The forced air flow in the Mohanlalganj plant was 1.5 times what it should be. It should be reduced and a control system designed to vary the air flow and to be easily operated by the kiln operator should be installed;

(c) The feeding of nodules should be controlled according to gas temperature at the base of the chimney, which should be kept around 60°C, and in no case allowed to exceed 80°C. The average in the Mohanlalganj plant was around 150°C;

(d) The flue-gas temperature can be further regulated by installing infinitely variable gearing for the grate, thus enabling the kiln operator to control the rate of clinker discharge easily and quickly, and to keep the burning zone stable at the correct level;

(e) The make-up of the raw mix, particularly the heat input, should be carefully controlled. For this purpose, the heat content of the fuel must be tested and the constituents adjusted accordingly, which was not done in the Mohanlalganj plant.

The proposed project

Based on the Mohanlalganj experience, the Appropriate Technology Development Association (ATDA), Lucknow, proposes to build a 25 t/d plant with assistance from the Intermediate Technology Development Group, London, experts from private cement producers in the Federal Republic of Germany and Kenya, Appropriate Technology International in the United States of America, the Government of India, the Ministry of Economic Co-operation of the Federal Republic of Germany, and its executive wing, the German Agency for Technical Co-operation, and private Indian interests.

The project is to be carried out in two phases:

Phase I	Examination of existing data and preparation of drawings and specifications by experts from the Federal Republic of Germany
Phase II	Purchase of land and construction of buildings and plant; testing and demonstration under operational conditions by the ATDA with the advice and guidance of experts from the Federal Republic of Germany

Total capital requirements are as follows:

	(Dollars)
To commission experts from the Federal Republic of Germany to examine data, prepare a new set of drawings and specifications and provide advice and guidance to ATDA in erecting and commissioning the plant	78 400
To cover 50 per cent of the capital cost of the land, building, and machinery required for the plant, the balance of the funds being provided by Indian interests	163 660
For overall control and management of the project, including the initial costs of operating the plant for one year while testing, demonstrating and documenting its viability	54 880
Total	296 940

A feasibility study of the proposed plant is given in the annex.

Annex

Feasibility study of the proposed plant

Capital investment	*(Dollars)*	*(Dollars)*
Land and buildings		
Land	6 250	
Buildings	37 500	
	43 750	43 750
Machinery (ready to run)		
Jaw crusher (capacity, 4 t/h)	1 875	
Hammer mill (760 mm)	2 500	
Weighing equipment (raw mix)	2 500	
Mixer, concrete type (capacity, 2½ t/h)	2 500	
Ball mill (raw mix), air conveying gravity separator (capacity, 2 t/h)	43 750	
Homogenizer, continuous circulation fluidizer	3 750	
Nodulizer and silo	5 000	
Vertical shaft kiln and Rootes blower, instrument panel, variable speed grate, drive discharge gates, staging etc.	75 000	
Ball mill (cement	43 750	
Elevators and conveyors	12 500	
Raw materials silos	6 250	
Cement silos	6 250	
Installation and erection	15 625	
Laboratory building with test equipment	12 500	
Miscellaneous	35 000	
	268 750	268 750
Working capital		62 500
	Total	375 000

Gross income

Production

Capacity 30 t/d

Actual production, 25 t/d,
320 days per year: 8,000 t/a

Sale price

Market price (1977) per tonne of Portland cement, transported and sold
in 50-kg bags: $56
Less taxes $18
Net price $38

The plant will market cement straight from the silo (unbagged) and customers will supply their own transport. The margin allowed by the Government for packing and transport is $10 per tonne. The price net to the plant is, therefore, expected to be about $28 per tonne.

Gross income expected per year is therefore:
8,000 t at $28: $224,000

Running costs

Running costs are estimated on the basis of 1977 prices and quantities from data on the Mohanlalganj plant. Costs are calculated in dollars per tonne of cement.

Raw materials

Limestone	0.90 t at $6	$5.40
Kankar	0.65 t at $2	$1.30
Correctives	0.05 t at $3	$0.15
Gypsum	0.05 t at $15	$0.75
		$7.60

Fuel

The Mohanlalganj plant regularly achieved a fuel consumption of 0.18 t per tonne of cement. The fuel is mainly coke breeze with some coal added. The heat input averaged 3,962 kJ/kg of clinker in the 175 t/d vertical-shaft kilns used in the Federal Republic of Germany and 4,795 kJ/kg clinker in the 1,200 t/d wet-process rotary kiln of the Cement Corporation of India.

Coke breeze	0.15 t at $9.38	$1.40
Coal	0.03 at t $18.75	$0.56
		$1.96

Electrical energy

The Mohanlalganj plant consumed an average of 150 kWh/t as compared to 140 kWh/t for the 1,200 t/d rotary plants of the Cement Corporation of India.

150 kWh at $0.025: $3.75

Labour (daily)

	Shifts	*Persons*	*Wage ($)*	*Total ($)*
Grinding and weighing	1	5	0.75	3.75
Mixer and ball mill	3	3	1.25	3.75
Nodulizer and homogenizer	3	3	1.50	4.50
Kiln operator	3	3	2.50	7.50
Clinker and cement mill	3	6	1.00	6.00
Silos	3	3	1.00	3.00
Packaging	1	1	1.00	1.00
Extras	3	6	1.00	6.00
Total		30		35.50

Cost per tonne: $1.40

Labour (monthly)

	Number	*Salary ($)*	*Total ($)*
Manager	1	188	188
Mechanical engineer	1	150	150
Supervisors	3	100	300
Chemist	1	125	125
Workshop machinist	1	75	75
Laboratory assistants	3	50	150
Electrician	1	62	62
Assistant mechanic	1	50	50
Accountant	1	88	88
Cashier	1	50	50
Clerk	1	50	50
Stenographer	1	75	75
Typist	1	50	50

Night guards	3	25	75
Additional worker	1	25	25
Total	21		1 513

Cost per tonne: $2.25
Total labour: $3.65 per tonne

Overhead

Overhead (including office expenses and contingencies) is calculated at 20 per cent total labour costs, or $0.75 per tonne.

Stores and repairs	Cost (dollars p.a.)
Buildings, at 2%	750
Machinery, at 4%	11 000
	11 750

Cost per tonne: $1.45

Summary of running costs

	($/t)
Raw materials	7.60
Fuel	1.96
Electrical energy	3.75
Labour	3.65
Overhead	0.75
Stores and repairs	1.45
Total	19.16
Safe estimate	19.50

Gross annual surplus	*(Dollars)*
Gross sales	224 000
Running costs	156 000
Gross annual surplus	68 000

This represents a gross return of over 20 per cent on capital invested, which is roughly what the Cement Corporation of India expects to earn on a large plant.

	(Dollars)
Deduct depreciation: Buildings, at 5%	1 875
Machinery, at 10%	26 875
	28 750

Net return: $68,000 – $28,750 = $39,250
Return on capital: 10.5 per cent

08304

Sisal-fibre concrete for roofing sheets and other purposes

*H. Persson** and *A. Skarendahl*†

A major problem in building in rural areas in developing countries is finding cheap roofing material with durability, fire resistance, and good insulation and thermal qualities. The past 10 years has seen a number of developments in concrete sheeting reinforced by fibres of steel, glass, carbon, plastics etc. Many developing countries, however, believe that sisal fibre (*Agave sisalana)* would be more appropriate because sisal-fibre concrete:

(a) Is made of easily obtained raw materials which utilize already established concrete technology;

(b) Does not need skilled labour or heavy machinery;

(c) Can be produced in thin sheets and formed to different shapes;

(d) Is a comparatively cheap material;

(e) Sharply cuts energy consumption.

Sisal cultivation originated in Mexico and has spread to tropical regions throughout the world. World production of sisal fibre in 1978 stood at 6,000 tonnes with East African countries, Brazil and Indonesia responsible for most of the output. Sisal is mainly used in agriculture as twine for binding sheaves automatically. However, its price of about $550 per tonne (1978) is unfavourable for producers and they are seeking new ways to use their product. It is also desirable to increase sisal cultivation as it has proved to be a means of arresting desertification.

Sisal-fibre concrete can be used for roofing sheets ranging in sizes from "tiles" to free spans of 5 metres or more, wall plastering, sun screens, window gratings, hollow blocks, wall sheets, storage bins etc. The sisal fibres can be either chopped into short lengths or rolled continuously.

Sisal-fibre concrete products can be produced, transported and erected with great flexibility, allowing the production and building processes to be adjusted to local conditions. The products can be used in traditional as well as in more advanced building techniques.

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*Consultant to the Royal Institute of Technology, Stockholm, Sweden.

†Consultant to the Swedish Cement and Concrete Research Institute, Stockholm.

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NATURE OF THE MATERIAL

Reinforcing brittle materials with fibres is an old technique; early examples exist of mud and clay reinforced with hair and straw. These composite materials are also used today in many parts of the world. More recent examples of fibre reinforcement are asbestos cement, where a cement-based matrix is reinforced with asbestos fibres, and ferrocement, where steel-fibre nets are used.

During the last decade there has been a rapid increase in work associated with fibre reinforcement of concrete, and many new products have emerged. Alkali-resistant glass fibres have been developed and glass-fibre concrete is now used on an increasing scale, mainly in thin-sheet applications. Steel-fibre concrete has been used in pavements, for rock strengthening and in a variety of pre-cast products. Softer fibres such as polypropylene have also been used in concrete, mainly for increasing impact resistance.

The use of sisal or other vegetable fibres in concrete has not been extensively studied, although a few examples can be found in the literature, as well as studies of sisal-reinforced gypsum.

A brief description of the matrix and the fibres used and a detailed review of the properties of the composite material follow.

Matrix

In sisal-fibre concrete, as in other types of fibre concretes, the matrix should preferably be of a high quality and it should have a small maximum aggregate size. With high strength and tightness of the matrix, the fibre material will be better utilized by a better bond, the matrix giving more efficient protection to the fibres. Ordinary Portland cement can be used and the sand can be the same type as that used for ordinary mortar. The cement and the sand are mixed with water to a rather wet, but not fluid, mix; no additives have to be used.

A reinforcing effect from fibres can also be obtained in leaner mixes, but these have some disadvantages, e.g. lower strength, less tightness, less durability, reduced ease of production.

Fibres

Sisal fibres can either be chopped into short lengths (15–50 mm) or in continuous lengths (up to 1,400 mm) in individual form or in nets. The fibres should not be pre-twisted into twines, but as far as possible should be used individually, so that every fibre is surrounded by the matrix.

Constituents in the fibre material or on the fibre surface can retard the cement hydration. This can be avoided by cleaning the fibres, but in most cases normal fibre processing will give satisfactory clean material. Before using a new stock of fibres, a simple test can gauge the risk of fibres affecting the cement's hydration. This test involves comparing the stiffening of a plain matrix made of cement and normal water, with the stiffening of a matrix made of cement and water in which fibres have been stored for a couple of hours.

Properties of the composite material

Properties in the fresh state

When adding short, chopped fibres into a concrete matrix a certain stiffening of the fresh mix takes place. The fibres often tend to interlock and to form balls. The stiffening creates a need for additional water to keep the workability constant, and the tendency towards balling limits the amount of fibres that can be added. For a matrix with a cement to sand ratio of 1 to 3 and a maximum aggregate size of 2 mm, the addition of chopped sisal fibres of different lengths means extra water is needed as shown in figure I. The amount of fibres of a given length that can be added before balling occurs is also shown in the figure.

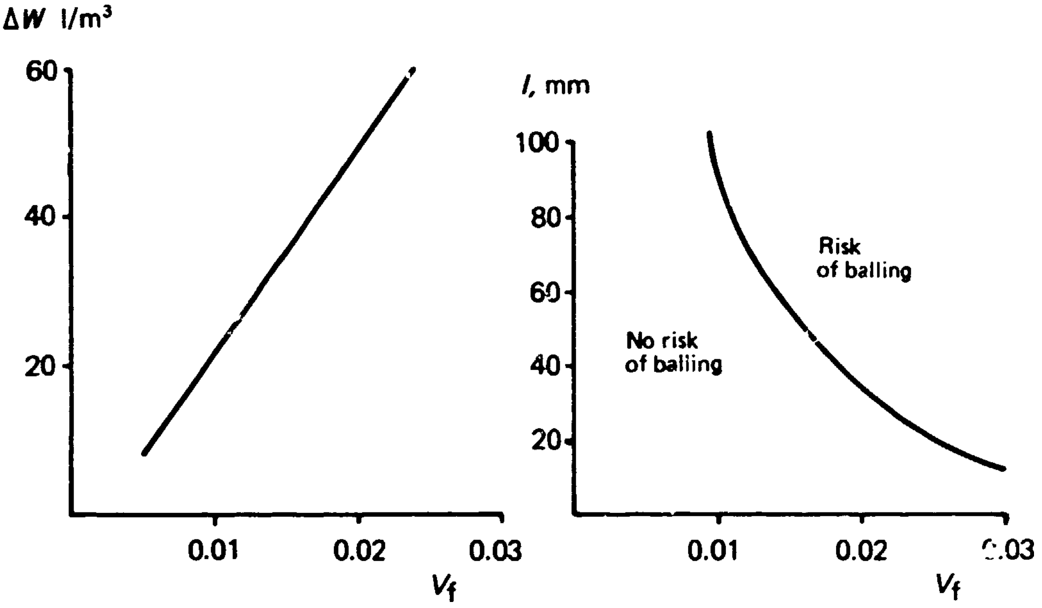


Figure I. Extra water needed (Δw) to keep a constant workability and tendency to ball as visually examined

As shown in figure I, the need for extra water to maintain constant workability is sensitive only to the fibre volume-fraction V_f, while the tendency to ball is dependent both on the fibre length l and on V_f. Both the need for extra water and the tendency to ball are affected by the type of mixer used, and so the figure should only be regarded as a guide.

When continuous fibres are used, the matrix is pre-mixed and spread on a mould in one layer on which continuous fibres are laid and pressed into the matrix layer. The process is repeated until the desired thickness of the laminate is obtained. The quality of the matrix, which mainly depends on cement content and aggregate grading, has a pronounced influence on the volume-fraction of fibre that can be embedded. When using a sand with a 2-mm maximum aggregate size, the maximum V_f is given in figure II as a function of the sand/cement ratio

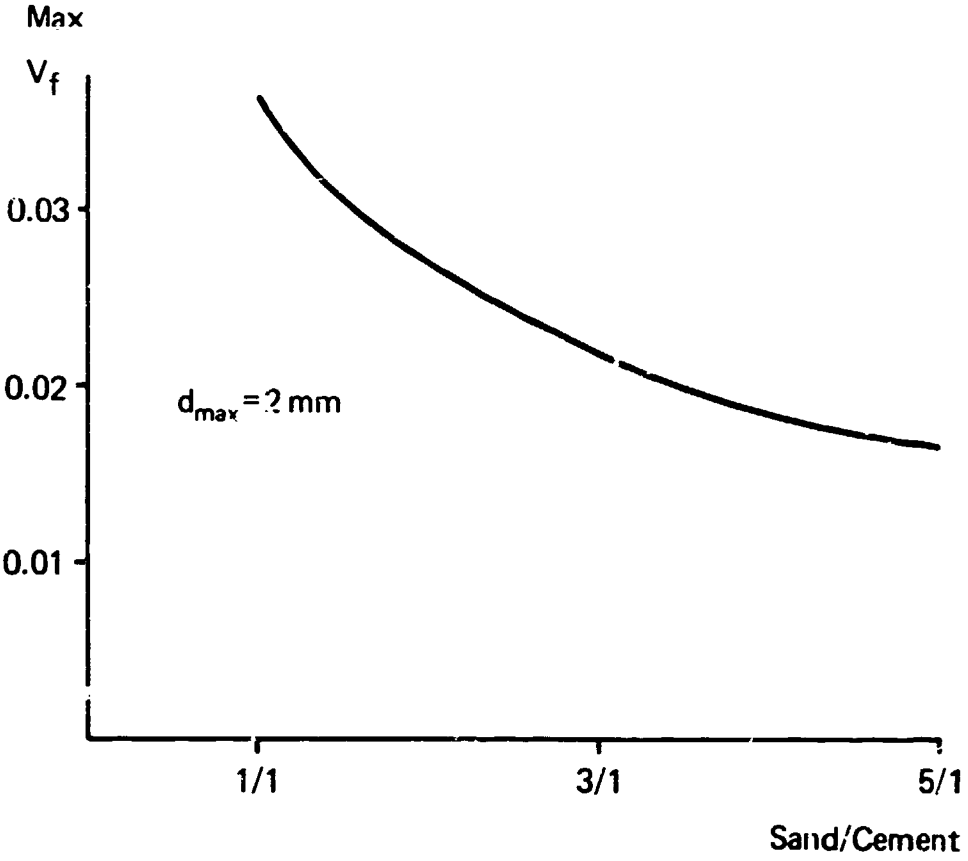


Figure II. Maximum volume of continuous sisal fibres embedded as a function of the sand/cement ratio

The volume fraction of fibres embedded can be increased by the use of finer sand.

The use of nets instead of single fibres would probably also increase the maximum fibre volume fractions.

With all types of sisal-fibre concrete, as with other types of concrete, it is essential to keep the material wet for a few days after production.

Flexural properties

When a concrete matrix is reinforced with chopped sisal fibres the stress-strain behaviour changes, as shown in figure III. Both unreinforced concrete and sisal-fibre concrete have a similar degree of elasticity and approximately the same stiffness up to the point where the material cracks (limit of proportionality). The stress at the first cracking (σ_P) may be somewhat lower for sisal-fibre concrete than for the unreinforced matrix, if the fibres have any negative effect on the cement hydration.

After the limit of proportionality is reached the stress in unreinforced concrete falls dramatically, i.e. the material collapses. In sisal-fibre concrete, on the other hand, the stress falls to a lower level and remains at this level until quite high levels of strain are attained before the final fracture.

With 2 per cent (by volume) of 30-mm long sisal fibres and a matrix with a cement/sand ratio of 1/3, which gives a flexural stress at the limit of

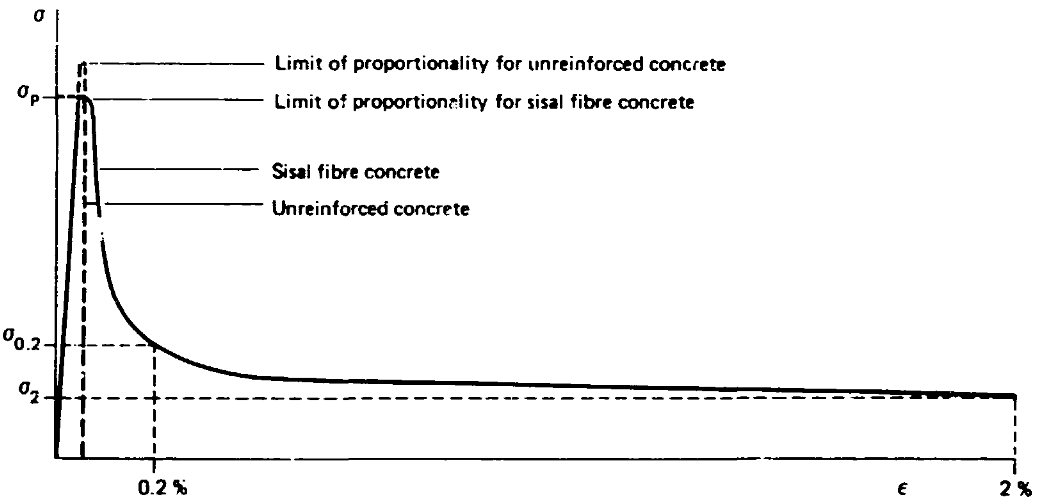


Figure III. Stress-strain behaviour for unreinforced and chopped sisal-fibre reinforced concrete

proportionality of approximately 5 MPa, the stress at a strain on the tensile side of 0.2 per cent (see figure III) can be approximately 3 MPa and at a strain of 2 per cent approximately 2.5 MPa.

A more pronounced strengthening effect is obtained when continuous fibres are used. A typical stress-strain curve in flexure for continuous sisal-fibre concrete is shown in figure IV.

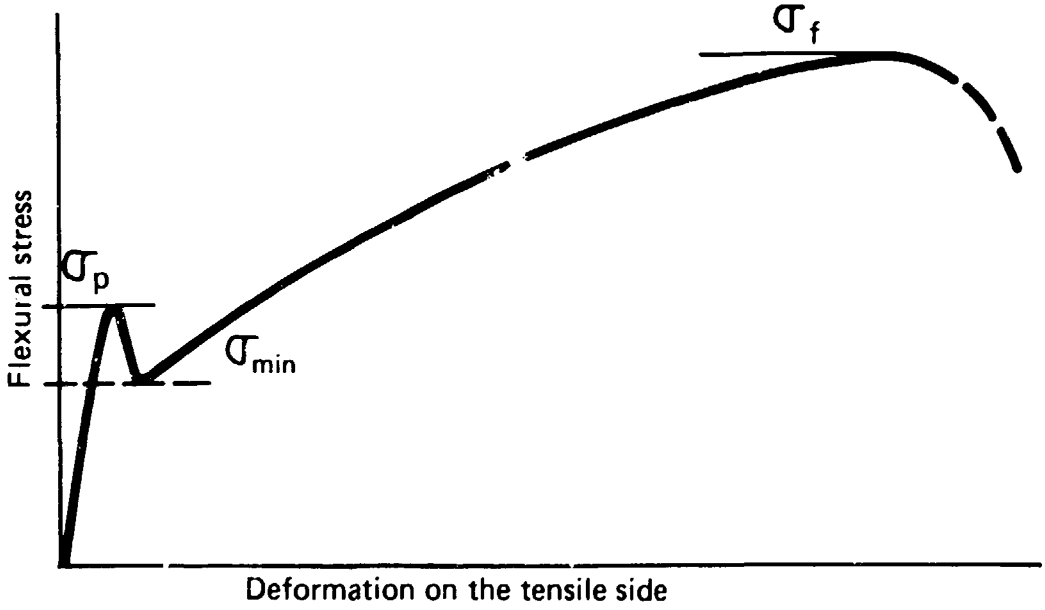


Figure IV. Stress-strain behaviour in flexure for concrete reinforced with continuous sisal fibres

A fall in load-bearing capacity is observed immediately after the limit of proportionality, but later the stress increases and surpasses the stress at the first crack before the maximum load is reached.

In tests with a cement/sand ratio of 1/2 and a V_f of continuous sisal fibres of 0.03, flexural strengths of approximately 12 MPa, almost double the stress at the first crack, have been obtained.

When changing the quality of the matrix, but keeping the volume-fraction of fibres constant, stress-strain behaviour as shown in figure V is obtained.

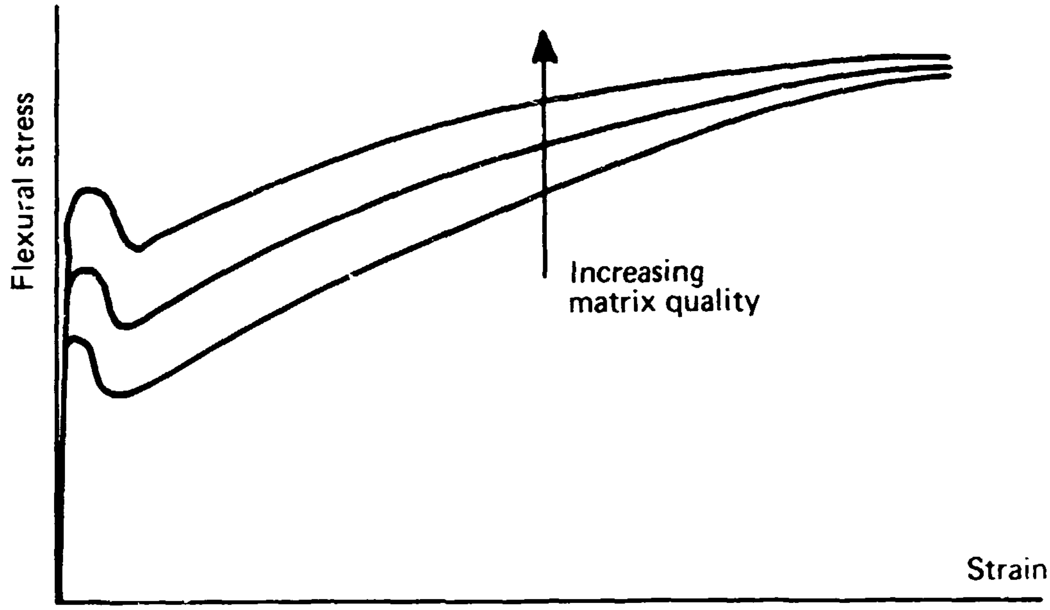


Figure V. Effect on the stress-strain behaviour for continuous sisal-fibre concrete when the matrix quality is changed

When changing the volume-fraction of fibres, but keeping the quality of the matrix constant, stress-strain behaviour is obtained as shown in figure VI.

From figures V and VI it can be seen that an increase in matrix strength gives an increase in the stress at the first crack, while an increasing volume fraction of fibres decreases the fall after the first cracking and increases the load-bearing capacity.

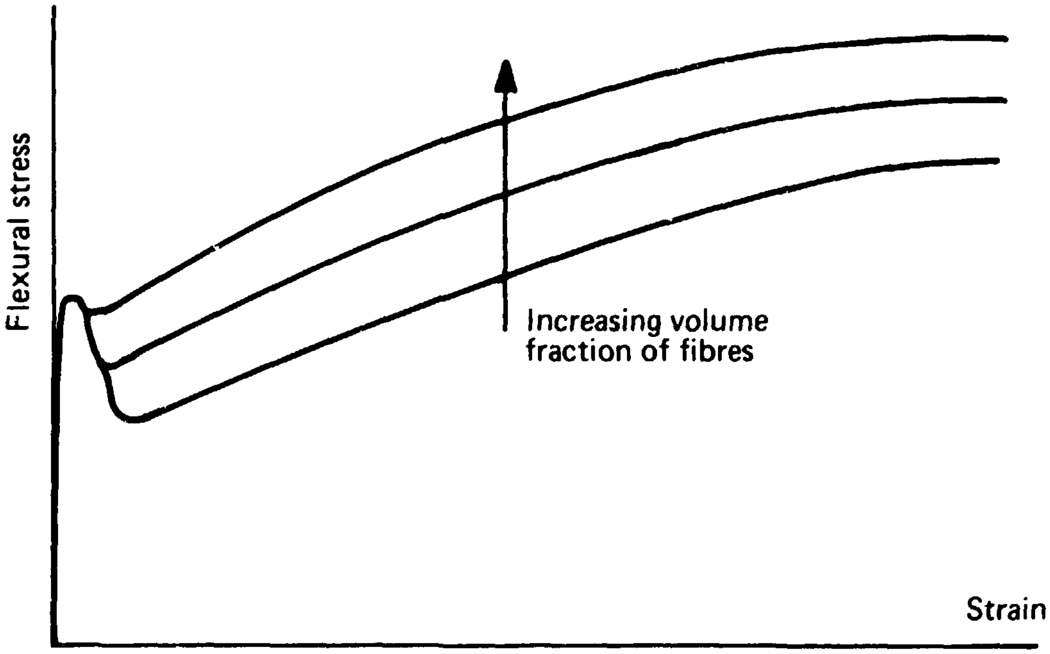


Figure VI. Effect on the stress-strain behaviour for continuous sisal-fibre concrete when the volume fraction of fibres is changed

Toughness

The energy-absorbing characteristics of a material, i.e. the toughness, can be estimated as the surface under the stress-strain curve and is thus bigger for sisal-fibre concrete than for unreinforced concrete. The toughness is a vital property in many situations, such as in handling and transport as well as in the working stage. When limited overstressing of unreinforced concrete takes place, total collapse and breakage is the result, while in sisal-fibre concrete overstressing only gives limited cracking.

Water tightness

When using concrete in thin sheets for roofing, the material must be able to withstand penetration of rain water. As most of the volume in sisal-fibre concrete consists of the matrix, the permeability of the matrix itself has the greatest influence on the permeability of the composite material. From traditional concrete technology it has been established that there is a close and strong relationship between the quality of the matrix and its permeability. With increasing cement content and a better chosen sand gradation the permeability can be drastically reduced. This calls for the use of a good quality matrix when thin concrete sheets which can resist water penetration are required.

Durability

The tests which formed the basis for the details in this section were mostly made on specimens stored in water for 28 days. Some tests were also made after 91 days in wet, alternating wet and dry and in dry storage, without any significant change in behaviour. Tests utilizing different storage conditions will also be made after longer periods.

The durability of the fibres is expected to be rather long, since the alkaline environment protects the fibres from attacks from bacteria and funguses. Long use of cement-impregnated wood-wool sheets has proved them to be excellent over long periods, indicating the protective effect of cement on biological fibres. Sisal-fibre material itself has good durability, as can be seen from twine used in old mud-and-pole houses, where the fibres, often not even covered with mud, are unaffected. The behaviour of sisal-fibre concrete will of course be further studied, and specimens have already been set up out of doors.

PRODUCT DESIGN

Fresh sisal-fibre concrete can be cast in different forms and in different shapes like ordinary concrete and can also be produced in thin flat sheets. After compaction and other treatment such as suction, the sheet in its fresh state can be placed on a curved form to create a corrugated or folded sheet. Design criteria such as loads, stresses, safety factors, crack-widths etc. are described below. Three types of roofing sheets are considered:

(*a*) Designed as ordinary burnt clay tiles;
(*b*) Designed as corrugated-iron or asbestos sheets, of 1 to 2 m in length;
(*c*) Long spanning sheets, with lengths of more than 3.5 m.

Sisal-fibre concrete can be used for plastering, as a wood substitute, for small beams, for making hollow blocks and as partition walls. It can be designed to carry loads and to have different shapes and applications. Full-scale tests to ensure design stresses and life-span are recommended.

Design criteria

Loads

Design loads usually prescribed in building regulations must be achieved. In roof design, consideration should be given as to whether the roof should be able to carry lifeload. Many traditional roofs in tropical rural areas cannot take such a weight.

Stresses

The stress-deformation curves described above show test results. The stresses were calculated according to the theory of elasticity, even in the cracked zone, where the behaviour was plastic. This corresponds to the normal method of designing and calculating results for other fibre concretes.

Choice of safety factors

There are two types of stress-strain curves for sisal-fibre concrete, one for continuous fibres and one for chopped fibres (see figure VII).

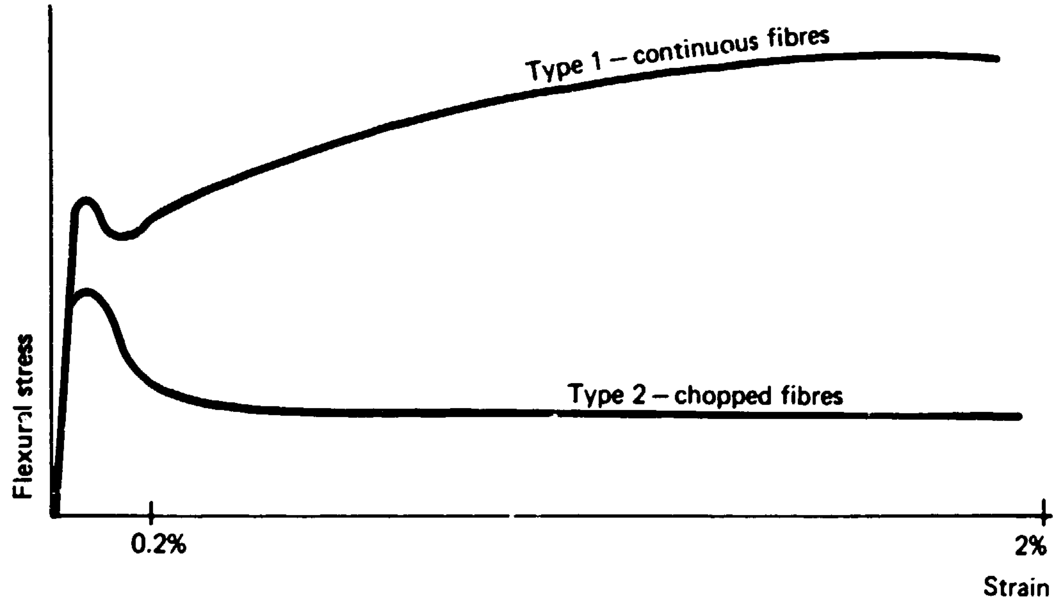


Figure VII. Typical stress-strain curves for concrete with different types of sisal-fibre reinforcement

The safety factors can be related to the limit of proportionality when continuous fibres are used. When using chopped fibres, where the stress level after cracking can be lower than the limit of proportionality, the safety factors should be related to the deformation stress of 0.2 per cent. Load-bearing constructions, according to building regulations, should be designed with safety factors of 2.0–3.0.

When designing a small tile of sisal-fibre concrete, care should be taken that it is strong enough, although the safety factor proposed is smaller than that for ordinary load-bearing construction, i.e. a little more than 1.0.

Crack width

If a crack exceeds a certain limit there is a chance that the pH around the exposed fibres becomes neutral and they begin to rot. The value of the maximum crack width that can be permitted has not yet been tested.

Other criteria

Depending on the product, other design criteria such as water tightness, impact resistance, fibre resistance etc. may be important.

Products

Roofing sheets

There are three types of roofing sheets as shown in figures VIII, IX and X.

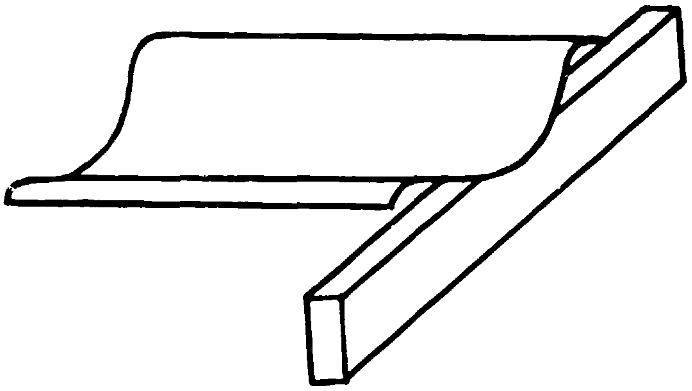


Figure VIII. Roof tile, estimated measurements 400 × 250 × 6 mm. Designed as ordinary burnt clay tiles. Weight of one tile is approximately 2 kg

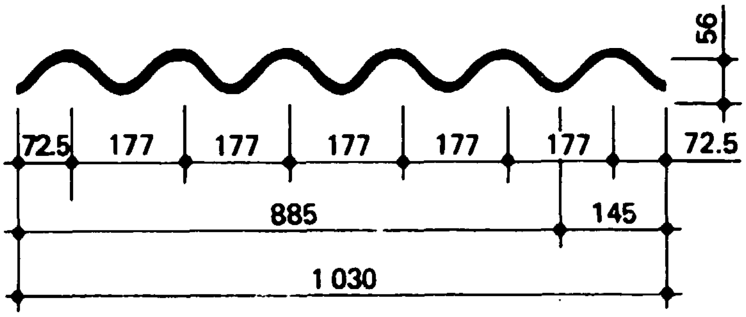


Figure IX. Corrugated sheet. Span l = 1,200 mm. Thickness d = 10 mm. Weight of one sheet 35 kg

Figure IX can be used as a substitute for asbestos-cement sheets or corrugated-iron sheets. The span is 1.0–1.2 m and it can carry the weight of an adult with an approximate safety factor of 2.

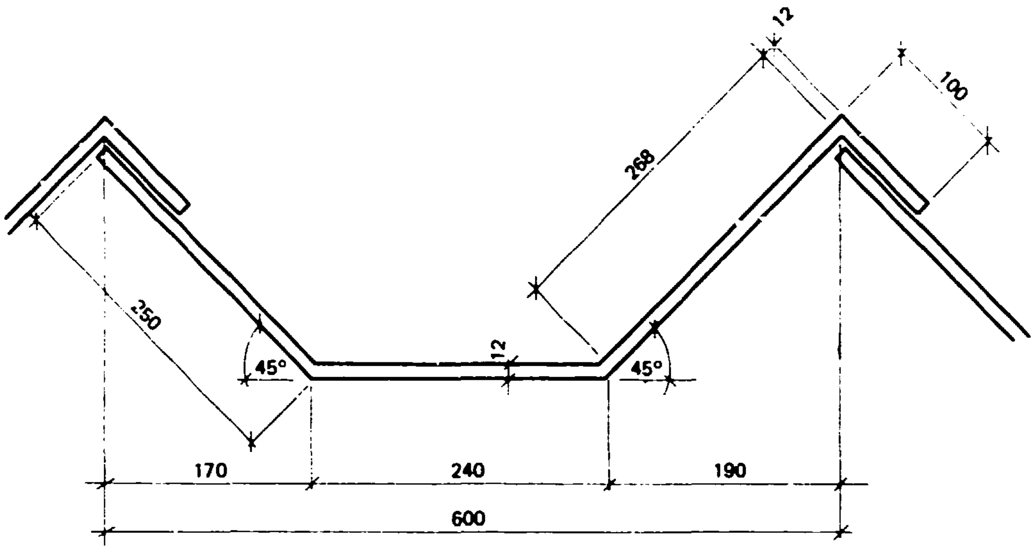


Figure X. Folded sheet

Figure X can have a span of 2.0–7.0 m. The sheet can be supported by two walls and in this instance the secondary construction system could be excluded. The weight of a slab with a length of 4.5 m is approximately 110 kg.

This type has been fully tested with point loads and a span of 3.3 m. Continuous sisal fibres in six layers were used. The result showed it was possible to walk on such roofing sheets with a safety factor greater than 2.0. When failure occurred the deformation was great. Cracks can be easily detected.

A folded sheet with a bottom part wider than in figure X has been stress calculated. The dimensions are given in figures XI and XII, and the following loads were considered:

P_1 = 0.8 kN, weight of one adult on the cantilever
P_2 = 0.8 kN, weight of one adult on the middle
P_3 = 1 kN/m^2, distributed load over the sheet
P_4 = 1 kN/m^2, wind load upwards on the cantilever

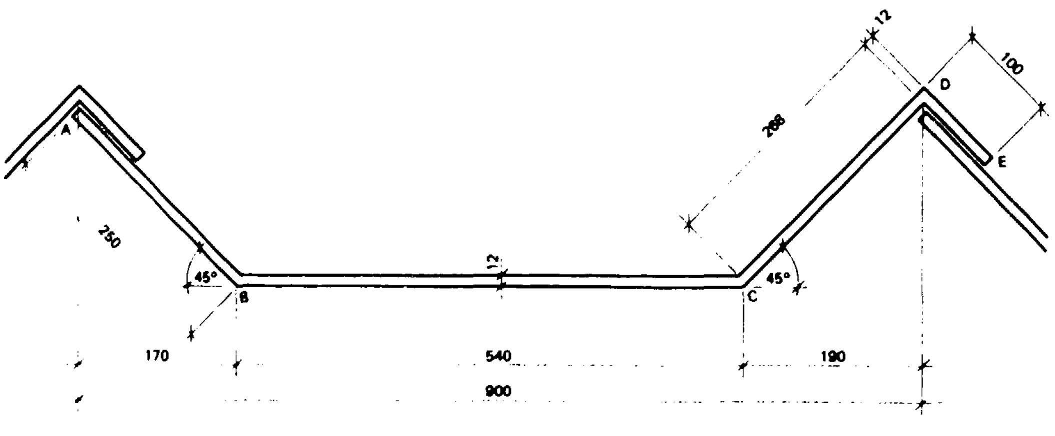


Figure XI. Folded sheet calculated by finite element analysis

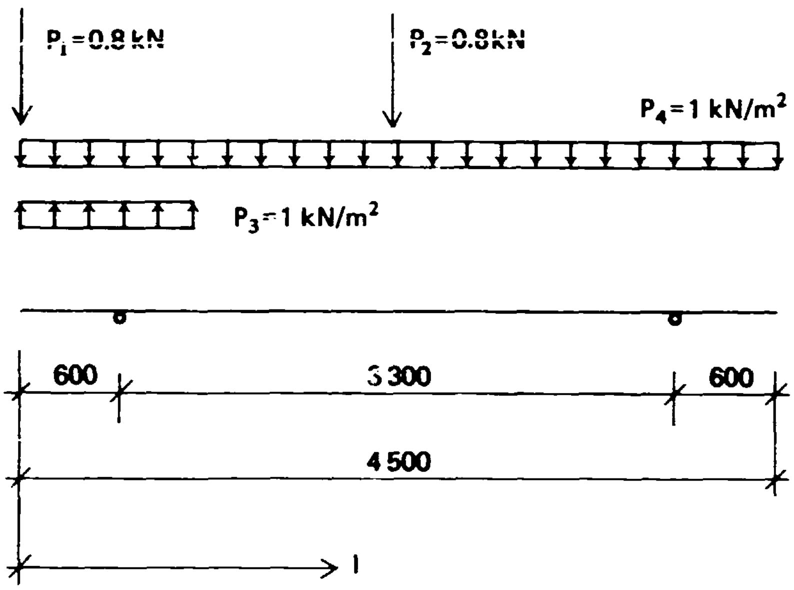


Figure XII. Loads on and dimensions of the folded sheet

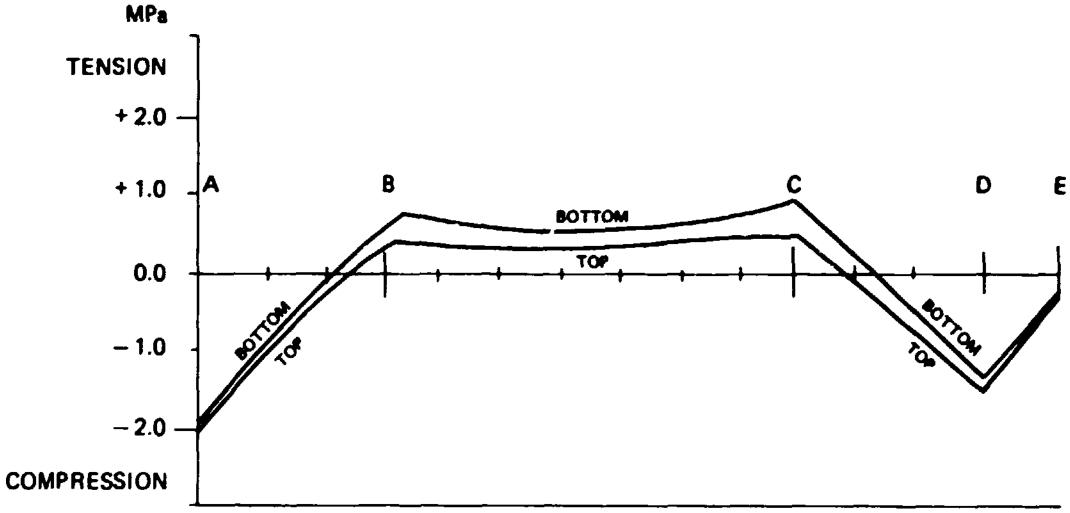


Figure XIII. Stresses in the cross-section from the weight of the element; l = 2,250 mm

Design stresses were evaluated on the basis of a finite element analysis computer programme and are shown in figures XIII to XVIII.

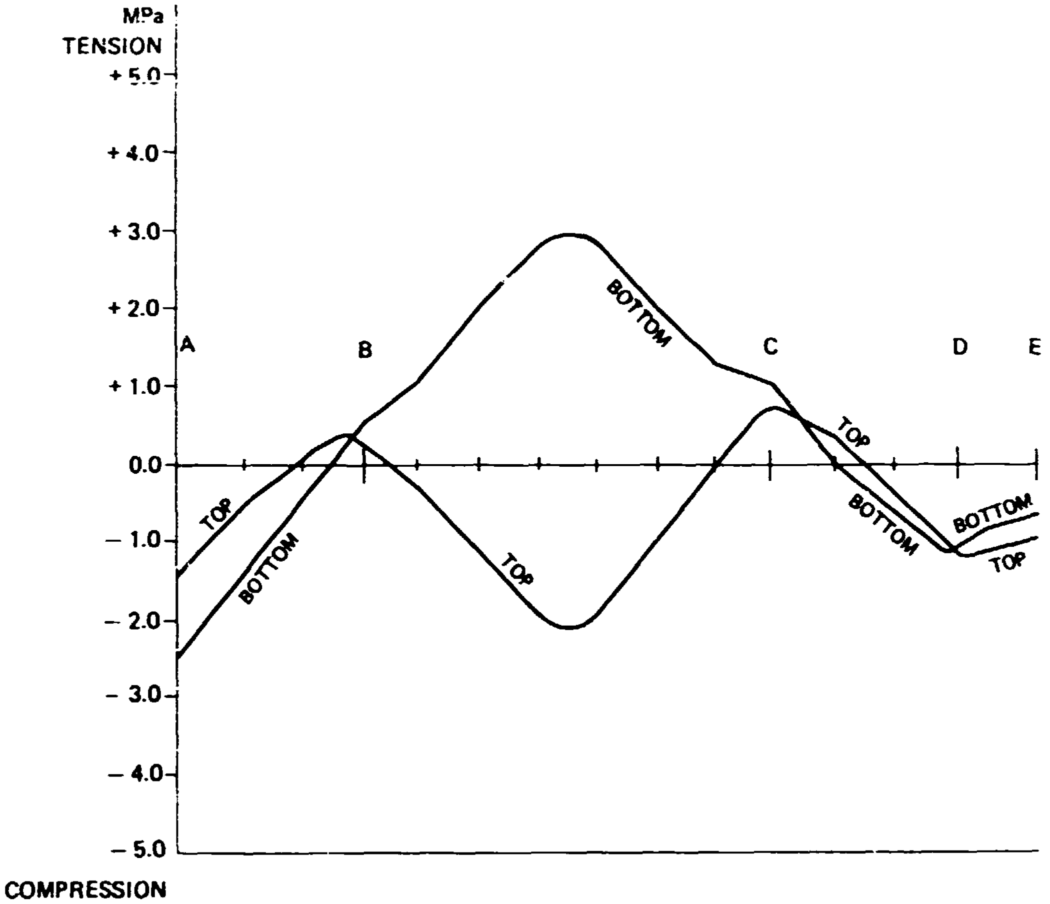


Figure XIV. Stresses in the cross-section from P2; l = 2,250 mm

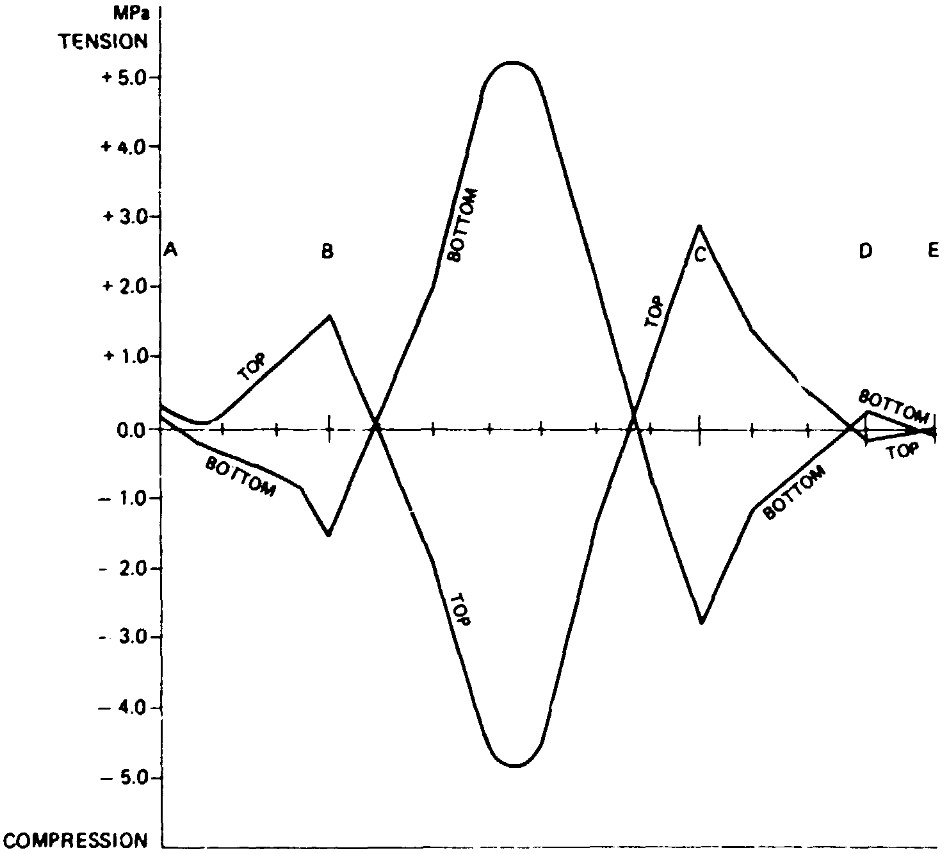


Figure XV. Stresses transverse the cross-section from P2; l = 2,250 mm

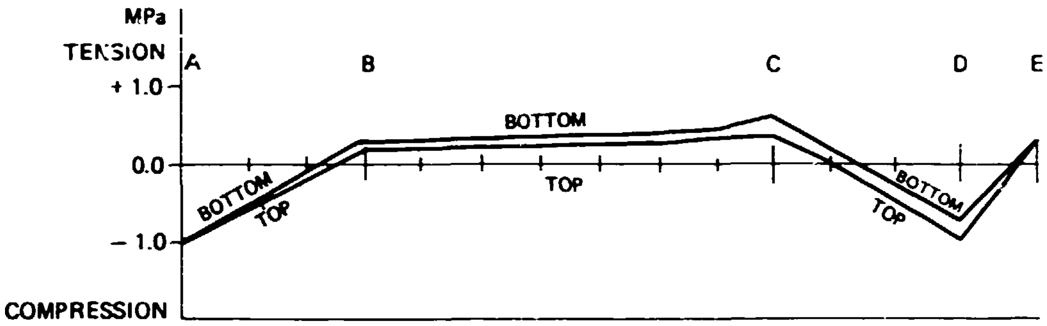


Figure XVI. Stresses in the cross-section from P₃; l = 2,250 mm

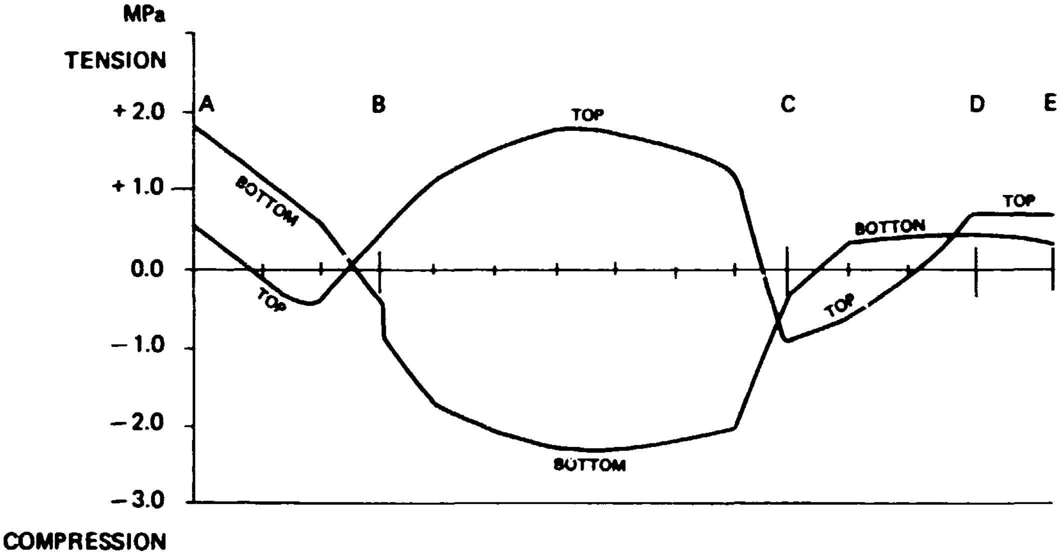


Figure XVII. Stresses in the cross-section from P₁; l = 600 mm

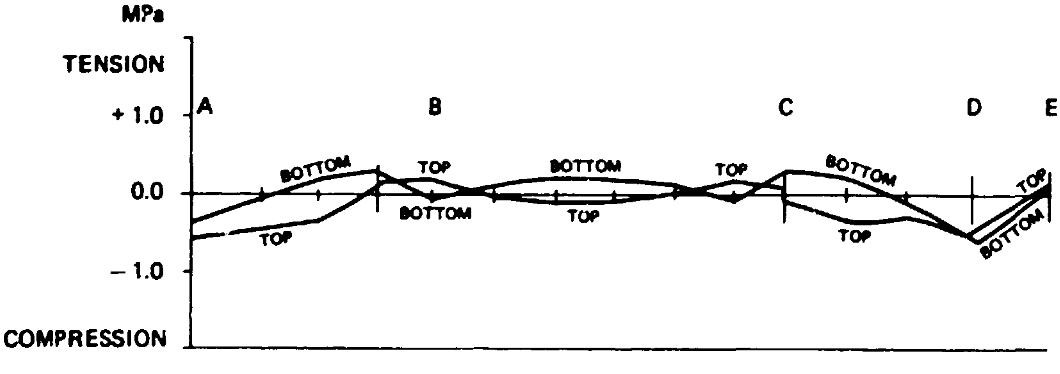


Figure XVIII. Stresses in the cross-section from P₄; l = 600 mm

Stresses in different parts of the slab from single or combinations of design loads could also be calculated, but they are of less interest in this instance.

The design stress is reached by the point load 0.8 kN (size 100 × 250 mm^2). In this case, the stress in tension from this load is about 5.0 MPa. Efforts to minimize these stresses should be made, as shown in figure X where the bottom slab is smaller. A similar calculation shows that the stresses from the same point load have been halved. Another way of minimizing the stress from the point load would be to make the corrugations of the bottom slab transverse the load-bearing direction.

Plaster

Walls of mud and poles often have a short life-span. In the United Republic of Tanzania, the average life of such walls is estimated at seven years. The main reason for their destruction is the effect of rain, especially heavy driving rain.

A sisal-fibre concrete surface on the outside of the walls can protect the construction. The coating can be fixed with sisal fibres knotted to the wall and cast into the coating. Although not yet tested in full scale, the idea seems sound and should provide more durable walls and lower the annual cost of houses.

Wood substitute

Sisal-fibre concrete can be made in various shapes and dimensions such as window gratings and sun screens. Trusses, even with large spans, are possible, although it might be preferable to use steel for bars if the tension forces are great.

Small beams

The probable limit of a maximum crack width for sisal-fibre concrete indicates that large beams of this material should not be designed without full-scale tests. Small beams and trusses, however, can be designed for use where the crack widths can be kept to a low level, for instance for openings, such as doors and window lintels, in brick walls or as a tie beam around a house at the top of a brick wall. The latter beam gives rigidity to the construction, for instance for the roof trusses, and as stability against such forces as earthquakes.

Blocks

It is possible for sisal-fibre concrete made with chopped fibres to be cast as thin-walled hollow blocks of the type shown in figure XIX.

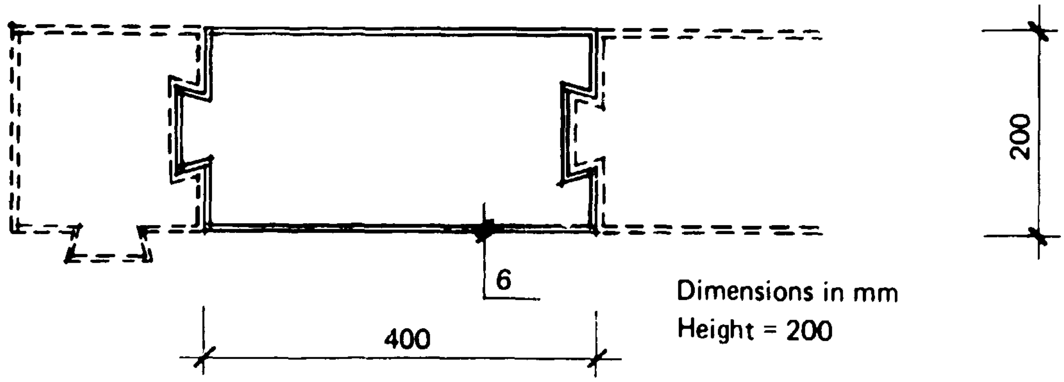


Figure XIX. Example of a hollow block without top or bottom with wall thickness of 6 mm

Cement-stabilized soil blocks are commonly used in many developing countries. They need less cement than concrete blocks; however, hollow blocks of sisal-fibre concrete need less than half the quantity of cement. The block shown in figure XIX needs about 1 kg of cement and its weight is approximately 4 kg. A wall area of 1 m^2 requires approximately 12 kg of cement.

Hollow blocks can be dry-laid without mortar. The interlocking details make the walls stable. After erecting brick walls the inner space inside the blocks can be filled with earth or sand. The surface, both inside and outside, is already finished. If it were intended to build a two-storey building it would be possible to place reinforcing and to cast concrete columns inside the hollow spaces of the blocks.

Wall system, sheets and beams

Dimensions in mm

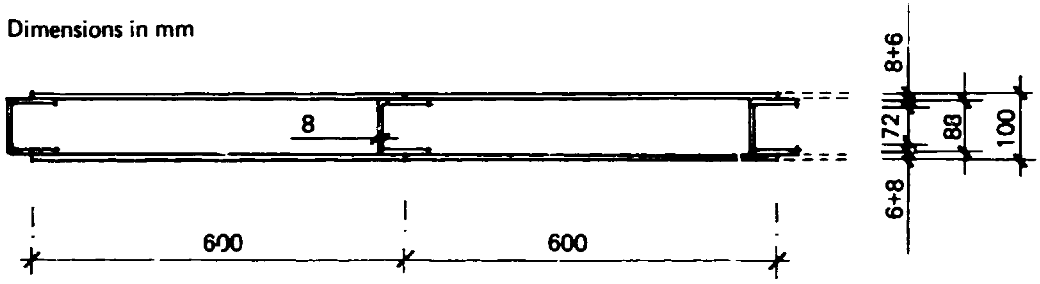


Figure XX. Example of a wall system using prefabricated beams and sheets of sisal-fibre concrete

The wall system shown in figure XX weighs approximately 35 kg/m^2 and consumes approximately 9 kg of cement per square metre of wall.

PRODUCTION

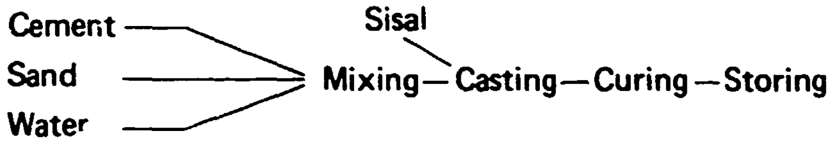
The production of sisal-fibre concrete sheets and other sisal-fibre concrete products consists in principle of the following operations:

Preparing
Mixing
Casting
Curing
Storing

Depending on whether chopped or continuous fibres are used the material flow can be described as follows:

Material flow with chopped fibres

Material flow with continuous fibres



With both types of reinforcement all the steps in producing sisal-fibre concrete can be manual; no electricity, heat, over-pressure or vacuum is necessary, and no extra chemicals have to be incorporated. Sisal-fibre concrete thus lends itself to production by local village craftsmen, but can also be mechanized at different stages to save labour, increase quality and speed production.

A description of the production process follows first in a general way and then with specific reference to production at three different levels, namely village, small-scale industry and mechanized industry.

Process description

Preparation

In some places cement is a readily available material delivered in bags. Normally no treatment or addition to the cement is needed before it is added to the mix. The sand should have a fine grading of about 2-mm maximum aggregate size and should not contain any organic substances that could adversely affect cement hydration. Water can be of varying quality, but it should not be contaminated to the extent that would make it unsuitable for use in cement-based materials. The water's acceptability can be tested easily.

The sisal will be either chopped into lengths of 15–50 mm or used continuously as individual fibres or in nets. The possible effect of contamination on the fibre surfaces on cement hydration should be examined before a new stock of fibres is used.

Mixing

Chopped fibres are mixed together with cement, sand and water but when continuous fibres are used, the matrix (cement, sand and water) is mixed separately. The mixing can be manual with shovels or forks, or mechanical in pan or drum mixers. The workability of the mix has to be selected according to the product, but the mix should be wet but not too fluid. Too wet a mix leads to separation and poor quality.

Casting

Chopped sisal-fibre concrete is simply cast by pouring the mix into a mould to the desired thickness. Slight stamping or hammering only is needed to get sufficient compaction, although a vibration table or a vibrator will give more effective compaction and thus a denser matrix. When continuous fibres are used, a thin layer of concrete matrix is cast on the bottom of the mould. Fibres are then laid on the matrix layer and pressed into it with the help of hand rollers. A new matrix layer followed by a fibre layer is then placed and compacted, and this is repeated until the required number of fibre layers is obtained. A thin matrix layer is placed on top of the laminate and the upper surface is made even and smooth with the help of hand tools.

Sisal fibres give the concrete matrix good plasticity in its fresh state, i.e. during the first few hours after the cement has been mixed with water. This property allows the material to be formed to different shapes after it has been cast. It is possible to cast a flat sheet of sisal-fibre concrete on to plastic foil and to transfer the flat sheet on to a corrugated sheet by placing the foil with the material on another, already corrugated product. The plasticity of fresh sisal-fibre concrete also allows different shapes to be formed by placing the concrete on to a product with the desired shape, thus making a replica. This method can be used for making buckets, bins etc. The moulds can also be made from wood, but if a post-forming technique is used, if high quality surfaces are desired or if a high production rate is needed, materials other than wood should be considered for the moulds.

Curing

All cement-based materials need to be cured after casting in order to prevent the water, needed for the hydration of the cement, from evaporating. The consequences of improper curing are cracking and a reduction in strength. Curing can be performed with wet rags, by covering the products with plastic foil or by keeping the products in a water basin. The time required for proper curing depends mainly on the type of cement used and the climate, and it should be evaluated for every production situation. In most cases three to fours days will be sufficient. De-moulding can usually be achieved, if carefully done, after one day.

Storing

The strength of concrete increases with time at a decreasing rate. If standard cement is used, a major part of the final strength will be obtained after four weeks. The products are thus not ready for delivery directly after curing, but have to be kept in storage for some weeks. When transporting the products to curing and from curing to storing, they have to be handled with care.

Production at the village level

Production at the village level usually takes place under the following conditions:

(a) Very little transport for constituent materials is available;
(b) Labour-intensive production is acceptable;
(c) Equipment is simple;
(d) Electricity is not available;
(e) There is no machinery;
(f) Limited knowledge is needed.

The production procedure is shown in figure XXI and involves the following operations:

(a) Preparing sand by hand-sieving;

(b) Chopping sisal fibres to required lengths or preparing individual fibres or nets;

(c) Mixing cement, sand, water and fibres with a shovel, using a simple mix design;

(d) Pouring the concrete in a mould. If continuous fibres are used, layers of fibres are laid in between layers of concrete. Compaction by stamping and surface treating with a wooden trowel;

(e) Curing the products under wet rags.

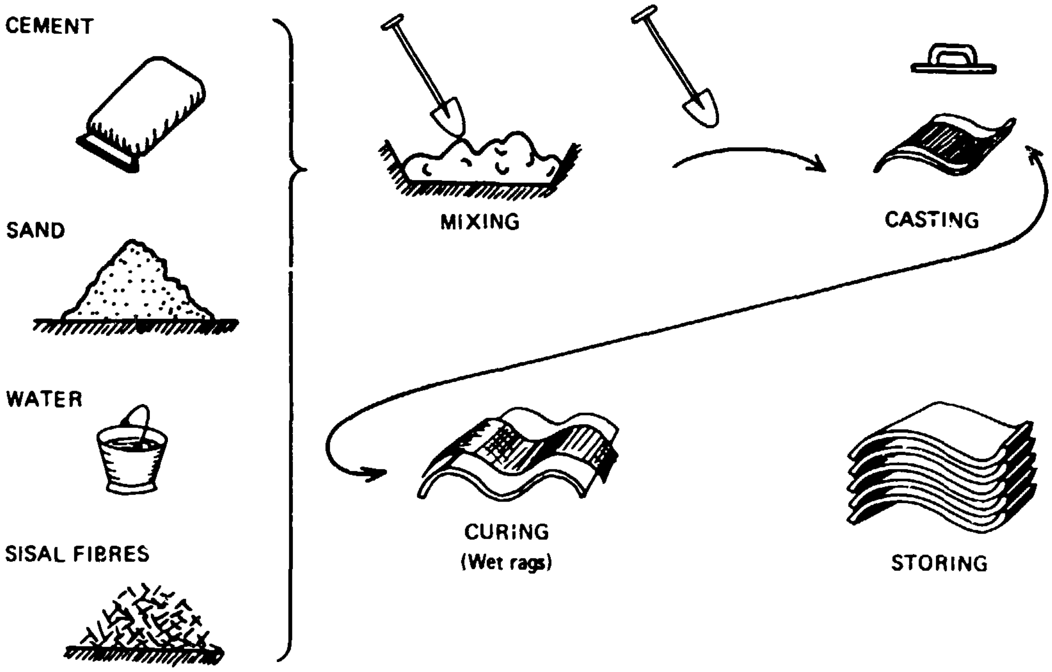


Figure XXI. Production at the village level when chopped fibres are used

The equipment needed for this level of production comprises shovel, bucket, wooden mould, wooden trowel, rags, equipment for cutting the fibres and a sieve.

The requisite information could be taught to a local craftsman by a visiting instructor and should comprise:

(a) How to prepare the sand;

(b) How to prepare the fibres;

(c) The mix design;

(d) How to mix, pour and compact;

(e) How to cure and store the finished products.

Production by small-scale industry

In order to increase the production rate, increase quality and obtain a larger ariety of products without complicated transport arrangements or heavy capital investments, production by small-scale industry is worthwhile. The following conditions usually exist for this level of production:

(a) Sand can be used from local resources or transported over limited distances;

(b) Labour-intensive production is acceptable;

(c) Electricity is obtainable;

(d) Simple machinery can be used;

(e) Limited specialist knowledge is needed.

Production procedures include the following operations (see figure XXII):

(a) Control of sand and sand preparation by hand-sieving;

(b) Chopping fibres to required lengths or preparing individual fibres or nets; a machine for cutting the fibres will be needed, and nets are preferable to individual fibres. Control of fibre quality;

(c) Mixing concrete using simple mix designs;

(d) Pouring the concrete into reusable moulds; compacting on vibration table and surface treatment with rollers or trowels;

(e) Curing the products under wet rags or in water basins. Quality control and storage.

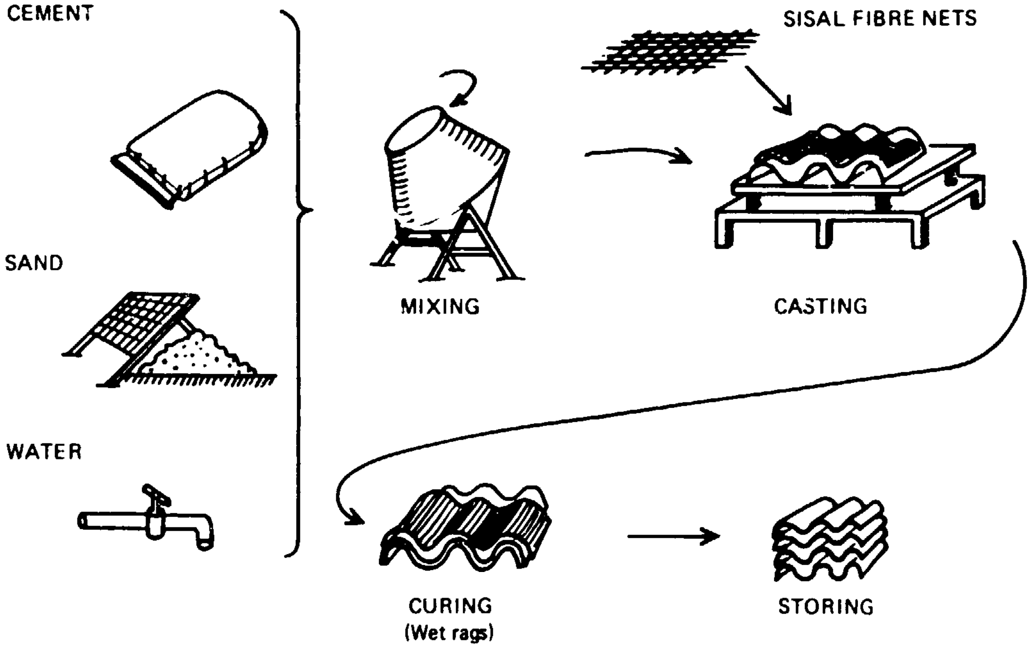


Figure XXII. Production in small-scale industries using fibre nets

Apart from sieves and hand tools, machinery for fibre preparation, concrete mixing and compaction will be required. For curing, a water basin can be used but rags will be sufficient.

The information needed to maintain small-scale industry production comprises limited knowledge of concrete technology, the needs for different products, control procedures and machinery maintenance. Some knowledge of administration, planning and economy will also be required.

Production in mechanized industries

Sisal-fibre concrete can be made in highly mechanized processes similar to those used for the production of asbestos cement. Mechanized production can increase production rates, quality and reduce labour requirements compared with small-scale industry production. On the other hand it will require high capital investments. The following can be considered criteria for the suitability of mechanized production:

(a) Facilities for transporting sand and finished products over long distances exist;

(b) Labour requirements are low;

(c) Advanced machinery is available;

(d) Advanced knowledge is necessary.

Production procedures involve the following operations (see figure XXIII):

(a) Preparing of sand in automatic sieving machines. Careful quality control of the sand. Cement and sand from silos:

(b) Chopping of fibres with cutting machines or using continuous fibres in nets. Quality control;

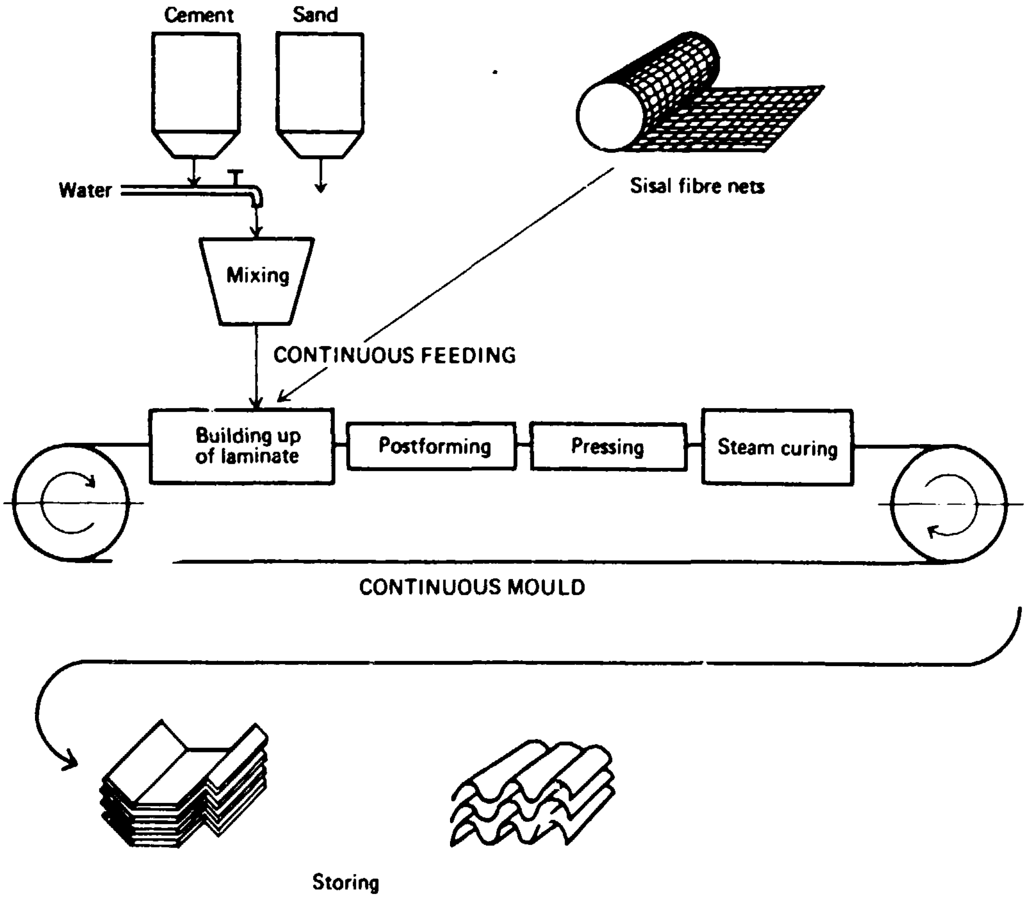


Figure XXIII. Production in mechanized industries *(c)* Mixing concrete in batch mixers or in continuous screw mixers;

(d) Discharging the mix in a continuous mould through pumping. Nets are continuously fed into the mould. Vibration, overpressure and vacuum are used to increase the compaction and to simplify the handling of the products;

(e) Curing the products in humidity chambers. Careful quality control and storage.

There is a large range of machinery needed for this type of production and it cannot be reviewed in detail. Apart from machinery, vehicles for handling and transportation will be needed. Advanced knowledge is required concerning administration, economy, production planning, concrete technology, machinery maintenance, marketing, sales and transport planning.

BUILDING TECHNIQUES

Sisal-fibre concrete has a fibre volume of less than 5 per cent of the total concrete volume. When designing constructions or components of buildings, sisal-fibre concrete should be thought of in terms of ordinary concrete. The difference between conventionally reinforced concrete with steel bars, and sisal-fibre concrete, is the possibility of manufacturing the latter in thin sections. Sisal-fibre concrete can be combined with both traditional building methods and more industrialized ways of building.

Sisal-fibre concrete is fire resistant, and has as good a thermal capacity as ordinary concrete. Indications are that its life-span should be long. Full-scale tests have not yet, however, been carried out. Skilled workers are not needed, and if cracks occur they can be repaired either with cement slurry or with plaster made from chopped sisal-fibre concrete.

Roofing

Small roofing tiles should be used in the same way as ordinary clay tiles. Overlaps from one tile to another should be made so that water cannot penetrate. Some of the tiles should be fixed to the secondary construction system. This can be done with nails or with sisal twine cast into the tiles and knotted around parts of the roofing construction. Corrugated sheets and larger sheets can also be fixed to the structure in the same manner. The sisal twine can be protected after knotting by plastering over with chopped sisal-fibre concrete.

Nails can be used, but it is better to use screws with rubber washers to ensure water tightness. This is the traditional method for fixing corrugated-iron and asbestos-concrete sheets. Holes for fixing the roofing sheets can be made when the sheets are being manufactured. If leakages occur, it should be possible to stop them with clay, and it is also possible to stop leakages through a crack by using cement slurry. Larger repairs can be made with chopped sisal-fibre concrete.

Roofing sheets made from sisal-fibre concrete create greater structural loads than corrugated iron, but they should not be a problem. Ordinary walls can withstand large vertical loads. The weight of the roof on the secondary construction system can be compared to the weight of a clay tile roof. When using small sizes of roofing sheets, the parts of the secondary construction system may have slightly larger dimensions compared with a roof of corrugated-iron sheets. The differences are marginal.

When using the corrugated sheet of sisal-fibre concrete on a secondary construction it is sometimes necessary to adjust the level of the supports, for instance by using small pieces of wood.

Beams

Beams over openings in a block wall can either be cast at the site or prefabricated. A ring beam at the top of the block walls should be cast on the site in order to create a proper interaction.

Window gratings and sun screens

Window gratings, sun screens etc. are preferably prefabricated. They can either be mounted later in the spaces left in block and other types of walls or be installed at the time the walls are erected.

COSTS

Costs of raw materials can be estimated accurately. Investment costs for tools, equipment, machinery and buildings depend on the type of production and are related to the cost of labour.

Other costs are related to the ongoing study in the United Republic of Tanzania (1978) but give the levels which might be useful in other countries, depending on actual conditions.

Raw materials

The costs below are for 1 m^2 of roofing sheet 10 mm thick. The assumed cement/sand ratio is 1/3 by weight.

A 50-kg bag of cement costs $2.50 in Dar es Salaam. Because of transportation charges and to some extent a cement shortage the cost in urban areas can reach $5, that is $0.10 per kilogram. Each square metre of roofing sheet requires 6 kg of cement.

For this type of production, sand often has to be crushed from larger sizes, sieved and transported. Also it may be necessary to bring sand from other sites in order to mix a sand material with the correct sieve analysis. The cost of sand is estimated at $4 per tonne, and 18 kg is needed per square metre of roofing sheet.

Each sheet generally needs less than 3 per cent by volume of sisal fibre. If a figure of 2.5 per cent is used, approximately 0.4 kg of sisal fibres per square metre is required. The export price for sisal fibres c.i.f. Dar es Salaam is $550 per tonne, but in urban areas the cost is lower.

Rain water could be used, although there might be a cost for transport etc. The cost of the water is estimated at $0.01 per square metre.

The total cost for raw materials thus totals $0.90 per square metre: cement, $0.60; sand, $0.07; sisal fibres, $0.22; water, $0.01.

Investments and labour

If the villagers grow their own sisal, collect their own sand and work with home-made tools and equipment, the cost for a roofing sheet will be just the cost of the cement. This may not be a common situation, and the cost of investment and labour is difficult to estimate but a rough guess based on small-scale production would be $0.60 per square metre.

The cost would then total $1.50 for a square metre corrugated sheet of sisal-fibre concrete which can be walked upon. In comparison, a roofing sheet of corrugated iron costs more than twice this sum, and it is not possible to walk on a corrugated-iron sheet without breaking it.

Transport

Transport is an important factor. The villagers themselves probably can carry both the raw materials and the products, and in this instance transport costs can be included in the cost of labour.

An ordinary house roof of 50 m^2 weighs 1.5 t and can be transported by truck. If the rate per kilometre and per tonne is known, it is easy to calculate the cost of transport and make a comparison with competitive roofing materials in the area.

In conclusion, the prospects today for sisal-fibre concrete seem more favourable than before. Steel, plastic, glass etc. require energy for their production. Vegetable fibres require less energy production because they utilize solar energy directly to grow by photosynthesis. The price situation in the long run will therefore be even more favourable.

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Appropriate technologies and materials for housing and building in India

P.L. De, T.N. Gupta, R.C. Mangal, D. Mohan,
M. Rai, J.S. Sharma and *N. Verma**

The most neglected and least satisfactory area of human needs is the provision of suitable shelter in a congenial environment. The quality of the vast majority of rural dwellings in Asia and the Pacific region has been described as "usually small, insanitary, often in a dilapidated condition and made of locally available building materials that are flimsy and non-durable. The roofs are very low and windows, if provided, are small and inadequate, on account of which rooms are dark and damp."[1]

This description can well be extended to the slum dwellings in urban areas with the difference that gunny rags, tins and scrap, wooden pieces from packing cases etc., form the building materials and the environmental conditions are far worse due to overcrowding and poor, undeveloped or even low-lying land sites. A World Bank survey of the principal cities of 40 developing countries shows that in 17 cities, more than half, in 11 cities between one third and one half, and in the remaining 12 cities, less than one-third, of the population live in slums and uncontrolled settlements. In Kanpur (India), the total population in slums increased from 242,750 in 1961 to 560,000 in 1976; 57.5 per cent of the houses had only one room and 25.7 per cent, two rooms; 75.4 per cent of the houses had no windows and 80 per cent, no latrines; 66.3 per cent of the houses experienced water-logging during rains. Similar conditions or even worse could be cited for many more cities.

Two factors are responsible for this situation:

(a) Cities and metropolitan areas are growing too fast and it is impossible to construct houses and provide services fast enough to meet needs;

(b) 60 to 70 per cent of the urban population cannot afford to pay for even a minimum house with approximately 20 square metres of floor area.

In 1971, the National Building Organization (NBO) estimated that India was short of 11.6 million houses in rural areas and 2.9 million houses in urban areas. Projections for 1977 would be 12.1 million houses for rural areas and 4.7 million for urban. Assuming a modest average cost of $400 for a rural house and

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*Staff members of the Central Building Research Institute (CBRI), Roorkee, India. D. Mohan is Director, and R.C. Mangal, Deputy Director, of the Institute.

[1] Economic and Social Commission for Asia and Pacific Survey of Rural Housing and Related Community Facilities in Developing Countries of the ESCAP Region, December 1976, p. 8

$1,500 for an urban house, $12 billion would be required: a sum difficult for any Government to provide.

Table 1 shows that congestion in housing is increasing.

TABLE 1. DISTRIBUTION OF POPULATION OVER HOUSE SIZE

Size of house (number of rooms)	*Percentage of population*					
	Total		*Urban*		*Rural*	
	1961	*1971*	*1961*	*1971*	*1961*	*1971*
1	41.33	47.81	46.81	50.16	40.86	47.24
2	26.98	28.17	24.93	26.97	27.16	28.46
3	13.25	12.00	11.69	11.44	13.40	12.13
4	7.64	5.98	6.75	5.72	7.72	6.04
5	9.50	5.94	9.16	5.64	9.45	6.02

As can be seen from the table, approximately three quarters of the population live either in one-roomed or two-roomed houses. The average number of rooms in a dwelling in India is only 2.02.

The investment and materials required to deal with this housing shortage are colossal. The financial resources of most of the homeless or inadequately housed masses are too meagre for them to build even a modest house. The affluent section of society is not interested in mass housing as the returns by way of rental are poor. Obviously, the responsibility for providing houses for the less affluent falls on the Government. The possibility of finding resources to undertake a mass housing programme on a large scale has been explored from time to time, but it has not been possible to mobilize sufficient funds for the purpose.

Financial constraints are not the only hindrance. Another important factor is the scarcity of key building materials. In spite of the priority given to producing and using local materials, the building industry still faces huge problems. Moreover a variety of problems are caused by erratic supply and indifferent quality of building materials. In the absence of any significant improvement in the productivity and expansion of building material industries, the discouraging trends have manifested themselves in the rising costs of key building materials and construction.

Factors inhibiting the growth of the building materials industry in India include:

(*a*) Absence of an organized sector except for cement and steel;

(*b*) Slow expansion of the building materials industries;

(*c*) Delay in commercialization of the results of R and D and even under-utilization of proven building techniques;

(*d*) Lack of legislation prohibiting misuse of materials;

(*e*) Energy shortages;

(*f*) Lack of an institutional arrangement to study, monitor and solve the physical and financial problems of the small building materials industries;

(*g*) Lack of standardization in some newer materials.

Unless all these constraints are overcome, the position will progressively deteriorate. A number of efforts have been made by the Government of India and various public organizations to overcome the housing shortage. Some of these are:

(a) Liberal institutional finance for social housing projects, particularly for the economically weaker section of society and for co-operative housing projects;

(b) Establishment of various housing agencies throughout the country, such as Housing Boards, Development Authorities, Rural and Harijan Housing Boards, Apex Co-operative Federations etc. to promote housing activities and to make cheap houses available to various income groups at a low rate of interest;

(c) Housing schemes for industrial workers;

(d) Provision of house sites to landless workers in rural areas;

(e) Allocation of more funds in fifth five-year plan for production of new building materials;

(f) Establishment of public sector projects for the production of such materials;

(g) Promotion of R and D of new building materials and techniques by providing funds to institutions such as the Central Building Research Institute (CBRI) and the Structural Engineering Research Centre (SERC).

Yet the housing shortage continues to be acute. The reasons are not difficult to seek. The unprecedented growth of population, the unchecked migration from the rural to the urban areas and the increase in the number of landless labourers, have far outpaced the overall increase in the housing stock of the country. It is obvious therefore, that something more is needed.

In order that the available resources may be utilized most productively, it is necessary to adopt such building materials and construction techniques as will minimize the use of scarce national resources such as capital, energy and transportation systems and generate more employment. It is essential to develop cheaper building materials, utilizing locally available raw materials; to evolve cheaper and time-saving building construction techniques; to ensure that both the new materials and new techniques are labour-intensive, particularly in developing countries where the labour force is large; to devise appropriate planning techniques and house plans at the cheapest cost, without jeopardizing the minimum basic requirements of the users; and to educate the profession and the industry in the production and use of these materials and techniques.

The building materials industry plays a key role in achieving economic and social objectives. Over half of the total investment in the fifth five-year plan was for construction alone. Consequently over 60 per cent of the budget for the construction sector was to be invested in building materials and components. Improving the capacity and productivity of the building materials industry could result in cost reductions and even improve the capital output ratio of other industries.

TRADITIONAL BUILDING CONSTRUCTION TECHNIQUES

Traditional techniques can be put into two groups: those suitable for urban buildings and those suitable for rural buildings.

Urban buildings can be grouped into two subgroups: upper- and middle-class residential buildings and general purpose buildings including offices, schools, hospitals, recreational buildings, factory buildings, marketing centres.

Strength and appearance rather than cost have been the main criteria in adopting the various techniques for these buildings. Availability of materials has also played an important part.

Traditional building construction techniques use:

Raft, pile or open foundation of reinforced cement concrete

Spread footings in brick masonry and lime concrete

Coarse or random rubble stone masonry

Brick masonry in cement or lime mortar for foundation and superstructure

Reinforced cement concrete columns, beams and lintels or reinforced cement concrete framed structures

Reinforced cement concrete roofs laid *in situ*

Lime concrete or mud-*phuska*[2] in roof terracing

Cement plaster in walls and ceilings

Plain cement concrete, mosaic or tile floors

Waterproof cement paints and distempers or simple white and colour wash

Glazed sanitary and water supply fittings served by galvanized-iron pipes

Flush or panelled door shutters of teak or other decorative or plain woods

Sal wood or rolled-steel section door frames

Brass, aluminium or oxidized-iron fittings for doors and windows

Glazed superior quality wooden or steel windows

Asbestos-cement, concrete or galvanized-iron sheet roofing

Terrazzo floors and wall facings

Low-cost houses

Until recently no special materials were available for low-cost houses and only the cheapest of the above-listed traditional building materials and techniques were used in them. Some minor changes were made by providing the low-cost houses with plain cement concrete or brick floors, finishing the walls with a white or colour wash, employing inferior quality materials for door and window shutters, using iron fittings, and providing inferior water supply and sanitary fittings.

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[2] Pulverized brick earth mixed with straw, damped, laid and compacted over roof to necessary thickness. Usually covered with brick tiles.

Rural buildings

Rural buildings can also be grouped into two categories: permanent and perishable stuctures.

Permanent structures

These include houses with reinforced cement concrete or reinforced brick (RB) roofs, which sometimes have asbestos-cement or galvanized-iron sheet roofing. In other respects the specifications are practically the same as for low-cost urban houses. More affluent farmers and land-owners construct houses with costlier materials and techniques but the number of houses is limited. Basically, the main difference between the costlier and the cheaper permanent buildings in villages is in the thickness of walls, the height and the number of storeys (costlier buildings are generally two- or three-storeyed, while cheaper ones are single-storeyed). Another difference is in the finish; and doors, window shutters and fittings.

Kuccha *(perishable) structures*

The bulk of rural construction, particularly houses, throughout India and in other developing countries, come into this category. General specifications vary from place to place depending on the local availability of building materials. The main specifications generally are as follows:

(a) Foundations. Compacted brick or stone ballast with or without lime mortar, sometimes using only mud as a binding material. Burnt or sun-dried bricks are used as a topping. In cheaper buildings, rammed earth foundations only are provided;

(b) Superstructure. This is made with mud or sun-dried bricks, sometimes entirely or partly of burnt bricks, mostly without plaster either inside or out. Another type of superstructure is made with bally[3] or bamboo frames which eliminate the need for wall foundations. The walls consist of thatch, palmyra leaves, reeds or split bamboo jafry,[4] either plastered with mud and cow dung on both sides or protected by gunny bags or thatch. No lintels are needed for such walling, and shutters can also be made of the same materials. If mud or masonry walls are used, lintels are provided by ballies, bamboo or planks of secondary species of timber;

(c) Roofs. These are generally sloping and consist of bamboo/bally frames covered by country tiles, slates, wooden planks, palmyra leaves, thatch etc. Sometimes flat roofs are made with country wood rafters, spanned by bamboo, wooden planks, reeds etc. and covered with rammed earth;

(d) Services. In general no electricity, water supply or sanitary services are provided. In most cases a hand pump or an open well serves as the water supply for a group of houses, while open fields or conservation-type latrines are used for toilet purposes;

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[3] Round, unsawn wooden pole used as post, strut, rake, rafter, purlin etc. in temporary structures or scaffoldings. Usually of "salwood" *(Shorea Robusta)*.

[4] Split bamboo mesh 7.5 cm to 15 cm, tied with jute, string or wire.

(*e*) *Finishing*. Floors and walls are finished with plaster covered with a cow dung rendering. Floors are sometimes provided with burnt bricks. These can also be plastered with cement mortar if the householder can afford the cost.

Regional variations

The general pattern for permanent and perishable structures varies from place to place, depending on:

Local materials
Available skills
Cultural and traditional values
Social systems
Climate

While the techniques used in urban areas generally utilize costly and scarce building materials, without any attempt to use local resources, rural houses are constructed with local materials without any attempt to improve their quality or to make them durable. Thus the former is wasteful and the latter is substandard. Hence, the need for appropriate technology.

BUILDING MATERIALS INDUSTRY IN INDIA

A very large number of traditional building materials are available in India, and are being used extensively both in rural and urban areas. Steel and cement are the most important for the building industry. Coal, thought not used directly as a construction material, is also important in building, as it is essential for burning bricks and clay tiles.

Apart from these three materials manufactured in the organized sector, other important building materials which are generally used in building construction include.

Lime
Flush door shutters and other factory-made door and window shutters
Bricks manufactured in mechanized plants
Glazed earthenware, sanitary and water supply fittings
Electric wires and other fittings
Polyvinyl chloride pipes
Asbestos-cement sheets and other asbestos-cement products
Reinforced cement concrete spun pipes
Stoneware and cast-iron pipes and other fittings
Doors and window fittings
Steel windows
Welded wire mesh

Most of these materials are manufactured in medium-scale industrial units of different capacities. However, these cannot be established at the village level due to the need for mechanical equipment, power supply and large investment.

Higher capital investment is required and few entrepreneurs can afford to start up these industries. The availability of raw materials and product demand will determine the industries' location.

The items that fall within the group of materials based on small-scale or cottage industries are these:

Bricks
Lime
Timber processing
Steel fabrication
Precast building components
Stone ballast and grit
Various types of tiles for building and decorative purposes
Roofing clay tiles

Most of these materials are produced in each district or near important towns and villages. They are mostly labour intensive and require comparatively less equipment and machinery and small investments which allows more scope for new entrepreneurs.

Apart from these traditional building materials a large number are available as agro or forest products which are extensively utilized in rural constructions. These include:

Timber (both primary and secondary species) and timber waste
Bamboo
Reeds
Thatch
Palmyra leaves

Some agro and industrial wastes are also available in large quantities which can be exploited for manufacturing new building materials. They include:

Coir waste
Lime sludge
Fly ash
Cinder
Slag from steel plants
Wood wool
Sugar-cane bagasse
Rice husks
Sawdust

Some of the items listed in these two categories could be utilized in new building materials and techniques, as they have not yet been fully exploited. On the other hand, most of the items have been used for many years.

Most of the materials can be used in the rural and urban sectors. However, certain materials are predominantly used in urban areas, while there is a specific group of materials which are used mainly for rural buildings and not in urban constructions. These materials are either available locally in a natural form, or are manufactured locally. These include:

Hydraulic lime from kankar[5] etc.
Ballies
Bamboo
Clay tiles for roofing and flooring
Thatch
Palmyra leaves
Mud

In spite of government efforts made in previous plan periods to improve the production of the building materials, the building industry continues to face problems of the same dimension and scale as in the past. The construction agencies continue to face a variety of problems caused by an erratic supply of building materials.

Suggestions to overcome these constraints are:

(a) A national policy is needed for the promotion of locally available traditional building materials as well as for the adoption of new or alternative building materials developed through research;

(b) Suitable legislation should be enforced to ban misuse of building materials, as has already been done in some of the developing countries;

(c) Financial allocations for the construction sector, in general, and housing, in particular, should be stabilized to reduce market fluctuations;

(d) The production of building materials should be linked with the construction programmes of housing and development agencies. To ensure materials are available in the necessary quantities to fulfil the plan targets, the five-year plan of the building materials industry should be one step ahead of the construction and development plans;

(e) The brick and lime industries should be listed as priority items of small-scale industry;

(f) Tax incentives for encouraging the building materials industry should be given. Some incentives by way of tax reduction and low transportation rates should be given to construction agencies which use locally produced and improved building materials;

(g) New entrepreneurs intending to manufacture building materials or components developed by the research institutes, resulting in saving of materials and costs, should be given incentives by way of financial assistance at low interest rates with a moratorium for repayment, tax concessions, preferential supplies of raw materials, marketing assistance etc.

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[5] Impure, earthy stone, rich in calcium carbonate; generally found in clayey soils.

TRADITIONAL AND NEW BUILDING MATERIALS: IMPROVEMENTS THROUGH R AND D

A number of R and D institutions are carrying out research work in India on building materials and techniques. Some of them are:

Central Building Research Institute (CBRI), Roorkee
Structural Engineering Research Centre (SERC), Madras and Roorkee
Cement Research Institute of India, New Delhi
National Environmental Engineering Research Institute, Nagpur
Central Road Research Institute, New Delhi
Regional Research Laboratory (RRL), Jorhat
Indian Plywood Industries Research Institute, Bangalore
Forest Research Institute, Dehradun

A large number of materials and techniques have been evolved as a result of their activities by various laboratories. The main objective being to minimize the use of costly materials such as cement and steel which require capital, energy and transportation for their production and distribution, and to increase the use of locally available indigenous materials so as to conserve these factors and to maximize employment. Results have been encouraging and some new materials and techniques have already been applied on a large-scale. Some of them have already been codified and Indian Standards are now available. Some of the most important techniques and materials are described.

Traditional low-cost materials

Soil, thatch, bamboo, timber, brick and stone are the main traditional low-cost building materials. In most countries specialized use is made of these materials. However, there is a lot of scope for improving the traditional techniques of soil stabilization, for making thatch roofs more durable and fire retardant, for waterproofing mud walls and making innovations in burnt-clay brick and tile manufacture, especially from highly shrinkable black soils and marine clays. Details of some of the work done by R and D organizations in this field in India, are given below:

Soil stabilization

Stabilization of soils, based on certain scientific evaluation of their physical and chemical characteristics needs more attention. A mud wall erodes as a result of rain, and its protection by a cheap and efficient waterproofing material has been the subject of research for many years. Although use of a low-cost soil stabilizer to replace cement, lime or bitumen is much desired, some training in scientific methods for making stabilized soil blocks or even rammed earth walls is also essential.

Waterproofing of mud walls

The CBRI has developed a technique of waterproofing mud walls by spraying them with a mixture of bitumen and kerosene. This mixture can be prepared easily and can be sprayed on the mud walls by unskilled workers.

A drum containing 80/100-grade bitumen is heated until it melts. Kerosene oil is placed in a second drum. The molten bitumen is slowly added to the kerosene oil and stirred vigorously. The mixture is then sprayed while it remains liquid.[6] The cost is about 25 cents/m^2 of wall area, and increases protection against erosion by rain by three or four years.

Soil stabilization presses

CBRI has developed hand-operated and mechanically operated brick presses with capacities of 100 bricks/h and 250 bricks/h, respectively. Presses usually available have low production capacities and give insufficient pressure for making soil-stabilized bricks or blocks. Presses with a pressure of 100 to 200 kg/cm^2 are usually more efficient. Several countries have shown interest in laterite lime or fly-ash lime bricks because of the low energy and capital investment required for their production. These presses can be made for $12,500–$19,000 each.

Laterite lime bricks

Attempts to produce lime-stabilized laterite bricks have been successful. Laterite is in abundance in many areas and is the only type of soil or rock in several parts of Africa, India and South America. Laterite bricks are sun-dried and give a wet compressive strength of about 50 to 60 kg/cm^2. Similarly, lime fly-ash soil-stabilized bricks can also be manufactured close to thermal power stations which produce fly ash. A normal size block of 50 cm × 20 cm × 20 cm moist cured for 28 days, gives a compressive strength of 20 to 25 kg/cm^2. Both CBRI and the SERC have studied the suitability of laterite as a conventional aggregate for concrete.

Building stone

Stones of proven quality such as sandstone basalt, marble etc. are being consumed indiscriminately. One problem is how to utilize the small pieces of rejected stone. One way, developed by CBRI, is to manufacture stone masonry blocks using odd shapes and sizes of stones and a lean cement concrete mix. It is simpler, more economical and faster to build with such blocks.

Bamboo

Bamboo grows abundantly in hot, humid countries. In India, the total production of all species is about 1.6 million t/a. Only about one third of this production is utilized today. The Forest Research Institute, Dehradun, possesses invaluable information on the use of bamboo.

CBRI has studied the use of bamboo as a reinforcement in cement concrete. The pre-treatment of bamboo against moisture swelling, decay and

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[6] A technical note (No. 14) published by CBRI describes the technique in detail.

termite attack has also been attempted with encouraging results. However, the overall durability of such bamboo reinforced slabs has yet to be ascertained. RRL, Jorhat, has also worked on the use of bamboo combined with cement mortar for roofing purposes.

Secondary species of timber

In most developing countries timber is costly, and first-class timber is mostly used for luxury houses. It would be wiser to use as many secondary species as possible and to avoid such wasteful and indiscriminate use of first-class timber.

The cost of seasoning in the use of secondary species of timber is a common problem. CBRI has developed a solar seasoning kiln in which timber such as mango *(Magnifera indica)* and *jaman (Syzygium cumini)* have been successfully seasoned, eliminating the use of fuel for steam seasoning. This kiln is made from a timber frame with a glass sheet cover. Solar kiln seasoning has proved to be 50 per cent faster than normal air seasoning. The Forest Research Institute has also developed a solar kiln. These kilns should find a wide application in developing countries where solar energy is plentiful.

Timber cutting and sawing wastes about 40 per cent in weight of the timber. A substantial amount of the waste consists of branches and leaves (pine needles) etc., which are left to decay in the forests. There is scope for systematic collection and use of such timber wastes, some of which also could be used to produce wood-based panel products. The Indian Plywood Industries Research Institute, Bangalore, has developed an economical roofing system using waste veneers.

Newer developments

Wood cement products

Wood cement-based products can be produced in densitites ranging from 300 to 1,300 kg/m^3. Such boards are cheaper than the wood particle boards bonded with urea formaldehyde or pheno formaldehyde resins, which are imported by many countries. Wood-wool boards are a type of cement-bonded panel product. CBRI has developed a scheme with a low capital cost for making such boards and has also identified cheaper species of timber from which wood wool could be made at a production cost of Rs 8 to 10 ($1.01 to $1.26) per m^2.

Coir fibre cement board sheets

Development work for making boards has been completed by the CBRI in the utilization of coir wastes, rice husks, ground-nut hulls etc. Such wastes are becoming increasingly available with the development of agro-industrial complexes. Table 2 shows the properties of coir fibre cement-bonded building boards. These boards could be used as infill panels for timber or reinforced cement concrete or metal-frame structures, as permanent shuttering for concrete, erection of free standing and sound-proof partitions for false ceilings, as well as roofs.

CBRI has also developed a roofing sheet (see table 3) made of coir fibre wastes and cement. The sheets can be used for semi-permanent roofs in the same way as asbestos-cement sheet, but at half the cost. The sheets have a cheap water and weatherproof coating, which lasts about 10 years. They have greater impact resistance and thermal insulation than asbestos-cement sheets, and an industry could be set up with an investment of about Rs 0.2 million ($25,316) to produce about 100 roofing sheets per day.

TABLE 2. PHYSICAL PROPERTIES OF COIR BUILDING PANELS

Property	*Coir building panel*
Size (cm)	300 × 100 × 5
Bulk density (kg/m^3)	500–650
Texture	Smooth
Moisture absorption (%) (24 h)	10
Bending strength (kg/cm^2)	9.5 for 5.0 cm thickness
Thermal insulation (kcal m^{-2} h^{-1} °C^{-1})	0.082–0.090
Sound absorption (MRC)	0.32

TABLE 3. PHYSICAL PROPERTIES OF CORRUGATED-ROOFING SHEETS

Property	*Coir cement*	*Asbestos cement*
Pitch of corrugation (mm)	145	146
Depth of corrugation (mm)	48	48
Length (m)	1.5–2.0	1.5–3.0
Breadth (m)	1.0	1.05
Thickness (mm)	7	6
Weight per unit area (kg/m^2)	11.0	13.0
Water absorption (%) (24 h)	1.0[a]	25 (max.)
Breaking load	Coir cement gives same strength at 0.6 m spacing as 1.0 m spacing of absestos-cement sheet	
Thermal insulation (kcal m^{-2} h^{-1} °C^{-1})	0.09	0.24

[a] With waterproofing.

Corrugated asphaltic roofing sheets

Asphaltic roofing sheets are now being produced in several countries but they have a short life in the tropics. CBRI and RRL Jorhat have developed a more durable type of asphaltic paper board roofing sheet with an expected life between 7 and 10 years. This sheet would cost about one third of the asbestos-cement sheet. Commercial production has been licensed to a company in India and the Philippines.

Magnesium oxychloride sawdust door frames

Sorel cement or magnesium oxychloride cement is generally used for railway coach flooring. It is produced from magnesite, magnesium chloride and fillers. A technique to make oxychloride cement-bonded sawdust door and window frames has been developed by the CBRI, and a large number of such frames have been used in houses constructed in Ahmedabad, a large industrial town. These frames are being sold for 40 per cent less than first-class timber frames. They can absorb impact, can be sawn and nailed, repaired by patching and are free from termite attack. However, these frames require regular, careful painting and should not be used in fully exposed situations.

Fireproofing

CBRI has developed and successfully demonstrated two types of materials which can impregnate or be sprayed to make a thatch fireproof. Di-ammonium phosphate forms the basis for the formulation. Plastering with bitumen-stabilized mud, both inside and outside of the thatch roof, also renders it fire retardant.

Burnt clay bricks and tiles

CBRI has developed several techniques to improve the quality of bricks made from traditionally unsuitable soils such as black and red soils, and of tiles from alluvial soils. These techniques have been used on a commercial basis in many parts of India. The "grog" (pre-calcined clay) used as an admixture in black soil especially has been adopted widely. The Institute has also developed a high-draught brick kiln costing about Rs 0.2 million ($25,316) which consumes 15 to 20 per cent less coal than the usual Bull kilns. Recent trials in the use of admixtures such as fly ash with soils, and firing the bricks with agricultural waste such as rice husks demonstrate a new approach for manufacturing burnt clay bricks and tiles on a small scale, with considerable savings in traditional fuels. The work of CBRI in making clay fly-ash bricks can, to a great extent, solve the problem of waste fly ash disposal. Fly ash could also be utilized usefully for making fly-ash sand lime-type bricks.

India produces and exports good quality Mangalore roofing and flooring tiles. These tiles are manufactured on a small- and large-scale in India as most of the plant and machinery are indigenously available.

Semi-mechanization in brick making

Highly mechanized brick plants have proved unsuccessful in many countries because of the lack of trained people to operate them. Such plants are also costly with high operating rates. Attempts should therefore be made to develop small and simple machines, possible portable, for making pressed bricks. Some difficult or unsuitable soils can be fired to make good quality bricks. CBRI has developed a semi-mechanized brick-making plant requiring a capital investment of about $125,000 compared to $600,000 to $800,000 for a fully mechanized plant. The machine-made bricks have a high strength, and thus can be used readily in load-bearing single-brick thickness walls for three- or four-storey buildings in urban areas. The CBRI brick-making machine has so far been adopted by 15 brick manufacturers in India.

Lime-based masonry cements and plasters

CBRI has developed several lime-based ready-to-use materials, including: *(a)* masonry cement made from a mixture of cement and waste lime sludge from sugar or paper mills. It gives comparable strength in 1:5 masonry cement-sand mix, compared with 1:6 cement-sand mortar with a saving of 40 to 48 per cent;

(*b*) rapid setting lime-pozzolana mortar and plasters based on lime kiln rejects and locally available ashes etc.; (*c*) lime sludge and rice husk cementitious material and rice husk pozzolana, a very suitable and cheap binder for rice-producing areas. Almost any pozzolanic material such as fly ash, cinder, burnt clay, brick surkhi,[7] kiln ashes, fuel ashes, rices husk ash etc. can be used to prepare the lime-based dry mortars which could well be used for one- or two-storey buildings. Industries to produce standard quality lime-pozzolana mixtures are now being set up in many parts of India.

Cementitious binder from rice husk

CBRI has developed a cheap binder by burning waste rice husks and the lime sludge rejected by the sugar and paper industries. No extra fuel other than rice husks is required. The technique is quite simple. Cakes of a mixture of sludge and husks are dried in the sun. After burning and grinding they form a fast-setting grey-coloured cementitious material. There is substantial economy if this binder is used instead of cement or lime. This material is also suitable for brick-masonry mortar and plaster and foundation concrete (see tables 4 and 5) and there should be no problem in promoting its manufacture and use for low-cost buildings, even in remote rural areas. The binder can be produced on a small scale (10 t/d) with an investment of $25,000. Similar studies have been carried out by RRL, Jorhat, which has also successfully made rice husk ash cement.

TABLE 4. PROPERTIES OF RICE HUSK CLAY POZZOLANA

Variable	*Value*
Surface area (coarsely ground material)	2,600 cm²/g (Blaines)
Compressive strength of mortar (IL, IP, IS)	10 kg/cm²
Surface area (finely ground material)	8,000 cm²/g (Blaines)
Compressive strength of mortar (IL, IP, IS)	70 kg/cm²

TABLE 5. PROPERTIES OF HYDRAULIC BINDER FROM RICE HUSK LIME SLUDGE

Variable	*Value*
Surface area (finely ground material)	8,000 cm²/g (Blaines)
Compressive strength of mortar (1:3)	50 kg/m²
Setting time	Initial: 60–70 min Final: 480–600 min

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[7] Coarse powder obtained by grinding bricks and used as a fine aggregate as well as a pozzolanic material.

Lime kilns and hydrators

CBRI has developed several designs of lime kilns ranging in production capacity from 3 to 15 t/d. Such kilns, constructed in brick or stone masonry, with a fire-brick lining cost $4,000–$5,000 for 5 t/d and $10,000 for 10 t/d.

The CBRI-designed lime hydrator, a three-tier semi-mechanized machine, produces 10 t of lime every 8 hours, and costs $6,000, which includes a small bucket elevator.

Slag cements and Portland pozzolana cements

The constraints caused by the cost and availability of Portland cement must be taken into account in the overall planning of low-cost housing. Many countries are attempting to set up their own cement industries. At the same time, more and more blended cements such as Portland pozzolana cement, Portland fly-ash cement and Portland blast furnace slag cement should also be produced. All these cements utilize waste materials as a substitute for 20 to 25 per cent of Portland cement and there is an increasing trend to utilize solid wastes. CBRI has developed a special method of mixing fly-ash cement concrete in the right proportions to replace 20 per cent of cement.

Mines and mineral processing industries such as beneficiation of gold, copper, zinc, iron and aluminium ores discharge enormous quantities of very fine siliceous and dolomitic wastes. These wastes can make masonry mortar, fillers for concrete blocks, flooring tiles etc.

In the phosphoric acid, hydrofluoric acid and ammonium phosphate fertilizer industries, gypsum emerges as a waste material. CBRI has shown that this waste can be used successfully as a plastering material as well as to produce super-sulphated cement in a combination of 70 per cent granulated blast furnace slag, 15–25 per cent waste gypsum and 5–10 per cent Portland cement. Alumina, the red mud waste of aluminium industries, could also find some use in blended cements. Further work on the utilization of phospho-gysum would be the development of beneficiation processes to upgrade the waste gypsum and to devise a kettle calciner to make gypsum plaster.

Aggregates

It is a problem finding stone aggregate in certain parts of developing countries. New sources for aggregates must be tapped, the chief among which are air-cooled and foamed blast furnace slag, an excellent material for concrete; colliery wastes as light-weight aggregate for making concrete blocks; slag wastes from foundries and mini steel plants; manufactured light-weight aggregates-by bloating or sintering of water works' silt or fly ash; stone mining wastes; and laterite stone, slate and shale wastes. CBRI has also developed a simple fluidized kiln for making exfoliated vermiculite for use in heat-insulating plaster.

Techno-economic feasibility reports

A number of the new materials already mentioned are commercially manufactured. Project proposals have been worked out by CBRI for these techniques. The proposals contain details of equipment, machinery and other inputs and operating costs etc. to help any entrepreneur assess production costs. Some of the processes for which project proposals have been prepared are:

Manufacture of expansion joint fillers from cashew nut shell liquid
Production of sintered aggregate from fly ash
Building lime from sugar press mud
Production of particle board from coconut husks
Gypsum plaster board
Production of bricks by a semi-mechanized process
Fire-resistant building boards from coconut pith
Good bricks from black cotton soil
Good bricks from red murram soils
New formulation of cement paint
Water and weather proofing resin composition
Boated clay aggregate
Engineering bricks, paving bricks, acid resistant bricks
Cement coconut pith concrete for thermal insulation
General purpose and heavy duty flooring tiles from magnesium oxychloride cement
Preparation of partially calcined dolomite magnesium oxychloride cement compositions
Fire retardant impregnant for wood
Corrugated-roofing sheet from coir fibre and cement
Corrugated-asphaltic roofing sheet
Manufacture of activated lime pozzolana mixture

APPROPRIATE CONSTRUCTION AND PLANNING TECHNIQUES

The need for buildings in all the developing countries requires an all-out effort in mobilizing resources and in developing appropriate building techniques which take into account the technological development, the skills and the materials available. As the available capital in India is limited whilst there is a large labour force it would seem more appropriate to adopt manual construction methods. However, there is some scope for improving conventional methods of construction, making them more productive without excessive use of capital and energy. The main aim of R and D in construction techniques therefore, has been in improvements which minimize the use of expensive materials such as cement and steel, improve the quality of work and accelerate the pace of construction. Some of these techniques, developed in India, are described below.

Foundations

Under-reamed piles

These are suitable for sites with a heavy filling, high water table, black cotton soil (expansive soil) or loose sandy soil. The saving in foundation costs compared with traditional foundations ranges from 20 to 50 per cent. Under-reamed pile foundations are useful for various types of structures such as multi-storey buildings, storage tanks and transmission line towers. They have been successfully adopted on a large scale in India and have been used also in other countries. They are codified under IS 2911 (Part III-1973).

Bored compaction piles

These are *in situ* concrete piles in which the compaction of the concrete as well as of the surrounding soil is effected simultaneously by driving the reinforcement cage in through the freshly laid concrete. The compaction increases the load carrying capacity of these piles by 50 to 100 per cent over normal piles. They are particularly suitable in loose to medium sandy and silty strata with or without a water table close to the ground surface. Bored compaction piles have been adopted at a large number of sites during the last five years and have resulted in an economy of 30 to 50 per cent compared with conventional types of foundations.

Hyperbolic paraboloid shell foundation

This is formed by a straight line moving in a direction which results in an easily adoptable structure for providing footings of columns. This is suitable for four- and more-storeyed framed building foundations in the case of soils with a poor bearing capacity. It is 10 to 15 per cent cheaper than conventional reinforced cement concrete footings.

Walling

Single-brick thick load-bearing walls

The wall is designed like any other structural element and the IS 1905–1969 code of practice for structural safety of buildings–masonry walls–provides adequate data for wall thickness design, taking into account the strength of bricks and mortar. With bricks of 105 kg/cm^2 many four-storey residential buildings have single-brick thick walls on each floor. This has reduced the cost of walling by 20 to 30 per cent.

Half-brick load-bearing walls

For smaller buildings and light loads, half-brick thick load-bearing walls have been adopted recently in a number of low-cost housing projects. These walls are, however, not suitable for external locations due to poor thermal insulation and resistance to rain. A half-brick thick staggered wall is structurally adequate for residential buildings of up to three storeys.

Pre-cast stone masonry block walling

In areas where stones are available, a simple technique of prefabrication using stone spalls up to 15 cm in size and a lean concrete mix of 1:5:8 cement:sand:stone aggregate 10 mm or less has been developed to make blocks of 30 cm × 20 cm × 15 cm. The average compressive strength of such blocks is 70 kg/cm^2 and any other desired strength can be obtained by suitably modifying the mix proportions. Load-bearing walls of 20 cm thickness have been successfully adopted for three-storey residential buildings and 15 cm thickness for double-storey small residential buildings. This techniques saves materials, increases productivity, requires less skilled labour and is over 20 per cent cheaper than conventional random rubble masonry. The technique has been successfully adopted in over 1,200 houses in various parts of India.

No-fines concrete blocks

Sand is unavailable in several areas and has to be transported over great distances. For such areas, no-fines concrete blocks of 1:10 cement:aggregate in 30 cm × 20 cm × 15 cm nominal size have been produced. These blocks have a compressive strength of 35 to 40 kg/cm^2; they can be used for load-bearing walls in single-storey buildings and as filler blocks in framed constructions.

Hollow concrete blocks

These have been used in load-bearing walls for buildings up to two storeys, and machines to produce such blocks are being made in India. They have also been used as filler blocks in framed buildings.

Cellular concrete blocks

Lime fly-ash blocks and cellular concrete blocks are being produced at a few places and have been used for load-bearing and non load-bearing walls.

Large panel prefabrication

Industrialized methods of construction with room size wall and floor/roof panels have been widely adopted in Western countries. These save labour and construction time. The CBRI has carried out research studies and a battery-casting technique with concrete moulds has been perfected for the production of large panels. Studies have also been made on jointing techniques and details for typical joints between wall to wall, floor to floor and wall to floor have been worked out. SERC has also done good work in developing large panel prefabrication. Multi-storeyed houses and other buildings using large panels have been constructed at New Delhi. However, it has been found that the initial capital investment required for the production, transportation and erection of large panels is quite large, employment potential is much less and the consumption of scarce materials such as cement and steel is comparatively high. Furthermore, walls with reinforced cement panels are thermally inferior compared with a brick-thick wall. For tropical climates, the walls have to be provided with sandwich panels which make the cost very high. The walls are also unsuitable for fixing or nailing utility fixtures.

Doors and windows

Secondary species of timber

A number of secondary species of timber have been found to be satisfactory for building construction. This timber should be seasoned and treated before use.

Magnesium oxychloride cement and sawdust frames

A process for making door and window frames using magnesium oxide powder, magnesium chloride, marble, or dolomite powder and sawdust as a filler has been developed. These frames compare well in cost with timber frames and the shutters can be fixed with hinges and wood screws in the same way as any timber frame. These frames can easily be erected and painted at the site.

Steel/angle-iron frames

These frames can be made from angle-iron or medium-size flats. A size of 40 mm × 30 mm × 5 mm is suitable for shutters of 30 mm thickness.

Reinforced cement concrete frames

These are 6.5 cm × 8.5 cm in size and have three bars of 6-mm diameter with 3-mm wire ties at 15-cm centres. For fixing shutters, a helical spiral of binding wire or an aluminium tube, threaded inside, is placed during concreting. These may be used for low-cost housing as they are slightly cheaper; one limitation is that their edges are easily chipped.

Lintels

Flat brick arches

These are suitable for small spans; they conserve steel and cement.

Stone slabs

In some parts of India, such as in Rajasthan, stone slabs of sufficient thickness and length are available. These are used as lintels.

Thin pre-cast reinforced concrete lintels

There is a composite action between reinforced concrete lintels and the brick masonry on top and, as such, lintels can be designed on the principle of a plinth beam. It has been tested and proved that for openings up to 1.8 m, 7.5-cm thick pre-cast lintels with three bars of 10-mm diameter and 45-cm brick masonry are sufficient. For spans between 1.2 to 1.8 m, lintels with only two bars of 10-mm diameter, placed centrally and having brick masonry of 30 cm on top of the lintel are adequate. The pre-cast lintel should be propped until the brick masonry above attains sufficient strength. The bearing of the lintel should not be less than 15 cm.

Roofing

Arch roofing

(a) Before reinforced concrete slabs we[illegible]ed the jack arch roofing was adopted with rolled steel joists on a larg[illegible]lled steel joists can be replaced with pre-cast reinforced concrete [illegible] a saving in cement and steel;

(b) The CBRI has worked on pre-casting the brick arch panels of 120 cm × 50 cm × 7.5 cm which can be placed between pre-cast reinforced concrete joists. This eliminates shuttering and saves in costs;

(c) Work has also been done to lay brick arches with a camber of 5 to 7.5 cm using gypsum mortar between pre-cast reinforced concrete joists. No shuttering is required as gypsum mortar sets quickly and holds the bricks in position. This technique should be adopted in areas where rainfall is scarce as moisture should not come in contact with gypsum mortar.

Reinforced brick or reinforced brick concrete slabs cast in situ

For reinforced brick slabs, bricks are arranged with gaps between them on the shuttering, and reinforcement is placed in the gaps on both sides. Cement mortar 1:3 is then filled in the joints. The bricks take the compressive stresses and, depending on the span, the slab thickness varies from 11.5 to 15 cm. The bricks should not be less than 105 kg/cm^2 and should be free from salts with low water absorption. This technique has been adopted in Uttar Pradesh where good quality bricks are available. Experience indicates that reinforced brick slabs only last for about 25 years as the reinforcement begins to become corroded. This technique is not suitable for coastal areas.

Reinforced brick concrete slabs are an improvement over reinforced brick slabs. The bricks are laid on the shuttering with gaps of 30 mm or more, and after reinforcement is placed, M-150 concrete is filled in the joints and a deck concrete of 30 mm or more is laid over the bricks with distribution reinforcement on both sides. The bricks then act as filler blocks and compressive stresses are taken by the concrete. Bricks should not contain salts and should have a low water absorption to avoid corrosion of the reinforcement. This technique saves substantially on cement and overall costs.

Prefabricated reinforced brick concrete panels for roofing and flooring

Bricks are arranged flat in a timber mould, internal dimension: 56 × 104 cm. This size has been selected so that 16 bricks can be laid. Two 6-mm diameter mild-steel bars reinforce the outer joints, and all the joints (2.5-cm wide) are filled with M-150 concrete. After curing, the panels are lifted out and placed on partially pre-cast reinforced concrete joists which are spaced at 1.2-m centres, and cement/sand mortar is applied on the sides of the panels as they are placed in position. Reinforcing wire, 3 mm in diameter, is placed both ways over the panels and 3-cm thick M-150 concrete is laid *in situ* on the entire area which forms the compression flange. The bricks act only as a filler material. A saving of 20 per cent in cement, 30 per cent in bricks, 40 per cent in steel and 33 per cent in the overall cost is achieved against the *in situ*

11.5-cm thick reinforced cement concrete slab. Their use also eliminates the shuttering for the slab; only props for the partially pre-cast joists are needed.

Funicular shell roofing

These are doubly curved shells of 1.2 m × 1.2 m, and have edge beams all around which contain a nominal reinforcement of 6-mm diameter. There is no reinforcement in the body of the shell and the shell concrete thickness is 30 mm. The shells are either placed on partially pre-cast reinforced concrete joists or after placing the shells on shuttering, the joists are cast *in situ*. Concrete is filled with lime concrete or lean cement concrete. This technique saves in cement and steel and has been adopted in a large number of residential and office buildings. Shells can be room size, but in such cases shuttering is required and the shell is cast *in situ*.

Madras terrace roofing

This technique has been adopted in the southern states of India, where specially made terrace bricks are placed on their edges in a diagonal pattern using lime mortar or lime cement mortar over the wooden joists spaced 30- to 45-cm apart. This technique saves on steel and cement. The cost could be reduced further by using secondary species of timber or reinforced cement concrete battens.

Structural clay units for flooring and roofing

Two types of structural clay units have been developed. In one type, the flooring or roofing panels are built in the same way as brick walls, with reinforcement placed in one of the grooves. The panels are lifted and placed horizontally to form the roof. The other is a joist and filler block construction, in which the same shape and size of the units for joists and fillers are used to form the roof. Both these types save 45 to 65 per cent in cement and 20 to 25 per cent in steel. The machine-made structural clay units are produced by an extrusion process.

Clay tiles and reinforced cement concrete battens roof

This technique has been used extensively in Punjab. Brick tiles are laid over reinforced cement concrete joists without the need for form work. This saves in cement and steel.

Pre-cast cellular concrete units

These are unreinforced hollow pre-cast concrete units of nominal size 120 cm × 60 cm × 7.5 cm. They are used in conjunction with partially, or fully pre-cast reinforced cement joists. The scheme results in savings of about 20 per cent in cement, 50 per cent in steel and 30 per cent in overall costs compared with a reinforced concrete slab.

Reinforced cement channel units

These are reinforced concrete trough-type units, 30-cm wide × 13-cm deep, and are suitable for spans 2.5 to 4.25 m. They do not require propping.

Adopted on a large number of housing projects by the Military Engineering Service and for primary schools and health buildings in rural areas, they save 40 per cent in cement, 4 per cent in steel and 20 per cent in cost.

Cored units

These are reinforced concrete, prefabricated, hollow box-type units, 30-cm wide × 13-cm deep and are suitable for spans 3 m to 4.5 m. The saving in cement is 25 per cent. The units have been adopted in a number of houses and save construction time.

Pre-cast reinforced concrete planks

These comprise reinforced concrete beams and reinforced concrete planks of 5 cm and 2.5 cm thicknesses. The beams with *in situ* concrete form the slab and the flooring is placed directly over the planks. The scheme saves 45 per cent in cement, 20 per cent in steel and 25 per cent in overall costs, compared with reinforced concrete slabs, and the technique has been adopted in over 500 housing projects. The scheme also provides monolithicity in the slab and the chances of leakages are considerably reduced because of jointing details.

Pre-cast batten and hollow-block construction

In this scheme partially pre-cast reinforced concrete battens are placed in position and pre-cast hollow concrete blocks are laid in between these battens. Adopted in a large number of housing projects in New Delhi, the scheme saves 10 to 15 per cent in cement and 5 per cent in steel compared with conventional *in situ* reinforced concrete slabs.

Pre-cast reinforced concrete "L" pan units for sloping roofs

In this scheme, cladding and purlins have been combined into one unit thereby saving in materials, cost and time.

Pre-cast waffle units

The waffle units are open-box type units, either square or rectangular, of up to 60 cm to 120 cm. Depth varies according to the span. After placing the waffle units on partial shuttering, reinforcement is provided at right angles in the joints between adjacent units. No deck concrete is provided on the top. This scheme results in a saving of 15 per cent in cement, 10 per cent in steel and 10 per cent in cost compared with traditional Tee-beam and slab construction.

Finishing

Lime plaster

Lime mortar was extensively used before the advent of cement, and buildings built with lime mortar are still standing. Its better workability, higher water retentivity, higher bond strength and capacity of autogenous healing are positive advantages over cement mortar. Good quality lime is not being produced, and there has been resistance to the use of lime mortar. Hydrated lime, however, is now being produced and is being supplied in bags in the same way as cement.

Building lime products

CBRI has developed an activated lime pozzolanic mixture which has such properties as adequate strength, better workability and high water retention. This material is supplied in bags and may be used as plaster for masonry work and also for base concrete work.

Composite mortars

Plain cement sand mortars develop cracks as a result of shrinkage, and thereby cause ingress of moisture; it is thus suggested that a composite mortar of cement:lime:sand in proportions of 1:1:8, 1:2:9 or even 1:3:12 should be used according to design requirements.

Building services

Single-stack system of plumbing

CBRI carried out experiments using a single-stack system of plumbing for discharges with unventilated traps, and noted no breakages of seals. This system has been incorporated in IS:5329–1969, and several organizations have also adopted it. It saves 54 per cent in overall costs and 60 per cent in labour as compared with a conventional two-pipe system.

CBRI has also studied a one-pipe modified system in which the appliances on alternate floors were connected with antisyphonage pipes. It was found that the load-carrying capacity of a 100-mm diameter stack is increased, and this system is economical for buildings of 10 to 12 storeys.

CBRI also developed a special "aerator" fitting on each floor level and "deaerator" at the bottom of the stack to increase the limiting capacity of a normal single stack. With these fittings, 100-m diameter stacks can be used for buildings of up to 15 storeys.

Dual-flushing tank

Flushing tanks in present use discharge their full capacity of water. A dual-flushing cistern has been designed and developed by CBRI. This involves low additional cost but economizes on water consumption.

Small-capacity flushing cisterns

By rationalizing the water seal in the Western-type WC pans and by altering the spacing and direction of the holes in the rims of the Indian pans, it was noted that efficient flushing could still be achieved with only 6.5 litres compared with 10 litres of water used at present.

Automatic flushing cistern

Automatic flushing cisterns are used for urinals in office buildings, public places etc. which have costly fittings made of brass. CBRI developed a simple fitting made of polythene pipe which is cheap and efficient

Techniques suitable for rural areas

Although the techniques mentioned above are suitable for rural areas, the shortage of materials and housing requirements in rural areas are so huge, that it is suggested that more use is made of locally available materials. Improvements in local construction practices should be adopted to upgrade the durability and appeal of village houses and to encourage self-help.

Foundations and plinths

The foundation can be laid either with burnt bricks, random rubble stone masonry or laterite blocks in a lime mortar. In areas where the water table is low, the masonry can be laid in a mud mortar.

The entire foundation can also be laid with boulders, gravels, and *kankar* with moorum, properly compacted to form a box structure over which the superstructure is laid.

Stabilized soil blocks with cement, lime or bitumen are also suitable for foundations. The mixing of the stabilizer has to be done thoroughly and where the water table is high, bitumen should be painted on the sides of the masonry up to ground level.

In areas where rainfall is scanty, the superstructure can be started for single-storey light buildings on rammed earth only.

Damp-proof course

At the plinth level, a course of burnt bricks soaked in a soap solution should be laid in lime or cement mortar.

Alternatively, a course of burnt bricks dipped in coal tar with a coal tar sand mortar could be laid. Used engine oil could replace coal tar.

Walling

Locally available burnt bricks, stones or laterite blocks can be laid in mud mortar or lime mortar. When mud mortar is used, the wall should be pointed with lime mortar, cement mortar or composite mortar.

Mud walls can be made of locally available well-kneaded clay or sun-dried clay bricks laid in mud mortar. These should be plastered internally with mud mortar and externally with a waterproof mud plaster made of cut-back bitumen or by spraying bitumen over the wall, or by applying a mud plaster mixed with used engine oil.

The main structural supports can be of timber, ballies or bamboos, whilst the cladding can be of split bamboo jafry, reed panels or palmyra leaves. These should be plastered internally with mud mortar; the external surface can be covered with non-erodable mud plaster.

Roofs

Flat roofs are made up of wooden joists, ballies or bamboos with country wood planks, reeds of bamboo mat covered with a layer of well-compacted soil and mud plastered. The top may be rendered with cut-back bitumen mixed with mud plaster.

Stone slabs, 60-cm wide × 10 to 12.5 cm deep, and up to 3-m span, may also be rested on walls.

Local wood, bally, bamboo trusses or rafters covered with thatch, reeds, palmyra leaves, country tiles, slates etc., depending on their availability in the region can also be used.

Galvanized-iron sheets or asbestos-cement sheet roofing with wooden ballies as rafters and bamboo as purlins are sometimes used.

Corrugated wood-wool/coir boards

The CBRI has developed two types of roofing sheets, one with wood wool and the other with coconut or jute coir waste. In both, cement is used as a binder. These sheets are made in sizes of 1 × 2 m and cost about half that of an asbestos-cement sheet.

Asphaltic-roofing sheets

These sheets are made from paper boards impregnated with asphalt. The life of the sheets is 5 to 7 years and they are suitable for temporary buildings. These sheets should not be used in areas where summer temperatures are likely to exceed 45° C.

Bamboocrete

The RRL, Jorhat, has made use of locally available bamboo in walling as well as in roofing. The bamboocrete roof was constructed in the shape of a cylindrical shell by arranging pre-treated bamboo splits in both directions in the form of an arch, and then applying two coats of cement-sand plaster. Apart from the low cost, this technique is labour-intensive and can be adopted on a self-help basis.

The CBRI and the Forest Research Institute, Dehradun, have also used treated bamboo as a reinforcement for reinforced concrete slabs. Prototype roofs have been made where the reinforcement is made entirely of bamboo splits. Bamboo-reinforced concrete slabs should last from 15 to 20 years.

Fire-resistance treatment for thatch

The CBRI has evolved the following types of treatments for making thatch fire resistant:

(a) Chemical treatment. Thatch and the binding ropes are dipped in a solution of fertilizer-grade diammonia phosphate and sodium fluoride. Since this chemical is soluble in water, a waterproof paint is later applied over the thatch. The cost of treatment is roughtly equal to the cost of the untreated thatch, but the life of the thatch is increased to 5 or 6 years as well as making it fire resistant;

(b) Twisted thatch roof covered with non-erodable mud plaster. The binding rope only is soaked in the chemical solution. The thatch is twisted to form ropes and tied with a rope at 15-cm centres. After placing the ropes side by side on a timber and bamboo frame, they are plastered on the top with a non-erodable mud plaster with cut-back bitumen mixed in with the clay. The top of the mud plaster is again sprayed with cut-back bitumen and a whitewash is

applied on the top. This treatment has been tried on prototype huts and the cost of the thatch is increased by about 25 per cent. It can be done on a self-help basis with a little training;

(c) Thatch plastered with bitumen-stabilized mud on the top side and with ordinary mud on the bottom side.

Floors

The soil should be well compacted and rendered dust free by regular application of mud and cow-dung plaster.

After ramming the earth it may be covered with broken stones, slab pieces, burnt bricks, burnt clay tiles or with soil stabilized with cement, lime or bitumen.

Doors and windows

Door and window shutters can be of a batten-type and braced with locally available timber.

Door frames can be completely eliminated and the shutters may be hung with pivots.

Lintels

Locally available timber planks of sufficient thickness can be used. Lintels can also be made by using a framework of bamboo. Stone slabs of over 5-cm thickness can also be used as lintels.

Finishing

Non-erodable mud plaster

Mud plaster is made non-erodable and water resistant by mixing clay with *bhusa* (wheat straw) and cut-back bitumen thoroughly. Finally, a *gobri leaping*[8] mixed with cut-back bitumen is applied on top of the plastered surface. This has been tried on a large number of houses in rural areas and has been found to be effective. The treatment should be repeated after 5 or 6 years.

Water-proofing existing mud-plaster walls

A solution prepared from asphalt and kerosene oil is sprayed on the plaster surface. The solution which is absorbed in the wall makes it waterproof.

Building services

Designed by the Planning Research and Action Institute (PRAI), Uttar Pradesh, the PRAI latrine is a hand-flushed, water-seal latrine connected to a cesspit or bored hole. The outhouse superstructure is similar to that of the pit privy, although the squat plate is set directly on the ground into which the toilet pan is inserted. The pan leads to a water trap and effluent line and may be hand-flushed by pouring water from a canister into the excreta undergoing anaerobic digestion. After a year in the pit the digested sludge can be used as a

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[8] Gobri is a mortar of flowing consistency prepared by mixing equal quantities of fresh cow-dung and finely sieved clay. Leaping means providing a thin surface coating.

fertilizer. During this period a second pit is dug and utilized. The major advantage the PRAI latrine has over the pit privy is that it employs a water seal so that flies and odours are obviated.

Systems of construction

Some of the techniques developed by CBRI may be called systems of construction. These are:

Holopan system

Basically, this is a framed-infil type of structure where the frame consists of vertical, reinforced concrete columns cast *in situ* between pre-cast hollow concrete panels. The same type of hollow units are used for floors and roofs by placing them over partially pre-cast reinforced cement concrete joists. This technique has been adopted for an industrial workers' housing project in Ghaziabad, Uttar Pradesh.

Pre-fabricated brick panel system

This system is based on pre-fabricated bricks. The wall panels are not reinforced, while the roof panels are reinforced. They are both made of bricks. The roof panels are placed on partially pre-cast reinforced concrete joists and a 25-mm deck concrete is laid on the entire surface. The wall panels are 7.5-cm thick; sun-dried brick walls can be built internally as a lining to improve thermal insulation.

Skeleton system

The CBRI has developed systems of skeleton construction in which the first durable support and roof is provided either of reinforced concrete, timber or bally. The walls, doors and windows can be put up later. The concrete skeleton system has been tried on a large number of houses.

Sarvatogriha

The CBRI has developed a system of making houses without using any cement or steel. The end walls are first built to the full room height and the side walls to the desired height. Two identical parabolas are then drawn on the end walls and guiding lines with string or thread stretched between them. Bricks are then laid in a mud mortar in alignment with the parabolic curve. This forms the wall and roof.

Conclusion

Tables 6 and 7 show the appropriate techniques for various building elements of low-cost urban and rural housing under Indian conditions.

TABLE 6. APPROPRIAE TECHNIQUES FOR VARIOUS BUILDING ELEMENTS AND PERCENTAGE SAVING IN OVERALL COST COMPARED WITH CONVENTIONAL TECHNIQUES: LOW-COST URBAN HOUSING *(continued)*

Building element	*Conventional techniques*	*Appropriate technique*	*Percentage saving in cost*	*Remarks*
Foundations	*(a)* Spread footing	*(a)* Under-reamed piles	20 to 50	In black cotton soil and loose strata
	(b) Raft	*(b)* Bored compaction piles	30 to 50	In black cotton soil and loose strata
		(c) Hyperbolic parabolic shell foundation	10 to 15	In loose soil for columns
Walling	Load bearing *(a)* Brick masonry *(b)* Reinforced cement concrete with infill panels in brick or block masonry	*(a)* Calculated or designed brick masonry in: (i) Compositon mortar (ii) Lime mortar (iii) Lime base products mortar	Up to 20	
	(c) Hollow block masonry	*(b)* Pre-cast stone masonry blockwalling	16	Against random rubble masonry
	(d) Random rubble masonry	*(c)* No-fines concrete blocks	10	In areas where bricks are of poor quality and sand not available
		(d) Cellular concrete blocks or panels	15	In areas where bricks are of poor quality and stone not available
Doors and windows	*(a)* Teak, deodar frames and shutters	*(a)* Steel frames	5 to 10	Against timber frames
		(b) Magnesium oxychloride frames	15	Against timber frames
	(b) Flush shutters of plywood	*(c)* Panelled or braced and battened shutters	5 to 30	Against conventional and flush shutters
Lintels	*In situ* reinforced cement concrete lintels	*(a)* Flat-brick arches	20 to 30	Where good quality bricks are available
		(b) Stone slabs	20 to 30	Where stone slabs are available
		(c) Thin pre-cast reinforced cement concrete lintels	50	

Building element	*Conventional techniques*	*Appropriate technique*	*Percentage saving in cost*	*Remarks*
Floors and roofs	*(a)* *In situ* reinforced cement slab and beam *(b)* *In situ* RB or reinforced cement concrete slab	*(a)* Prefabricated reinforced brick concrete panels resting on partially precast joists	33	Against *in situ* RB slab
		(b) Funicular shell roofing	20	Against *in situ* reinforced cement slab
		(c) Structural clay units of joist and filler type and of panel type	25	Against *in situ* reinforced cement slab
		(d) Clay tiles and reinforced cement concrete battens	20	Against *in situ* reinforced cement slab
		(e) Pre-cast cellular concrete units resting on reinforced cement joists	30	Against *in situ* reinforced cement slab
		(f) Pre-cast reinforced cement channel units	20	Against *in situ* reinforced cement slab
		(g) Pre-cast cored units	8 to 10	Against *in situ* reinforced cement slab
		(h) Pre-cast reinforced cement planks resting on partially pre-cast joists	25	Against *in situ* reinforced cement slab
		(i) Pre-cast battens and hollow-block fillers	5	Against *in situ* reinforced cement slab
		(j) Pre-cast reinforced "L" pan for sloping roofs	5 to 10	Against asbestos-cement and galvanized-iron sheet roofing
		(k) Pre-cast waffle units	10 to 15	Against reinforced cement concrete beam and slab construction

TABLE 6. APPROPIATE TECHNIQUES FOR VARIOUS BUILDING ELEMENTS AND PERCENTAGE SAVING IN OVERALL COST COMPARED WITH CONVENTIONAL TECHNIQUES: LOW-COST URBAN HOUSING *(continued)*

Building element	*Conventional techniques*	*Appropriate technique*	*Percentage saving in cost*	*Remarks*
Finishing	Cement mortar	*(a)* Composite mortar	5 to 15	
		(b) Lime mortar		
		(c) Lime base product mortar		
Services	Two-pipe system	*(a)* Single-stack system of plumbing	54	
		(b) Modified one-pipe system	35	For building 10–12 storeys

TABLE 7. APPROPRIATE TECHNIQUES FOR VARIOUS BUILDING ELEMENTS COMPARED WITH CONVENTIONAL TECHNIQUES: RURAL HOUSING

Building element	*Conventional technique*	*Appropriate technique*	*Advantages of appropriate technique*
Foundations	Rammed earth and mud walls	*(a)* Burnt bricks, random rubble or laterite blocks in lime mortar	Longer life
		(b) Boulders, gravels, kankar with morrum (disintegrated lava) properly compacted	Longer life
		(c) Stabilized soil blocks with cement, lime or bitumen	Longer life

Building element	*Conventional techniques*	*Appropriate technique*	*Advantages of appropriate technique*
Damp-proof course	Not provided	(a) Burnt bricks dipped in soap	Longer life
		(b) Burnt bricks dipped in coal tar	Longer life
Walling	*(a)* Mud walls	*(a)* Locally available burnt bricks in mud mortar with waterproof mud plaster	Longer life
	(b) Bamboo fabric	*(b)* Sun-dried bricks in mud mortar with waterproof mud plaster	Longer life
	(c) Tin sheets etc.	*(c)* Split bamboo jafry reed panels or palmyra leaves cladding over timber or ballies framework	Longer life
Roofs	Thatch roof	*(a)* Flat roof of wooden joists, ballies or bamboos having country wood planks, reeds, bamboo mat covered with compacted soil and top plastered with bitumen-mixed mud	Longer life
		(b) Stone slabs resting on walls or timber joist	Longer life
		(c) Balley or bamboo truss covered with thatch, reeds, palmyra leaves, country tiles, slates	Longer life
		(d) Galvanized-iron/asbestos-cement sheets with wooden ballies	Longer life
		(e) Corrugated wood-wool or coir boards with timber purlins	Longer life
		(f) Asphaltic-roofing sheets with timber purlins	Suitable in areas where temperature in summer is below 45° C
		(g) Bamboocrete	
		(h) Thatch with fire-resistant treatment	Life increased by three to four times
Floors	Rammed earth and gobri leaping	After ramming earth, cover with broken stone slab pieces, burnt bricks, clay tile or with soil stabilized with cement lime or bitumen	Longer life
Doors and windows	Local wood, sheets	*(a)* Braced and batten-type of seasoned secondary specios of timber	Longer life
		(b) Pivots for hanging shutters and no frame	Longer life
Lintels	Bamboos, timber planks, stone slabs	*(a)* Locally available timber planks	Longer life
		(b) Bamboo framework	
		(c) Stone slabs	

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Case study of building materials and building techniques for rural areas

M.K. Garg*

Traditional rural housing in India may be classified as follows:

(a) Simple huts of bamboo and grass;

(b) Mud-wall houses with sloped, thatched roofs, or roofs covered with red clay tiles;

(c) Houses with a superstructure of mud or sun-dried, unbaked bricks in mud mortar; roofing of rough wooden beams covered with thin mud paste and compact mud; compact earth flooring;

(d) Houses with a superstructure of baked bricks in lime mortar, roofing of good quality standard timber beams with wooden planks and lime-concrete top; flooring of lime-concrete.

Practically all the materials for constructing these houses used to be available near the villages. The clay was usually dug at the site or transported from the village pond. Thatch for roofing was usually available within a 10–15 mile radius. Rough wooden beams were prepared from trees growing around the village, although standard wooden beams were obtained from the towns. Labour was supplied in part by the family itself and in part engaged from the village. Specialized labour was occasionally provided on a barter basis.

The position has gradually changed over the years. Because of a growing shortage of timber, wood had to be imported from urban areas and paid for in cash. Land where thatched material used to grow wild was cultivated and thatch became costly. The system of payment in kind was changed to payment in cash.

Traditional housing construction costs increased at a higher rate than the cost of other necessities. The major factor in this cost escalation was roofing. Flat wooden beams and tile roofing required a large amount of timber, the cost of which rose steeply because of the wood shortage in the villages.

Various government and non-government research bodies tried to find a means of reducing costs so as to accelerate house building in rural areas. Research and development in the field of low-cost housing has been concerned with:

(a) Prefabricated brick slabs for roofing with concrete beams;

(b) Design of houses requiring no cement or iron;

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*Director (Projects), Appropriate Technology Development Association (ATDA), Lucknow, Uttar Pradesh, India.

(c) Development of waterproof plaster, fireproof thatch, and certain implements to increase masonry output;

(d) Pre-cast blocks with low cement content;

(e) Improvement in lime mortar designed to give it quick-setting properties.

Bricks

The Hoffman type of continuous brick kiln was first introduced in India during the 1860s, with wood being used as fuel. The kiln was an oval-shaped structure divided into 12–16 permanently roofed compartments with a high central chimney. The investment cost was high. The kiln was designed for countries with frequent yearly rainfalls. In India brickmaking is a seasonal industry carried out during the dry season from October to April. A new type of kiln design, known as the Blum kiln, was therefore introduced. The oval-shaped structure of the Hoffman kiln was retained, but the permanent compartments and roofing were dispensed with. The permanent chimney was replaced by moving iron chimneys. The various compartments were built at the time of loading and the chimneys were placed on the compartment and gradually moved with the fire. Fuel was changed from wood to steam coal dust. This type of kiln gradually replaced all others for brick manufacture, and it is now a standard design which has spread to rural areas. Its normal capacity of 4 to 5 million bricks can be raised to about 8 million. The industry suffers from a chronic shortage of coal for firing. Coal transport costs have recently increased sharply, thus raising the cost of bricks. The cost of transporting bricks to the villages amounts to 25–33 per cent of the cost of the bricks. It is therefore necessary to develop a smaller kiln which can be owned and operated by the villagers themselves.

Lime mortar and cement

The traditional binding material was lime mortar. It was prepared by burning widely spread local deposits of *kankar* in an open kiln. The fuel used was cow dung. Lime was prepared and grinded for use at the site. In some places limestone was burnt and slaked in water. Sandy loam clay was burnt separately and then mixed with slaked lime solution. Lime mortar takes about three months to develop strength, which is even then lower than that of Portland cement. The latter has gradually replaced lime mortar and is now usually preferred except in times of shortage. Cement is made in large-scale factories, and transport, packing and distribution costs raise the price by 30 per cent for the villager.

The Planning Research and Action Institute has developed a 25-ton vertical-shaft-kiln cement plant based on local raw materials. Cement produced in this plant can be about 26 per cent cheaper than that produced in a large-scale plant. The establishment of mini cement plants in rural areas will substantially reduce the cost of housing in villages.

With regard to construction technology, the following design improvements have taken place.

Walling

A new type of wall design has been developed using unfired bricks and baked bricks in an interlocking arrangement. The wall thickness has been maintained at 37 cm (14.6 in.), 50 per cent of which consists of baked bricks and 50 per cent of unfired bricks. The superstructure has the following advantages:

(a) The cost of a 37 cm (14.6 in.) thick wall is equivalent to that of a 27 cm (10.6 in.) thick baked brick wall;

(b) The heat load is reduced;

(c) The stability of the house is improved.

The walls were tested during two rainy seasons by keeping them standing in rains without any roofing. The interlocking system was found to be completely stable. Since unfired bricks were not easy to obtain at the house site, they had to be transported from the brick kiln, which resulted in increased costs. Such bricks were therefore superseded by using mud mortar filling between baked bricks. These walls were also tested in the open during the rainy season and found to be stable. The cost of reduction was about 20 per cent less than that of a completely brick wall. The cost of constructing a 13.5 in. (34.3 cm) wall to the new design is approximately 20 per cent cheaper than that of a 9 in. (22.9 cm) baked brick wall.

Roofing

A roofing system based on trapezium beams of reinforced cement concrete has been developed. These beams could be either pre-cast on site or supplied from a rural centre. The construction process involves the following steps. The trapezium beams are placed 12 in. (30.5 cm) apart. The larger part of the beams is on the lower side. A 9 in. (22.9 cm) brick is inserted on the width side between the beams by breaking the lower corners. This makes the lower side similar to reinforced brick slab roofing. The top is filled with cement concrete to complete the roofing. This type of roofing has the following advantages:

(a) No centring is required to cast the roof;

(b) Heat load is reduced;

(c) It gives the same strength as reinforced cement concrete roofing. Existing specifications are therefore maintained;

(d) The cost is reduced to about 80 per cent of the cost of standard reinforced brick slab roofing.

Another major advantage of this roofing system is that even if cracks appear because of sinking walls, the roof can be easily repaired by removing the defective part, whereas this is not possible with reinforced brick slab roofing. If the villager wants to redesign the house, the roof can be dismantled and almost all the material reused. Such flexibility is desirable and was availabl when timber roofing was used. About 50 houses were built according to this design, and the roofs have shown no deterioration after a period of 10 years.

This system was reviewed and it was decided to place the beams 18 in. (45.7 cm) apart. Instead of filling the gap with brick, a ferrocement slab 1 in. (2.5 cm) thick was put on the lower side, and another plate 2 in. (5 cm) thick placed on the upper side. A space was therefore left between the two blocks, which helps to save heat load and to reduce the roof's own load. The cost of this type of roofing was 70 per cent of the cost of standard roofing.

Flooring

Besides stability, another essential requirement of a floor is impermeability or a very low water-absorbing capacity. Both these qualities, impermeability and stability, could be achieved when the flooring is in two layers, a lower layer of 1:6:12 cement concrete at least 4 in. (10.1 cm) thick, and over it a second layer of 1:4:8 cement concrete at least 1 in. (2.5 cm) thick. But this is generally not done in rural areas. Usually broken baked bricks are packed with lime and ash mixture or with a weak cement mortar, and a plaster is laid on the surface. Such floorings do not last long. Since the cost of standard cement concrete flooring could not be reduced, a new type of red clay flooring was developed.

Red clay tile moulded from the same clay from which baked bricks are made was developed. The size of the tile is 20.3 cm × 20.3 cm × 5.1 cm (8 in. × 8 in. × 2 in.). It is baked in the same kiln as standard bricks. After baking, the tiles are given a 1-mm thick cement coating and cured in a water tank for about three weeks. By using white cement and colouring oxides, many good mosaic flooring patterns can be produced.

The flooring is laid in two ways. On the one hand, broken bricks are spread over the floor and compacted. The compact surface is covered with a thin layer of sand and tiles are laid dry. The joints are pointed with cement-sand mortar. On the other hand, tiles may be laid with mortar over the compact bed, and every joint filled with cement-sand mortar. The cost of this flooring is about 60 per cent that of standard flooring and about 5–10 per cent less than that of the unstable cement flooring generally found in village houses. This flooring remains intact and looks neat and clean even after five years of use. It has the advantage of being flexible and easy to repair, and the materials can be reused when the house is remodelled or reconstructed.

Evolution of the construction and building materials industries in Indonesia

*Z.A. Abbas**

Realizing the important and increasing role of construction and building materials in the overall economic and social development of the country, the Government of Indonesia is paying considerable attention to developing local capabilities in various technological aspects of these industries. Negligence of these limitations could become a major obstacle to present and future efforts, while indiscriminate adoption of technological innovations from industrially developed countries could make existing conditions even worse. Effective enforcement of regulatory measures and preventive as well as corrective actions are being undertaken on a co-operative basis, through the involvement of various institutions in co-ordinated efforts to introduce appropriate technologies.

General situation

The Republic of Indonesia is an archipelago of more than 3,000 islands extending along the equator between the mainland of Asia and Australia. It is the third largest country in Asia after China and India.

The archipelago is one of the most volcanic areas in the world, having some 500 volcanoes of which 128 are considered active. Earthquakes occur rather frequently, but are usually mild. The country is fortunate in that it lies outside the path of typhoons on course to the Asian mainland.

The population of Indonesia is currently growing [illegible] more than 2.4 million people a year. Various projections for the year 2000 indicate a population of between 200 million and 290 million. An acceptable estimate is a population of 220 million, almost twice the present level. Some 440,000 housing units must be built every year to keep up with that growth.

Indonesia's population problem is also aggravated by the disproportionate distribution of people among the country's islands. By the year 2000 the expected population density in Java will be not less than 1,000 persons per square kilometre. By contrast, the density in Kalimantan, Borneo, is estimated to increase only up to 19 persons per square kilometre.

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*Head, Sub-Directorate of Development, Directorate of Building Research, Bandung, Indonesia.

The construction industry

The construction market in Indonesia can be fairly represented by public sector demand, since it amounts to 70 per cent of the total, although the demand for construction in the private sector has been increasing rapidly. Some 60 per cent of total construction is concentrated in Java, 40 per cent in Djakarta alone.

The building materials industry

Cement and cement products

The Government has given high priority to the development of the cement industry, which is now one of the major building materials industries in Indonesia. According to the Ministry of Industry, national production of cement will be able to supply domestic demand in 197[illegible] and leave an exportable surplus of 500,000 t. However, *per capita* cement consumption in Indonesia is still only 25 kg/a.

Only ordinary Portland cement (ASTM type 1) is produced in Indonesia, but research and market studies are going on to develop and produce other types of cement for specific purposes.

Some types under development are:

Portland-pozzolana cement and sulphate-resistant cement for marine structures

Lime-pozzolana cement for low-cost housing

White cement for architectural concrete

Low-heat cement for mass concrete

Asbestos-cement sheets, flat and corrugated, are used in factory construction, while corrugated asbestos-cement sheets are now being used for mass housing, as they are a compara[illegible] cheaper roof covering and local production of clay roofing tiles is [illegible] to meet demand. The growth of the industry is, however, hamp[illegible]-availability of asbestos fibre, which must be imported. To repl[illegible] research is being carried out to use organic fibres in the manufacture [illegible] cement products, and there are already many small plants in Indonesia producing fibre-cement sheets using waste textile fibres. Research on the development of cement-bonded particle board with various kinds of agricultural waste material is also being carried out by the Directorate of Building Research.

In addition, a small pilot plant for manufacturing prefabricated concrete building elements and components for use in l[illegible]ost housing construction is now in operation and shows a 15–20 per cent reduction in building costs as compared with conventional methods of construction.

Lime

Lime has been used very successfully in the past, but its quality has been deteriorating over the years. However it is still being used in large quantities, as Portland cement is in high demand for heavy structural work and sometimes is either not available or too expensive.

Lime is produced in numerous types of kilns ranging from primitive to modern vertical-shaft kilns, using limestone or coral stone as raw material and usually wood as fuel. Most of the industry is located in Java, although other regions of Indonesia have good lime-producing potential. In Java there are approximately 3,200 lime-burning kilns with a total production of about 3.3 million m^3 of slaked lime per year and a labour force of some 12,200.

If the quality can be improved, an increased demand for lime can be expected. What is needed is technical assistance in the form of more efficient kiln design, better constructional techniques and advice on kiln operation using locally available materials and fuel. Research has already led to the development of a newly designed, highly efficient 10-t lime kiln and an improved 6-t kiln. Two of each of these demonstration kilns are now in operation.

Structural clay products

Clay bricks and roofing tiles are used extensively in Indonesia, but there is much scope for improved production methods, as the bulk is manufactured in small and inefficient kilns operated by families on a village co-operative basis. In addition, owing to the rapid growth in the housing sector, the qualitative and quantitative requirements of bricks and roofing tiles have been increasing and they cannot be met by existing industry.

Timber and timber products

Indonesia is endowed with sufficient forest resources providing an average forest density of one hectare *per capita*. Timber is therefore the most important organic building material in the country. But first-class timber species are prime export commodities, and it is important to promote the use of secondary and less durable timber species for building, particularly for housing construction. Measures must be taken to extend the functional life of semi-durable and non-durable timber species through proper seasoning, chemical treatment and preservation. Lumber-drying kilns and preservation plants are now in operation in and around the big cities. But due to the high cost of investment and of the chemicals (most of them have to be imported), air-drying and dipping or painting of timber are still general practices in Indonesia. The timber industry is composed of hundreds of small workshops scattered throughout the country without the means of setting up their own processing units. The solution may be to develop small-scale processing units, managed co-operatively, as well as to develop mobile timber treatment plants and portable seasoning kilns. Research in the design and development of such plants is now in progress.

The use of plywood, fibreboard, and particle board as building elements in housing, in joinery and furniture making, and in the construction of forms has increased considerably, and some 14 plywood factories, one particle-board plant and one fibreboard plant are now in operation.

Research is concentrated on the development of cement-bonded particle board and pulp cement boards.

Bamboo and allied materials

Nearly 70 per cent of all houses in Indonesia incorporate some bamboo, but chemical treatment of bamboo is not yet widely practised due to prohibitive costs. However, research in preservative treatment to extend the service life of bamboo and allied materials is being carried out.

Pozzolanic materials

The use of pozzolanic-lime mixtures has been declining due to competition from Portland cement and deterioration in the quality of both lime and pozzolanic material. But recently the question of using pozzolanic-lime as a substitute for Portland cement, which is becoming too expensive, has been taken up again. Both lime and natural pozzolanic material exist in abundance, particularly on Java.

In addition to use in mortars and plasters, pozzolana-lime mixtures are also extensively employed in making, by machine or by hand, relatively good-quality volcanic trass-lime in solid or hollow blocks. Dozens of labour-intensive block-making cottage industries are now in operation in and around Bandung providing brick-size or block-size building elements for low-cost housing projects. This method of block-making with trass-lime is now being practised all over Indonesia wherever deposits are available. It is also possible to make floor tiles of volcanic-lime mixtures by the same process for block-making, but a cement layer is necessary to cover the tiles.

Lightweight aggregates

Due to the rapid development of the construction industry in Indonesia, particularly in the housing sector, the demand for non-traditional, non-conventional and more industrialized building materials and components is increasing. Research and Development (R and D) activities for producing lightweight concrete elements for high-rise buildings and prefabricated elements for mass housing has therefore become one of the main activities of the Directorate of Building Research. The use of lightweight concrete in multi-storeyed buildings is receiving special attention because its low unit weight considerably reduces dead loads in buildings, resulting in savings in the cost of foundations and structural members. Savings in reinforcement steel alone justify the choice of light-weight concrete for high-rise buildings.

One of the results of the R and D activities has been the construction of a pilot plat for producing light-weight concrete panels, beams, and window- and door-frames. Other products include expanded clay produced in a small-scale laboratory rotary kiln, and thin reinforced wall panels and hollow blocks using the expanded clay.

R and D has also been undertaken on various other aspects of the building industry such as the building environment, economics and management, low-cost housing development and planning, standardization, legislation, sanitation etc. The eventual adoption of international building standards would require thorough research on the applicability of the imported standards to local building materials, taking into account national conditions. Building regulations and by-laws are also a field of concern, since existing codes dating from colonial times are not appropriate to present conditions.

Also being investigated is the possibility of making high-quality pozzolana-lime cement by intergrinding the trass with partly slaked lime to a fineness comparable to that of Portland cement. The appropriate strength and setting properties of the mixture can be obtained through the use of additives. A pilot plant for the production of binding materials is being considered.

Government policies for the development of appropriate technologies

A comprehensive policy is needed for the development of the building materials and components industries based on long-term plans for the construction industry. Current policy involves the direct participation of the Government in the development of the building materials and components industries. Different measures have therefore been introduced, including the following:

(a) Long-term loans at low interest to establish or expand the production of key building materials;

(b) Increased import duties on building materials and components that could be replaced by nationally produced commodities;

(c) Provision of subsidies and assistance for the establishment of workshops producing building elements and components and for the purchase of machinery and equipment;

(d) Promotion of R and D on new building materials and construction techniques.

It can be concluded that before 1966 a building materials industry in the proper sense did not exist. Since then it has developed along the lines laid down in the Government's Five-Year Development Plans.

The building materials industry in Indonesia at present can be broadly classified into two categories:

(a) Large-scale building materials industry catering to the demand for high-quality, high-performance, expensive products. It is in general an organized, capital-intensive industry using modern technology and modern management techniques in its production processes. Many factories have recently started in this category, both as joint ventures and as foreign and domestic enterprises under the applicable investment laws. They cover a spectrum of products which has already become impressive in a relatively short time, including ceramic tiles and sanitary ware, hardware, aluminium extrusions and mouldings, wall sheets, weather-resistant paints, electrical goods and cables, plywood, wood-wool boards, particle boards and furniture, asbestos-cement sheets (flat and corrugated), ready-mixed concrete, concrete iron mesh and iron bars, steel structures and components, linoleum sheets and tiles, high-quality structural clay products etc. These products are of controlled quality and conform to set standards. Most of the factories are located in and around the big cities;

(b) Small-scale building materials industry producing building materials, including bricks, roofing tiles, clay pipes, lime, cement products, floor tiles, pipes, blocks and ceiling sheets, bamboo mats, timber components, stone, gravel and sand, pozzolana-lime blocks etc. The small-scale industry is mostly an unorganized, labour-intensive cottage industry run on traditional lines in small units. They may work occasionally or seasonally, and their volume of

production, generally adequate for current local consumption alone, would not be able to meet increased demand created by an accelerated programme of construction. Their products, generally irregular and uneven in shape and quality, do not comply with accepted standards, and cost far less than those produced by modern plants. There is no competition between the products of modern plants and those of small industries, since they serve different quality and performance needs. In this context, the Government is playing an important role by ensuring balanced development of the large-scale and small-scale building materials industries. Small-scale building materials industries are spread throughout the country, in rural villages as well as in and around urban cities and towns.

Most of the building materials used in Indonesia fall into the second category. They account for a major share of both the material for and the financing of house building in Indonesia, particularly in the rural areas. Of the total housing stock of approximately 19,700,000 dwellings in 1961, only 6 per cent can be considered of permanent construction using durable building materials, 60 per cent of semi-permanent construction using a mixture of durable and non-durable building materials, and 34 per cent of temporary construction using non-durable building materials. In 1971 the housing stock was estimated at approximately 22,500,000 dwellings with little improvement in the quality of the materials used.

The slow development of the small-scale industry in coping with increasing demand for more and better quality materials is due to the following factors:

(a) Lack of capital needed for investment to improve and increase production;

(b) Use of traditional technology in the production process;

(c) Low-level and unsteady demand for building materials resulting from the very limited purchasing power of the population and the uncertainty of construction programmes;

(d) Lack of managerial skills required for efficient operation of small-scale industries;

(e) Marketing procedures detrimental to both consumer and producer and profitable only to dealers and middlemen;

(f) Disorganized system of transportation and marketing of building materials;

(g) Scarcity of, or difficulty of obtaining, fuel and electricity.

With the increasing tempo of industrialization, the demand for traditional as well as modern building materials has grown and more exacting quality and performance requirements are being made on the industry. This has led to the expansion and modernization of traditional building materials industries. Improved methods of brick production are needed for the manufacture of better-quality bricks; scientific methods of lime burning must be adopted to produce a reliable quality of lime; better methods of extracting timber from forests need to be developed to avoid wastage in tree felling and cutting etc.

In such a situation there is an even greater need for rationalization in the building materials industry. But, rapid improvements cannot be expected where there is a shortage of capital goods and managerial skills, where competition is weak and where priorities are not clearly defined. However, if the cost of manufacturing building materials could be reduced, and both the quality of the product and construction techniques improved, then more capital would be available for the construction of more durable houses. Greater durability would result in lower maintenance and repair costs. Hence the quality of the building materials used is of great importance. Building materials research is the only means of achieving improved quality, lower production costs and suitable building materials.

Conclusions

Having reviewed the situation in the construction and the building materials industries and the relevance of R and D activities in those industries to national development efforts, the following general conclusions may be drawn:

(a) The choice of technology will primarily depend on the industrial development policy of the country. Many factors will have to be taken into account in the decision-making process, which should be based on the actual conditions of the industry and related fields;

(b) Given the specific conditions of Indonesia, traditional technology with a relatively large amount of unskilled labour will be needed for a long time to come, especially in rural areas. On the other hand, where the need is evident, as in high-rise building and in the basic building materials industries, advanced technology should be introduced, even if it is capital-intensive and labour-saving. The solution would therefore be for Indonesia to develop a balanced plural technology, drawing on traditional, intermediate and advanced technology according to needs;

(c) A technology development plan designed to achieve technological independence should be incorporated in the national development programme;

(d) National, regional and local efforts are required for the efficient organization and management of the construction and building materials industries. A national policy should be established to guide both private and the public sector if the cost of building is to be reduced substantially;

(e) The importance of various construction and building materials, for national development programmes should be considered in identifying appropriate technologies;

(f) The improvement of local technology depends largely on the development of technological manpower and infrastructure, technology dissemination and international co-operation.

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Choice of appropriate construction technology in the building industry in Iran

*F. Neghabat**

Data on urban housing in Iran

Statistics on the current and predicted urban population, provided by the Plan and Budget Organization, the government agency in charge of planning development projects in Iran, are shown in table 1.

TABLE 1: URBAN POPULATION IN IRAN, 1978–1993

Year	*Number of persons (millions)*	*Number of families (millions)*	*Average family size (persons)*
1978	16.3	3.4	4.83
1983	20.5	4.4	4.63
1988	25.2	5.7	4.43
1993	30.1	7.1	4.23

There is a density of 1.82 families per housing unit. The Government's objective is to reduce this figure to one family per house over the next 15 years.

Table 2 shows the current and planned number of housing units, rate of growth and average floor area as provided for by the Sixth, Seventh and Eighth Development Plans.

TABLE 2: PLANNED GROWTH OF HOUSING, 1977–1993

Period	*Number of units (thousands)*	*Average annual increase (%)*	*Average floor area (m²)*
1977	145	11	140
1978	150	4	130
1979–1983 (Sixth plan)	980	12	110
1984–1988 (Seventh plan)	1 720	12	110
1989–1993 (Eighth plan)	2 900	11	110

The data for the Sixth Development Plan (1979–1983) indicates an average requirement of some 200,000 units per year. The major portion of this construction is undertaken by the private sector; the Government's contribution

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*Director of Building and Housing Research Centre, Tehran, Iran.

is estimated at 15 per cent. However, 40 per cent of the activities of the private sector receive some form of government support such as tax benefits, land provision, long-term, low-interest loans and other incentives.

Further details as to the distribution of housing forecast by the Sixth Development Plan as regards income groups and required investment is reflected in table 3.

TABLE 3. DISTRIBUTION ACCORDING TO INCOME GROUPS AND TOTAL INVESTMENT NEEDED FOR SIXTH DEVELOPMENT PLAN (1979–1983)

Income group	*Monthly salary (dollars)*	*Number of units (thousands)*	*Average number per year (thousands)*	*Average floor area (m²)*	*Investment (billions of dollars)*
1	< 290	334	66	75	5.68
2	290–599	254	54	95	6.84
3	600–1000	196	40	125	8.33
4	> 1000	196	40	170	10.38
Total		980	200		31.23

Table 4 shows the supply and demand of building materials for housing projects based on development projects under way and planned.

TABLE 4: PRODUCTION AND DEMAND OF BUILDING MATERIALS FOR HOUSING PROJECTS

Building materials		*1977*	*1978*	*1979*	*1980*	*1981*	*1982*	*Remarks*
Cement (millions of tonnes)	Production	7	11	15.5	19	20	21	1976 imports were 1.2 million t
	Demand	2.9	2.7	2.8	3	3.2	3.7	
Bricks (billions)	Production	14.8	16.3	18	20	22	24.5	Cement blocks and sand-lime bricks to fill the gap
	Demand	6.7	6.3	6.3	6.3	6.5	7.6	
Steel profiles (millions of tonnes)	Production	2.4	2.8	3.2	5.2	5.4	5.5	1976 imports were 0.6 million t
	Demand	1	1	1	1.1	1.2	1.4	
Gypsum (millions of tonnes)	Production	4.2	4.8	6	6.8	7.2	7.2	
	Demand	2.2	2.1	2.2	2.3	2.4	2.8	
Tiles (millions)	Production	587	1 200	1 670	1 670	1 670	1 670	Surplus to be exported
	Demand	289	377	379	409	433	502	
Glass (millions of square metres)	Production	6	6	10	13	13	13	Shortage
	Demand	4	4	4	4	4	6	
Aluminium profiles (thousands of tonnes)	Production	26	32	40	44	44	44	
	Demand	12	12	12	13	14	16	

Industrialization of the housing industry

Traditional methods of construction have their place and will continue to be most commonly employed in building. However, the introduction of advanced technology and the industrialization of the housing industry are inevitable if the requirements of the Development Plans are to be met.

The pace of the industrialization is illustrated by the number and sizes of plants for producing light to heavy prefabricated building components that are now in operation or under construction (see table 5).

TABLE 5. DATA ON PLANTS FOR PREFABRICATED BUILDING COMPONENTS

Type of component	*Number of plants in operation*	*Annual production capacity (thousands of square metres of floor area)*	*Number of plants under construction*	*Annual production capacity (thousands of square metres of floor area)*
Heavy	15	812	11	3 465
Light	33	900	10	250
Total	48	1 712	21	3 715

The Government's objectives in the industrialization of urban housing construction may be briefly outlined as follows:

(a) Long-term establishment of a support or component industry that is product-oriented rather than system-oriented and is also adaptable to local conditions;

(b) Application of modular co-ordination, in order to achieve standardization, minimize wastage, and obtain better co-ordination among building products obtained from different plants;

(c) The exercise of quality control, supervision, and compliance with local and national codes, which are to be established;

(d) Improving existing and traditional building materials and allowing innovations to produce new materials utilizing indigenous resources.

Short- and medium-term objectives include:

(a) Introduction of construction management techniques for building industry through local or foreign large-scale developments capable of producing the most economical housing in the shortest time;

(b) Establishment of heavy prefabrication plants on a limited basis in order to meet specific large housing requirements of given regions, while giving due consideration to the socio-economic, cultural, and physical characteristics of the regions;

(c) Establishment of on-site portable plants based on technical and economical feasibility studies of specific projects;

(d) Use of lightweight prefabricated systems as an interim solution;

(e) Encouragement of the private sector towards greater participation in establishment of plants aimed at low- and medium-cost housing. Incentives provided by the Government include: attractive long-term, long-interest loans

through specialized banks, land provision, tax benefits, issuing of appropriate permits, and guarantees to cover part of the finished products;

(f) Encouragement of building research activities and creation of information and documentation centres;

(g) Training for skilled labour as an inseparable part of all construction contracts;

(h) Better co-ordination among all individuals and organizations involved in construction activities.

Financing policies

Implementation of the foregoing objectives depend largely on strong financing arrangements. Therefore, the following housing loan policies have been introduced:

(a) For developers of low-cost housing, up to 70 per cent financing can be obtained from the Government's specialized banks. The loans have low-interest rates with a duration equal to the construction period. These short-term loans can be converted to long-term purchaser loans governed by the scale set out in table 6;

(b) The loan period is 25 years for income groups 1 and 2;

(c) The lower interest rates for the housing projects in cities other than Tehran is in line with the decentralization policy of the Government. Furthermore, each city has its own quotas as related to the maximum number of housing units permitted which have been decided on the basis of the materials, manpower and construction capability available to the city.

TABLE 6. GOVERNMENT LOANS AND INTEREST RATES

Amount of loan (dollars)	*Interest rate (%)*	
	Tehran	*Other cities*
< 20 000	4	3
20 000–35 000	6	5
35 000–60 000	9	8
> 60 000	Regular	Regular

Indigenous technology and rural housing

Construction activities in rural regions have lagged behind urban areas where extensive large-scale development projects have been concentrated. This uneven development has resulted in the migration of large numbers of the rural population to the cities in search of jobs. This massive labour force has been absorbed unproductively in the urban areas creating social and artificial housing problems in certain cities. A decentralization policy with the objective of generating employment in rural areas was therefore enacted. Emphasis was given to small-scale, labour-intensive industries and services that develop locally available resources and meet local needs.

Introducing sophisticated technology in rural areas has its drawbacks. It requires efficient management and administration know-how such as personnel systems, budgeting reforms, communications networks, tax collection, record keeping, supervision, training, and handling of financial transactions. The labour force lacks any such industrial tradition, has little experience with machinery and thus scant perception of the discipline required or the risks incurred when dealing with various types of equipment. It also often has a concept of time different from the tempo of modern industry.

Therefore, the policy for rural housing is to use traditional construction techniques that are labour-intensive and indigenous. These indigenous building systems remain relevant to local needs, relate to the users' needs and finances, and are under the users' control. The general result is low-rise, small-scale, informally organized shelter. A certain amount of modernization as well as mechanization is, of course, inevitable for reasons of higher productivity and better utilization of indigenous resources.

Conclusions

A comparison of the advantages and disadvantages of indigenous housing technology and heavy prefabrication technology follows:

INDIGENOUS	HEAVY PREFABRICATION
Advantages	
Use of local know-how, energy, and resources	Standardization and uniformity of products
Lower prices	Better quality control
Better acceptance by people	Quick installation
	Less on-site activity and waste
Adaptability to local conditions	Easier design and engineering calculations
Flexibility	Mass production
Disadvantages	
Cannot be used for large-scale, short-term projects	Transportation difficulties
	Need for heavy machinery
Lacks uniformity in materials and finished products	Limited flexibility
	Capital-intensive
	Need for training
Labour-intensive	Economical only for large projects
Slower construction rate	Depends on imported technology

One economic factor should not be overlooked: in evaluating alternative construction techniques, distortions in the price of capital and the wages of labour should be given careful attention. Failure to consider this factor may result in selection of techniques that are more capital-intensive than is economically justifiable.

Construction and building materials industry in the United Republic of Cameroon

*E. K. Mundi**

The objectives of this paper are to examine the building materials available in the United Republic of Cameroon, look at their geographic distribution, present some of their known characteristics, discuss the research taking place on local building materials and make recommendations on action that should be taken regarding the transfer of foreign building technology.

Local building materials

Local building materials means all the materials existing or processed in the United Republic of Cameroon that are used in the building industry. Some of this material is used for modern structures while some of it is used in more primitive structures which have proved successful in housing.

Cement

Cement in the United Republic of Cameroon is produced at two main centres: one in Bonaberi (south) and the other in Figuil, in the north. The cement is classed as follows: CPJ 250, a slow-setting, low-resistance cement used in non-reinforced civil engineering works such as soil-cement stabilization for road works and the manufacture of cement blocks; CPA 325 (CPJ 350). the standard cement used for reinforced concrete works; and CPA 450, rapid-setting high-performance cement which is commonly used in prestressed concrete works. The Bonaberi and Figuil factories produce 350,000 tonnes per year, more than 85 per cent of this is produced by the coastal town of Bonaberi.

Sand

Sand is one of the constituent elements of concrete. Abundant deposits exist in the northern part of the United Republic of Cameroon, most of which is river sand. In general the following sands are known: Abem, Bakara, Benue, Chari, Logone, Mbalmayo, Ndelele, Obala, Pitoa, Sanaga and Wouri.

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*Director, Public Works Research and Investigations Centre, (CRETP), Yaoundé, United Republic of Cameroon.

The characteristics of these sands as a concrete constituent have been studied by the Public Works Research and Investigations Centre (CRETP). A summary is given later in this paper.

Gravel

Crushed gravel is generally used in the building industry. Most of the main quarries produce gravel for building and road projects with varied granulometries, such as 0/3, 0/8 sand; 3/8 coarse sand/fine gravel; 8/12.5, 12.5/18 medium and coarse gravel; 5/15 and 15/25 concrete gravel. Alluvial gravel is found in the littoral region, deposited by the Wouri river, hence the name Wouri gravel. The characteristics of this gravel are also summarized later in this paper.

Stone

The building stone used in the United Republic of Cameroon is a type of highly weathered precambrian white granite that is easily worked even with a machete and can be shaped into various forms for building purposes. Basalt is commonly used also, and a kind of sheeted granite/gneiss is used in the central south region, mostly as a wall surface dressing. In some parts of the northern province a reddish-brown sandstone is used as a building stone.

Cement blocks

Standard sizes of cement blocks are manufactured by various contractors and individuals. Cement and sand are mixed in a predetermined proportion by weight of about 1:13 to 1:12 and compacted in moulds and left to set over a long period. These semi-hollow blocks constitute the main element used in modern architecture in the United Republic of Cameroon and are 10 cm × 20 cm × 40 cm and 15 cm × 20 cm × 40 cm in size.

Clay blocks

Clay blocks are sometimes called *poto-poto* blocks, and they are widely used in many parts of the country. Plastic clay, generally lateritic, is loosened, flooded with water, and thoroughly mixed with the hands or feet. The material is in a plastic state and the moisture content is generally close to its liquid limit. This ensures good workability. The thoroughly mixed paste is deposited in wooden forms of 15 cm × 30 cm, and placed on a fairly moist and level ground surface. When the *poto-poto* fills the form, it is levelled off with a straight edge. The form is then removed, leaving the clay block behind, and manufacture of the next block begins. The optimum moisture content is such that after the form is removed, the moulded block retains its shape. The blocks are then covered and allowed to dry slowly. Normal shrinkage occurs depending on the characteristics of the clay soil used.

Many localized processes exist. For instance, in the northern regions, the *poto-poto* is made from a plastic, black, soil (*karal*), treated with chopped straw, and used to mud wooden structures.

Burnt bricks

In the United Republic of Cameroon, burnt bricks are known as tiles; but they should not be mistaken for the tiles used for flooring, even though the manufacturing processes are quite similar. A well-chosen, plastic, grey clay is moulded in the same way as clay blocks. After drying the blocks are baked in huge furnaces to a reddish-brown colour. Burnt bricks are not made in large numbers any longer as their manufacture demands large quantities of plastic, grey clay. They are extremely resistant to rain and heat.

Hardwood (sticks)

Many semi-permanent houses in the United Republic of Cameroon are constructed from a framework of hardwood sticks. The sticks are driven vertically into the ground according to the foundation plan, and at close intervals, making allowances for doors etc. These sticks are attached with horizontally spaced members and tied with metal strings. The wooden framework is mudded on both sides with *poto-poto,* then sealed and plastered thoroughly. Lintels are generally constructed of concrete. In most areas in the central south region, houses are built in this way because of the abundance of good hardwood sticks.

Houses are built in other forested regions using planks nailed horizontally across the exterior of wooded structures. These houses are known as *karabout* houses and are abundant in the littoral and south-west provinces.

Raffia bamboo

Raffia bamboo is used in the west and north-west region. The bamboo constitutes the horizontal members that hold the vertical, hard, wooden elements together. The bamboo is tied to the sticks in chosen designs and tightly spaced; it needs no mudding with *poto-poto* but can be loosely spaced and mudded.

Palm leaves

Good roofing material can be obtained from palm leaves, either of raffia or from the oil palm. The leaves are meticulously woven around two or three fine wooden bars up to 4 metres long. Each palm leaf is folded over the bar, so that its edge overlaps the previous leaf and the loose end runs in the same direction. A sheet of woven palm leaves constitute what is known as a thatch. These thatches are placed on a frame consisting of rafters and poles. The thatches are tied parallel to the poles with the loose ends pointing downwards. The thatch above is overlapped, and so on. If the roof develops a leak, the thatch can be replaced by a new one.

Grass (straw)

Many roofs in the rural areas of the savannah and other parts of the northern province are made of grass. During the dry season the soft grass which covers the rounded hills of the savannah dries up. This grass is cut and tied in bundles so that the lower ends face the same direction. The bundles are then used as a roofing material in the villages. Closely arranged horizontal members, generally of raffia bamboo, are tied to the rafters. The grass is carefully inserted between the bamboo members, leaving the loose ends facing downwards. A tight network constitutes a good grass roof. Rain which falls on the roof flows down the slope until it reaches the eaves. In the rural areas these roofs are abundant.

Other materials

Iron rods for concrete reinforcement are manufactured in the United Republic of Cameroon. Corrugated sheets of aluminium are also manufactured locally, of varying thicknesses, and this constitutes the major roofing material in modern houses.

Distribution of building types

The following types of buildings in the United Republic of Cameroon consist of:

(a) Concrete cement-block buildings. These constitute the bulk of modern architecture in the country. Such buildings are to be found in the cities and towns and a few also in the villages. These buildings are normally plastered and roofed with corrugated sheets;

(b) Stone buildings. These are concentrated in areas where stone is relatively cheap, and which can be easily worked. Stone buildings are abundant in the north-west province. In the central south and northern provinces a few can also be seen. These buildings are commonly roofed with corrugated sheets;

(c) Clay block buildings are found primarily in the west and north-west provinces and parts of the central south province. They are roofed with corrugated sheets, and in remote areas are roofed with grass and thatch;

(d) Mudded bamboo buildings are found only in the remote areas as well as in the villages. Generally they have grass roofs. Since bamboo is predominant in the west, north-west and parts of the central south (northern part) provinces, the buildings are common only in these areas;

(e) Plank or *karabout* buildings are found in the forested areas where wood is cheap. They can be found in the south-west, littoral, central south and east provinces;

(f) Stabilized-clay buildings. Clay is mixed with chopped straw to form a paste and *bukaroos* are constructed with it. The roofs are generally made of straw, and occasionally of corrugated sheets. These round buildings are found mostly in the north and extreme northern parts of the country;

(g) Burnt brick buildings are virtually no longer in existence in the United Republic of Cameroon due to the lack of primary materials in the production areas around the towns. A few old houses in the north-west province and central south still exist. In most cases the roofs are also made of tile.

Characteristics of some building materials

Cement

The three classees of cement manufactured in the United Republic of Cameroon have the following characteristics:

CPA 450: 96 per cent clinker, 4 per cent gypsum, no secondary constituents

CPA 325 (CPJ 350): 86 ± 5 per cent clinker, 10 ± 5 per cent secondary constituents of either pozzolana from Djoungo or of natural highly siliceous sand, 4 ± 1 per cent gypsum

CPJ 250: 66 ± 5 per cent clinker, 30 ± 5 per cent secondary constituents of either pozzolana from Djoungo or natural highly siliceous sand

Abundant data on the mechanical characteristics exist for CPA 325 (CPJ 350), the class of cement that has been controlled systematically by the laboratories of CRETP. Table 1 shows the results for the Bonaberi and the Figuil factories.

TABLE 1: MECHANICAL CHARACTERISTICS OF CEMENT CPA 325, UNITED REPUBLIC OF CAMEROON

Characteristic	*Days*	*Range (bar)*	*Mean (bar)*	*Coefficient of variation*
		Bonaberi		
Compressive resistance	2	77–252	158	0.22
	7	181–403	281	0.17
	28	259-548	379	0.14
Tensile resistance	2	20–56	35	0.16
	7	34–71	52	0.11
	28	51–82	65	0.08
		Figuil		
Tensile resistance	2	53–224	122	0.27
	7	124–383	251	0.19
	28	52–86	65	0.09

The chemical analysis of the cement CPA 325 (CPJ 350) is shown in table 2. The analyses were carried out in the associated laboratory in Paris, France.

TABLE 2. CHEMICAL ANALYSIS OF CEMENT (CPA 325)

Chemical composition	*Range*	*Mean*	*Standard deviation*
	Bonaberi		
Loss on ignition	1.89–3.89	2.77	0.59
Insolubles	0.14–9.84	2.09	2.14
Total silica	19.03–22.58	21.37	0.86
Iron oxide	1.92–3.28	2.59	0.39
Alumina	4.98–6.80	5.87	0.48
Lime	56.94–64.89	61.72	2.38
Free lime	1.02–2.67	1.75	0.47
Sulphuric anhydride	1.47–3.06	2.31	0.50

Chemical composition	Range	Mean	Standard deviation
	Bonaberi		
Magnesium	0.67–2.45	1.58	0.56
Sodium oxide	0.08–0.42	0.22	0.10
Potassium oxide	0.46–1.00	0.69	0.16
Titanium oxide	0.22–0.56	0.35	0.10
Manganese oxide	0.00–0.10	0.05	0.03
Phosphates	0.00–1.02	0.12	0.22
	Figuil		
Loss on ignition	1.45–4.61	2.77	0.94
Insolubles	0.12–15.95	3.40	3.93
Total silica	19.78–30.97	23.03	2.64
Iron oxide	1.82–2.87	2.42	0.29
Alumina	4.20–6.12	5.26	0.54
Lime	52.07–65.39	61.06	3.01
Free lime	0.37–3.50	1.61	0.87
Sulphuric anhydride	0.57–3.25	1.83	0.70
Magnesium	0.67–2.55	1.27	0.63
Sodium oxide	0.18–6.18	0.56	1.24
Potassium oxide	0.47–1.22	0.64	0.18
Titanium oxide	0.12–0.41	0.29	0.09
Manganese oxide	0.00–0.22	0.11	0.05
Phosphates	0.00–1.85	0.72	0.55

Sand

The wide geographic distribution of building sand in the United Republic of Cameroon accounts for its highly varied characteristics. Table 3 summarizes the characteristics of some sands.

TABLE 3: CHARACTERISTICS OF SANDS IN THE UNITED REPUBLIC OF CAMEROON

Characteristics	Range	Mean	Standard deviation
	Sanaga		
Fineness modulus	2.07–3.95	2.87	0.33
Percentage passing 80 µ	0.00–2.90	0.72	0.76
Sand equivalent			
Visual	75.1–98.0	93.7	3.9
Piston	81.9–96.0	–	–
Specific gravity	2.61–2.71	2.67	0.04
Apparent density, t/m^3	1.36–1.60	1.50	0.04
	Obala		
Fineness modulus	0.90–2.14	1.65	0.33
Percentage passing 80 µ	1.2–23.4	9.66	6.30
Sand equivalent			
Visual	20.2–80.1	42.1	13.8
Piston	–	–	–
Specific gravity	2.60–2.76	2.67	0.03
Apparent density, t/m^3	1.22–1.54	1.40	0.06

TABLE 3. CHARACTERISTICS OF SANDS IN THE UNITED REPUBLIC OF CAMEROON
(Continued)

Characteristics	*Range*	*Mean*	*Standard deviation*
	Mbalmayo		
Fineness modulus	1.72–1.96	1.88	0.14
Percentage passing 80 μ	9.0–11.3	10.2	1.6
Sand equivalent			
Visual	27.2–95	50.6	23.9
Piston	–	–	–
Specific gravity	2.60–2.72	2.66	0.05
Apparent density, t/m^3	1.30–1.50	1.38	0.08
	Abem		
Fineness modulus	1.01–1.80	1.32	0.20
Percentage passing 80 μ	0.1–9.8	3.46	2.41
Sand equivalent			
Visual	51.6–79.9	68.3	7.1
Piston	–	–	–
Specific gravity	–	–	–
Apparent density, t/m^3	–	–	–
	Wouri sand		
Fineness modulus	1.75–4.60	3.13	0.59
Percentage passing 80 μ	1.0–5.0	–	–
Sand equivalent			
Visual	39.0–96.2	77.6	18.8
Piston	37.1–94.0	73.3	18.4
Specific gravity	2.41–2.70	–	–
Apparent density, t/m^3	1.03–1.71	–	–
	Benue sand		
Fineness modulus	1.88–3.71	2.75	0.50
Percentage passing 80 μ	0.7–2.6	–	–
Sand equivalent			
Visual	55.0–96.5	83.5	10.4
Piston	84.5–93.2	–	–
Specific gravity	2.47–2.68	2.60	0.07
Apparent density, t/m^3	1.30–1.57	1.43	0.07

Wouri gravel

Wouri alluvial gravel has variable granulometry which depends upon the producers. Two granulometries are usually used for concrete studies, 0.25/10 and 12.5/25. Generally the percentage passing 5 mm, varies from 5 to 45 per cent. Concrete foundations are recommended to be mixed with the largest gravel sizes possible, after verification of the rod network for the part of the structure concerned. In general, the specific gravity of this gravel varies from 2.555 to 2.67, with an apparent density of 1.49 to 1.615 t/m^3.

Yaoundé gravel

One of the largest quarries for crushed gravel is found in Yaoundé. The quarry produces gravel for highways and concrete works. For concrete works the gravel generally is of the granulometry 5/15 and 15/25. The specific gravity of the gravel is 2.88 to 2.905. The apparent density is 1.50 t/m^3. The Los Angeles Abrasion Coefficient varies from 38 to 42.2. The volumetric coefficient is around 0.18.

Burnt bricks

Very little is known of the mechanical properties of burnt bricks in the United Republic of Cameroon. A study carried out in 1972 by CRETP, for the Department of Construction, produced the following characteristics for bricks manufactured in Nkolbisson near Yaoundé:

Format (cm)	*Weight (kg)*	*Compressive strength (bars)*
15 × 20 × 38 (with holes)	14.4	6.3
10 × 20 × 38 (with holes)	9.1	43.5
3 × 6 × 21	0.72	197.2

A more recent study on a range of burnt bricks produced in the same factory in Nkolbisson, gave the following mean results:

Format (cm)	*Compressive strength (bars)*
10 × 20 × 38 (with perforations)	13.0
15 × 20 × 38 (with holes)	8.0
21 × 20 × 55 (full)	9.5

Cement blocks

No recent systematic study has been carried out on cement blocks. The study on burnt bricks in 1972 for the Department of Construction gave the following results on randomly collected cement blocks from private manufacturers in the Yaoundé area:

Format (cm)	*Mean compressive resistance (bars)*
10 × 20 × 40	10.6
15 × 20 × 40	16.6
10 × 20 × 40	11.0
10 × 20 × 40	7.6

Clay blocks

The Department of Construction also studied ordinary clay blocks and clay stabilized with chopped straw, 28 days old, as follows:

Format (cm)	*Density (tonnes per m^3)*	*Moisture content (per cent)*	*Compressive strength (bars)*
11.5 × 13.5 × 28.5 (ordinary)	1.51	12.0	23.3
11.5 × 13.5 × 28.5 (stabilized)	1.50	10.4	31.5

This shows that clay blocks stabilized with straw gave higher strengths than ordinary bricks. However, the optimum straw content was not studied systematically and requires further research since the compressive strengths seem to be quite high, which raises the possibility of their use in pilot housing projects. It is well understood, however, that different clay soils composed of different mineralogic constituents, may present different results for ordinary or stabilized clay blocks. There is thus a need to carry out a study in order to propose norms for their manufacture and control.

To reach a decision on the technology appropriate for the United Republic of Cameroon, some basic data are needed, and research is leading in this direction.

Current research trends

It is erroneously believed that research is a luxury in a developing country. When a country controls its own research it orients foreign technology to suit its needs and development trends. Technology is thus not simply transferred and implanted, it is modified and adapted to specific needs.

Already, the United Republic of Cameroon has initiated research to develop local building techniques using local materials. The Department of Construction (Buildings) of the Ministry of Equipment and Housing funded a research project carried out by CRETP for preparing a manual on low-cost housing. This manual is not yet finished, but it will illustrate the need of the Government to develop building techniques using local materials.

CRETP, in conjunction with the National Polytechnic School of the University of Yaoundé, has also carried out research to develop building technology using local materials. A summary of the findings from these research projects follows.

Characteristics of concrete with palm nut shells as aggregate

Building costs in the United Republic of Cameron demand a search for cheaper concrete constituents, of local origin to form light-weight concrete.

More than 48,400 t of oil were exported from the United Republic of Cameroon in 1975. In the fourth five-year development plan, oil production is expected to reach 80,000 t/a. The palm nut shells account for about 15 to 40 per cent by weight of the oil produced and thus form an important industrial waste.

The apparent density of cracked palm nut shells varies from 0.56 to 0.66 t/m^3. The real density is 1.33 t/m^3. The nut absorbs water and tends to stabilize after 30 days at a rate varying from 22 to 24 per cent. The behaviour of the nut under the influence of chemical elements show it to be resistant to acid attack. The acid mostly attacks the exterior fibres but does not attack the actual shell. There is thus the need to destroy the tiny fibres on the nut before use to prevent attack by the chemical activity of the setting cement.

Concrete was made using the Dreux method, with natural sand of granulometry 0/1 and 0.2/2.5 and the CPA 275 cement manufactured at Bonaberi. Two mixes were studied. One with cracked shells with granulometry of 2/12.5 and the other with granulometry of 1.25/5. In the case of the concrete with 2/12.5 nuts, mixes with 300, 350, 400 and 450 kg of cement per cubic metre of concrete were studied. The strengths of the first two batches were too low. The strengths of the other two are shown in table 4.

TABLE 4. CONCRETE MIXES WITH CRACKED PALM NUT SHELLS

Cement in batch (kg m^3)	*7 days (bars)*	*14 days (bars)*	*28 days (bars)*
400	26 slump: 0 cm	33	35
	30 slump: 4.3 cm	36	40
	38 slump: 0.8 cm	50	53
450	41 slump: 2.1 cm	44	55

The mortar constituent was later increased (sand raised to 45 per cent and the nuts to 55 per cent by volume). The results are shown in table 5.

TABLE 5: CONCRETE MIXES WITH CRACKED PALM NUT SHELLS

Cement in batch (kg/m^3)	*7 days (bars)*	*14 days (bars)*	*28 days (bars)*
300	10 slump: 5.8 cm	15.0	22.0
450	29 slump: 3.0 cm	37.5	47.0
	40 slump: 6.8 cm	63.0	74.2

The average Young's modulus of elasticity measured using extensometers was 60,000 bars in 28 days.

A micro-concrete was also studied with the same nut shells but with a granulometry of 1.25/5 and natural sand of 0.2/2.5 and 0/1, for a composition of 300 and 350 kg of cement per cubic metre of concrete. The results obtained are shown in table 6.

TABLE 6: CONCRETE MIXES WITH CRACKED PALM NUT SHELLS

Cement in batch (kg/m^3)	*7 days (bars)*	*28 days (bars)*
300	37.0	62.0
	40.0	81.0
	44.0	115.0
350	36.0	87.5
	–	106.0
	–	81.0

Using both mixes, the tensile strength varied from 8 to 13 bars at 7 days, and 10 to 20 bars at 28 days.

In general, the compressive and tensile strengths of the industrial waste material were low. In no case were the nuts themselves sheared or broken during the compressive tests. There is the possibility of poor adhesion between the cement and the nut. The nut is generally smooth at the surface and this probably accounts for the poor compressive and tensile strengths. It is possible to use this lightweight concrete of palm nut shells for structures and buildings, and for elements that support their weight only. There is, however, the need for further research in this area.

Lateritic concrete

This study was carried out as a thesis at the National Polytechnic School of the University of Yaoundé. It was a follow-up to a similar study carried out at the University of Lagos, Nigeria.

More than 70 per cent of the land surface area of the United Republic of Cameroon is covered with lateritic material. The need to exploit this cheap material for the building industry is obvious.

Lateritic concrete is a mixture of lateritic gravel, sand, cement and water to the extent that its mechanical characteristics approach those of classic concrete. The laterite used in the study came from the Yaoudé area.

The material is sieved and fractioned 0/3, 3/15 and 15/25. The Dreux mix method was used and the lateritic concrete was composed of the following constituents: cement (350 kg/m^3), Sanaga sand, lateritic gravel 5/15, and water.

A total of 14 test samples were prepared and the following results were obtained:

Mean 28 days compressive resistance: 240 bars
Range: 226–263 bars
Variance: 9.42 bars
Coefficient of variation: 40 per cent

These results were compared with the results of classic concrete using crushed gravel and with similar proportions of cement. The following results were obtained:

Type of concrete	σ_3/σ_{28}	σ_7/σ_{28}	σ_{14}/σ_{28}	σ_{21}/σ_{28}
Concrete of reference	0.48	0.69	0.81	0.92
Lateritic concrete	0.50	0.70	0.83	0.93

These results show that the evolution in strength of lateritic concrete is similar to that of classic concrete.

Another aspect studied was the variation in strength as a function of the proportion of cement. The results shown in table 7 were obtained:

TABLE 7: STRENGTH OF LATERITIC CONCRETE AS A FUNCTION OF CEMENT CONTENT

Proportion of cement (kg/m^3)	*Compressive resistance (bars)* σ_3	σ_7	σ_{14}	σ_{21}	σ_{28}
300	105	145	180	–	225
350	120	170	200	225	242
400	130	180	220	–	260

An increase in cement content thus increases the concrete resistance just as in the case of classic concrete.

The tensile strength of this lateritic concrete was also studied. The mean of 28 days tensile strength is 17.56 bars. The relation between the tensile strength (T_{28}) and the compressive strength is expressed in the formula $T_{28} = 14.56 + 0.013\ \sigma_{28}$.

For classic concrete the French recommendations propose $T_{28} = 7 + 0.06\ \sigma_{28}$.

The adherence of lateritic concrete to reinforcement bars was also investigated with the following results:

Type of rod	*Mean adherence resistance (bars)*
Smooth reinforcement bars	23.60
High performance reinforced bars	41.33

The price of transplanted technology is too high to be paid by a developing country. Technology needs to be adapted with a view to general reduction of costs. In the building industry in the United Republic of Cameroon there is a tendency for modern buildings to be made of foreign raw and primary materials–even though some of these materials are available locally–they are still processed using techniques available in advanced countries. The average modern building thus becomes exhorbitantly expensive.

Since the available scientific data is scanty, Governments should build pilot housing projects with locally available building materials, and technologically advanced countries should help to sponsor projects whereby innovative manufacturing processes for building materials are adapted to local materials in developing countries.

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Construction and building materials industry in Nepal

*P. B. Singh Tuladhar**

Nepal had a population of 11.3 million in 1971. Its annual demographic growth rate is 2.3 per cent, and the population should reach 16 million within the next decade.

About 94 per cent of Nepal's economically active population is engaged in agriculture and allied activities, which contributes over 66 per cent of the country's GDP. Only 0.1 per cent of the population is employed in the construction industry, where qualified technicians and skilled workers are few.

Status of the construction industry

Himalayan region

In the extreme climate and hostile topography of the Himalayan region, the houses in the settlements are mostly clustered in terraces. The houses themselves are one-storey or two-storeyed, depending upon the slope and location of the building site. The main problems of construction are the lack of building materials and the shortage of unskilled workers. The only building material easily available in the region is stone. A serious problem is the lack of a suitable binder, without which a massive structure cannot be built. Walls, made of stone and mud mortar, are not suitable for many openings and as a result rooms are usually dark. In the case of multi-storey buildings, stones are used only up to the ground floor level, and wood is used for the rest of the construction. The roof is covered with shingle made locally. Roofs are often composed of stones and are flat, which provides a much needed sunny terrace to the next row of houses above. In this region more than 90 per cent of the houses need constant repairs to walls, roofs and terraces.

Hill regions

Hill settlements have more choice in building materials. Houses are usually loosely scattered along hill slopes, on hilltops, in flat valleys or along ledges, as the terrain allows. Most traditional houses are two-storeyed, with walls of stone and mud mortar, and roofs of local slate or in some cases, thatch. In a few places, burnt bricks have been extensively used for walls, together with red clay tiles.

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*Architect, Department of Housing, Building and Physical Planning, Ministry of Public Works and Transport, Nepal.

In these areas, more than 50 per cent of dwellings have thatched roofs which have to be repaired frequently. Similarly, there is a need to repair walls, beams, flooring and several other components. These repairs are due to poor housing construction resulting from lack of skill. It is customary for families to be involved in their own house construction. The major factor in the substandard construction is the population's inability to afford better building materials.

Tarai region

In the southern plain, the houses are generally somewhat flimsy because of the use of primitive building materials. The standard rural houses have bamboo walls which are plastered with mud mixed with cow dung. The roofs are mostly thatched and a few are tiled. Houses are usually built in a cluster near a river or stream because of the lack of public utilities, with the result that dampness is a great problem. The use of organic building materials for roofing means more than 60 per cent need constant repair

Technological aspects in construction

Construction problems in rural areas

In rural areas almost every family has to build and maintain its own dwelling because of insufficient skilled labour and shortage of money to hire any available skilled workers. There are still no institutions to provide housing loans, construction aid, technical guidance etc. and therefore it is necessary for a householder to have ready money and labour available to build a house.

The low level of living does not permit popular methods of improving housing. Therefore an ingenious method is needed to organize cheap village manpower resources and cash. As an experiment, a small 10-unit self-help housing project launched at Surkhet district in far western Nepal has successfully demonstrated the feasibility of combining local materials, local manpower and outside technical help to a desired end. Local development departments should start similar rural-scale housing construction projects.

Wide use of locally processed materials such as stone, timber, slate, bamboo, thatch etc., reduces the price of housing. Whatever technical knowledge a householder may lack is compensated for by the size of the labour force it can afford to mobilize for the construction of the house. Improvement of existing housing can only be introduced if external sources of cash are provided. At present home builders are expected to select suitable land, collect materials, arrange labour and finance the building costs.

To deal with the problems of developing the building industry in rural areas of Nepal, it will be necessary to introduce new areas of experience, using appropriate technology for construction based mainly on the locally available materials and skills. One should not forget the time factor, which influences the choice of methods. However, the possibilities of standardization and modular systems should be carefully considered. In this connection training needs can be minimized by simplifying production processes and concentrating on improved traditional construction methods.

Construction problems in urban areas

In most urban areas burnt bricks and stone are the two most frequently used materials for walls. Roofs are nearly always slate or clay tiles. Recently, reinforced cement concrete and reinforced brick concrete slabs are often used to roof the houses.

Generally, the existing houses have defective foundations, walls and roofs. Houses concentrated in the centre of valleys are usually affected by dampness. Householders can neither afford damp-proof materials nor do they know how to use them properly. Foundations and plinths are not damp-proofed. The main defect in foundations is the incorrect use of binding materials, such as mud mortar. Moisture penetrates dwellings even where the walls are made of bricks with cement or lime mortar.

Houses are constructed with burnt brick walls, to half of which mud mortar is applied and cement or lime mortar to the other half. Dwellings with mud mortar have asbestos or tin roofs, the others have a tiled reinforced cement concrete or a reinforced brick concrete roofing structure. All building structures including doors, windows, stairs and roofing are prepared on the building sites. Often some experienced workers do the carpentry work and the masonry. In most cases, the householders themselves supervise the construction work, because an ordinary family cannot afford to hire an architect or an engineer.

Building materials are scarce and it is very difficult for the private sector to obtain good bricks. Housing construction can only be developed if the required building materials are sufficient and a proper share of what is available is allocated to this sector. The scarcity of building materials and the annual increase of 10–20 per cent in the cost of building materials such as good quality bricks, cement, timber, roofing materials etc., are the two main constraints to improving housing construction in Nepal. The use of improved local materials and traditional construction methods should therefore be applied as far as possible. Provision of requisite building materials alone will go a long way towards solving the housing problem.

Of the existing houses in urban areas, 69 per cent are permanent, 11 per cent semi-permanent and 20 per cent temporary. Permanent houses are those made of stone, burnt brick or wood set in mud, cement lime, or brick dust mortar, with roofs of slate, tile, reinforced cement concrete or reinforced brick concrete. Temporary houses are those made of sun-dried bricks with a thatched roof and semi-permanent houses are those with either the walls or the roofs made of a permanent material.

It is very difficult to generalize about the cost of building on a national scale because of basic differences in topography, accessibility to markets, availability of standard materials and requirements. However, it can be roughly estimated that, excluding the cost of development and land, the construction of a standard housing unit with an area of about 100 m^2 would normally cost not more than $5,000–$6,000 at the present price using current technology, which exceeds the average annual income of a houshold by more than three times. This means that more than 90 per cent of households in urban areas cannot afford a house of a normal standard.

It is apparent that the dimension of the building construction problem in urban areas is quite different from that existing in rural areas. In urban areas the problem becomes conspicuous because of the sheer concentration of population, whereas in rural areas it is more hidden. Moreover, due to the concentration of resources in selected urban areas the rural housing construction problem is magnified, since the rural environment does not have the basic infrastructure for succesfully launching housing improvement programmes. During the current fifth national plan period, a housing agency is expected to be established to promote housing construction activities in the urban areas. Various financial institutions have shown their interest in house construction programmes by providing loans, at least for employees, at low rates of interest.

Building materials industry and the problems of supply

The use of building materials is quite different in rural and in urban areas. Generally there is a difference in their application in construction. Without an infrastructure, prices of building materials vary significantly from place to place.

Building materials used in rural areas

Most of the building materials used in rural areas are local. No systematic survey of building materials resources has so far been made. The traditional building materials in the rural areas are earth and stone, with their allied products, as well as timber and other forest products.

Earth and its allied products

In this group the main materials used in building construction are earth, bricks, roofing and floor tiles.

In rural areas, earth is abundantly used as a building material, because it is readily available. Earth is used especially as mortar for masonry work with stone or bricks; to make sun-dried as well as burnt bricks; to make roofing tiles like *zhingati;* as a filling material in bamboo walls, mud-and-daub walls and ceilings and floors. For plastering walls, ceilings or floors, the earth is generally mixed with cow dung and rice husk.

Sun-dried bricks are extensively used for walls as well as for foundation and floor flooring. Locally burnt bricks are used only by comparatively affluent families in rural areas. Burnt bricks are used for foundations, structural walls, partition walls, flooring, pavement of courtyards, and so on. They are also used to make brick-powder, which is mixed with lime to make mortar. This mortar is used as a binder for brickwork and stonework in place of cement, which is not available. In this category there are other products such as *telia* bricks and roofing tiles. *Telia* bricks are made from earth. They differ in that their surfaces are oiled before they are burnt in a kiln. They have more stability and strength and are stronger than ordinary bricks although they are only 2.5 cm thick. They are extensively used for paving floors, corridors, staircases, terraces, courtyards etc. These bricks are quite popular and are mostly produced in the rural areas of the Kathmandu valley.

Roofing tiles, the best materials for roof covering, are very cheap and popular, but because of their high maintenance cost, they are now being replaced by corrugated galvanized-iron sheets. *Zhingati* roofing tiles, popular in the Kathmandu Valley, are used in a special way: They are laid on the roofs over a layer of mud. The mud layer ensures airtightness but is heavy. Hardly any research is being conducted on improving the traditional method of production or on the use of these tiles.

Stone and allied products

The main building materials used in construction are stone blocks for load bearing structures, stone slabs for pavements, slates for roofing, crushed stone, and lime.

In the hilly regions, especially on the northern mountain slopes where the soil is too rough to make into materials such as bricks, stone is the only building material. In many parts of the country, except the Tarai region, stone is easily available. Masonry is constructed with mud or lime mortar, but where neither is available, particularly in the extreme Himalayan region, the walls are constructed without binders. The shearing stress is then borne by the horizontal beams set in the walls one metre apart, which makes a good facade.

Nepal is rich in different types of stone such as limestone, marble, granite. Stone slabs suitable for paving porches, ground floors, terraces, courtyards etc. are abundant but stone slabs are difficult and costly to transport. In order to develop technology for the processing and use of stone slabs, qualified technicians, machines, transport and power are needed.

Slate is very popular as a roofing material in parts of western Nepal, particularly in the hilly region. However it is used less frequently than corrugated galvanized-iron sheet. Locally quarried slate is not always available.

Crushed stone is used as stone chips to make cement concrete. Its use is limited, however, to important public buildings, since production and transport factors make cement too costly for most of the rural population.

Limestone can be found in different parts of Nepal. Lime is one of the oldest and cheapest binding materials and can be produced locally on a small scale almost everywhere. Yet lime manufacture is not developed, due to the lack of technical know-how, machinery, and transport. However, the current five year plan emphasizes developing and improving the lime manufacturing process and encouraging the use of lime instead of cement.

Timber and other forest products

Timber, bamboo and thatch form the main building materials.

The climate varies from region to region depending on the topography and altitude of the land. Almost every type of climate can be found in Nepal:

	Elevation (m)
Tropical monsoon	1,200
Warm temperate monsoon	1,200–2,100
Cool temperate	2,100–3,300
Alpine	3,300–5,000
Tundra	5,000

Accordingly, forest resources can be classified into tropical evergreen forests, deciduous monsoon forests and evergreen coniferous forests. The largest concentration of forest is in south Nepal where the relatively better transport facilities enhance their commercial importance. About one third of Nepal is covered by forest, although probably only 31,000 km^2 is commercially exploitable, the rest being shrub. The principal forest species in Nepal are deodar, fir, juniper, Sal (*Shorea robusta*), sisso (*Dalbergia sisso*) and simal (silk cotton). Sal is one of the most important timbers, both for the domestic and export markets. The relative amount of the various kinds of forest is as follows (percentage):

Deciduous oak	45.7
Sal (Tarai)	20.0
Old Riverian	6.9
New Riverian	4.6
Softwood coniferous	11.4
Other	11.4
Total	100.0

Timber is a common construction material in Nepal. It is also used for doors, windows, staircases, flooring, roofing, and wall panels as well as for structural members such as columns, beams and trusses. The use of timber in ancient palaces, residential buildings and temples illustrates the ingenious use of wood for building construction. But its use has not developed since ancient times. In most cases, evergreen timber is used for construction. Therefore drying and warping takes place in timber structures.

The Department of Housing, Building and Physical Planning produced some typical timber structures using modern technical design intended for public buildings in rural areas. But these have not been used due to lack of skilled manpower. Therefore, particularly in the remote areas, the utilization of timber is still substandard and wasteful.

Bamboo, and its many varieties, is an important building material in south Nepal and is extensively used instead of timber in rural areas. Its strength and durability depends upon its maturity: for construction purposes bamboo takes about three years to mature and is used only for permanent buildings. Where there is a shortage of timber, bamboo is generally used in less important buildings. Bamboo is used for thatching rafters and split bamboo as wall partitioning; it can be used as flooring instead of planks, as a spanning member and runner, for posts and joists, for scaffolding and temporary support works etc. Different bamboo products are also used as fixtures and fittings. Skilled labour for traditional construction styles is available in almost all parts of the country.

Thatch is widely used as a roofing material in the hills because it is cheap, popular, and as the most readily available local material it can be collected in winter when people are unemployed. The life of a thatched roof depends upon the type of dried straw used and its application; even the best quality thatch lasts only 12 years.

Building materials used in urban areas

Urban dwellings are usually made of clay brick, stone or concrete. The building materials used can be divided into local and imported materials, both of which are used for permanent buildings.

Local building materials

The main local materials are mud, sand, *surkhi*, stone, bricks, roofing and flooring tiles and timber. There are many other allied earth and stone products and forest products which are still used in the city outskirts. Mud mortar with brick or stonework is still used in urban housing. The use of mud is similar to its use in rural areas. River beds and tributaries are the main sources of sand which seems to be available in a sufficient quantity and quality. Brick bats are traditionally used as *surkhi*, a component of lime concrete and lime mortar. Its production is declining steadily as cement mortar replaces lime mortar and lime concrete is replaced by cement concrete. No systematic effort has been made to use this local material or to encourage its use. Stone is used for making foundations and walls; in Pokharia, for example, the housing survey reveals that almost all the houses (93.9 per cent) have stone walls.

Bricks

The quality of mass produced bricks is substandard except for those from the Harisiddni brick and tile factory. In the whole country there is only one factory, the Nepal Brick and Tile Factory established in 1967, and which produced only 14 million bricks and tiles during the first nine months of its operation.

The following table gives a rough idea of the annual brick production in the Kathmandu valley:

Means of production	*Number*	*Production (millions)*
Brick and tile factory	1	25
Continuous type kilns	33	132
Intermittent type kilns	150	45

The total number of bricks, 202 million, produced in the Kathmandu valley every year is not sufficient. There is a great demand for bricks produced by the factory but these are very difficult for the general public to obtain. The brick and tile factory also produces about 500,000 each of red clay floor and roofing tiles annually. The quality of the factory products is better and stronger than that of traditional bricks and tiles. Another brick factory is scheduled to go into production during the current five-year plan period.

Timber

Most of the Kathmandu valley's timber supply comes from the Tarai, but due to the lack of adequate processing facilities and transport, other cities in Nepal are not provided with timber.

Although there is an abundance of timber, it is not easy to obtain. Timber is distributed in the Kathmandu valley by the Timber Corporation (a government enterprise) and other entrerprises. Timber sold by the Timber Corporation is half the price of that sold by other enterprises which is probably why it usually takes months to obtain supplies whereas it is readily available from private firms. As previously mentioned timber is not seasoned and therefore a good deal of drying and warping occurs in timber structures. Other wood products such as plywood, blockboards, hardboards are not yet produced on a commercial scale. There are a few small plywood and bobbin factories in Tarai, but their products are only suitable for packaging. One factory in Butawal is now trying to produce plywood for building.

Several other sawmills have been installed at various centres located in Tarai and in the inner Tarai areas. Most of the timber produced is exported to India and provides an important source of Indian currency.

Imported building materials

Because local building materials are insufficient to meet the needs of the building industry, people have to depend on imported building materials which constitute a major portion of the country's total imports. The main items of such imports are:

(a) Non-metallic products: cement, clay products, asbestos-cement products, cement products including pipes, prefabricated units, flat-glass products;

(b) Wood-based building products: plywood, board products;

(c) Metal building materials and components: iron and steel products, bars, rods, light and heavy sections, sheets and plates, tubes and pipes etc., non-ferrous metal products, aluminium sheets and pipes, tin sheets, lead and zinc pipes etc., finished structural parts made of various metals;

(d) Building fittings and fixtures: heating fixtures, sanitary ware of various materials, metals, fittings and fixtures, lighting fixtures and fittings.

Nepal has one cement plant of 160 t/d capacity which only meets 20 per cent of the demand now estimated at 195,000 t/a. The establishment of a second 170,000 t/a cement plant has been planned.

Nepals's Department of Housing, Building and Physical Planning has recently established a Building Materials Research Unit. Plans for the decentralization of construction through a programme of scattered micro building industries are being launched, which it is hoped will lead to an extension of appropriate technologies for building materials and construction practices.

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Appropriate technology in the construction and building materials industry

G. Sebestyén[*]

INTRODUCTION

The Lima Declaration and Plan of Action adopted by the Second General Conference of UNIDO in March 1975 calls for an increase in the share of developing countries in total world industrial production to 25 per cent by the year 2000. This target will not be achieved without a substantial increase in the output of the construction industry. Since the use of appropriate technologies is one of the principal means of improving the efficiency of a productive sector, this paper will concentrate on the problem of appropriate technologies in the construction and building materials industry.

The study is divided into three sections. The first section describes the main features of the construction and building materials industry and summarizes the important role played by this sector in the national economy.

The second section deals with the trends of economic and technical development in the construction and building materials industry and discusses the appropriate technologies for different processes.

The third section is devoted to government policy and international action designed to promote the industrialization of construction and the use of appropriate technologies in the construction and building materials industry.

I. THE CONSTRUCTION AND BUILDING MATERIALS INDUSTRY

Background

The traditional construction and building materials industry has the following features:

(a) In the mining and manufacturing industries, production is permanently located and the product has to be transported to the place of consumption. In

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[*] Director, Building Research Institute, Budapest, Hungary.

construction, production takes place at the place of consumption; the finished product is immobile;

(b) The product is not standardized. It has to be designed and produced in each case according to particular requirements and circumstances;

(c) Buildings have subsoil foundations and are affected by natural forces (wind, rain, sunshine, ground water, seismic forces etc.). Construction techniques and architectural design also depend on the raw materials available and on historic development and habits. Since these factors differ at different locations, the standardization of buildings as products of construction activity is hampered;

(d) For centuries or even thousands of years, procuring building materials has meant extracting materials from nature, e.g. stone, timber and clay, and perhaps one stage of transformation of these raw materials, e.g. the burning of bricks, lime, gypsum, sawing of timber etc. In many cases the cost to volume ratio is low, and the building materials (stone, bricks etc.) are bulky and heavy. High transport costs prevent the transport of such materials over great distances;

(e) Foreign trade in building materials is insignificant, but designers, builders and artisans travel from one country to another to build prestige works such as churches and palaces;

(f) Although the production of building materials has been insufficient in developing countries, it has gradually reached a very high level in developed countries. As a result, foreign trade in building materials started to grow in recent years, with developed countries exporting to developing countries. Statistics for 1960 show that Africa had to import a total of 58 per cent of its building materials, including 100 per cent of its glass consumption, 60 per cent of paints and varnishes, 50 per cent of bricks, tiles and ceramics, 33 per cent of cement, and 33 per cent of sawn wood and wood products. A similar picture could be drawn of other developing regions;

(g) This situation has arisen from the high degree of concentration of production of building materials in developed countries. In 1966/67, Europe, the Union of Soviet Socialist Republics and the United States of America, accounted for 72 per cent of the world's cement production. As regards wood products, their share was 83 per cent of sawn softwood, 79 per cent of plywood, 85 per cent of fibreboard and 92 per cent of particle board;

(h) Buildings are expensive products with long production and life (use) cycles;

(i) Construction characteristics have resulted in a lack of central organization and concentration and traditional, medieval forms of organization have long survived. There are many small construction enterprises working for only a limited area and with a small annual turnover;

(j) Construction processes are very labour-consuming, and many unskilled workers are required in addition to artisans;

(k) In construction, the capital outlay for machines and equipment is lower than in manufacturing industries, and management techniques have hardly been affected by the industrial revolution;

(l) The design of the products (buildings) is not (as in the manufacturing industries) a prerogative of the producer. On the contrary, design is usually carried out by designers (architects, civil engineers and others) independent of construction firms.

Some of the features new to the construction and building materials industry in developing countries are as follows:

(a) In developing countries, the traditional small-scale construction sector was unable to satisfy all needs. This led to the emergence of new national and international firms active on a larger scale in the market. National firms may adopt conventional or modern production techniques; international firms usually introduce modern techniques. A gradual, often very slow, concentration of firms is taking place even in developed countries. A certain degree of concentration is required to ensure a sufficient accumulation of capital to enable firms to make the necessary investments in up-to-date production techniques (purchase of powerful building machines etc.);

(b) Value added by construction represents 2–10 per cent of the gross domestic product (GDP). For most developing countries it represents 3–5 per cent, and for most developed countries, 5–9 per cent;

(c) The volume of construction activity during the past decade increased considerably in several developing countries;

(d) The range of building materials has been considerably extended. Traditionally, the building materials industry covered only the extraction and production of stone, clay, sand, gravel, cement, lime, gypsum, glass, bricks and tiles. At a later stage, the production of building components (prefabricated concrete and reinforced concrete components, doors, windows, building equipment etc.) has been introduced. The manufacture of products from materials mainly applied by industries other than construction steel, aluminium, plastics etc.) is usually not considered to be an activity of the building materials industry;

(e) During the past 10 years, several developing countries have successfully increased their production of cement and prefabricated concrete components. Many other materials still have to be imported;

(f) Some developing countries not previously active in the export field (India, Republic of Korea, Yugoslavia) have made successful efforts to win construction contracts abroad, e.g. in Arab countries.

All this has resulted in increased foreign trade in building design and construction, civil engineering works and building materials. Several factors, notably foreign technical co-operation arrangements, have contributed to a strengthening of the domestic construction industry even in countries that import construction capacity.

Formerly, the construction and building materials industry was not regarded as an economic sector to be developed on a high-priority basis. For a number of years this situation has been changing, and it is now generally accepted that its development is of crucial importance to developing countries. Some of the reasons for this new position are outlined below.

Role and importance of the industry

Let us take two imaginary countries A and B, the first developed, the second developing, and look at the following hypothetical (but very realistic) figures:

	Country		*Ratio*
	A	*B*	*A : B*
GDP (dollars *per capita*)	5 000	250	20 : 1
Value added by construction (per cent)	10	4	5 : 2
Value added by construction (dollars *per capita*)	500	10	50 : 1

Obviously country A already has infrastructure, a built-up environment and a high-level stock of buildings; in country B these are yet to be created. The need for new construction is therefore higher in country B than in country A. However, the actual volume of construction is much lower, and the ratio of volumes of construction is higher than that of GDP. This means that the gap between the two countries is widening instead of being reduced. It is true that some types of buildings (new housing) are cheaper in developing than in developed countries. However, the costs of major civil engineering works and industrial buildings are on the same level. Hence, to close the gap between the volumes of building stock, developing countries must substantially increase construction activity.

This means that construction (including in this case the building materials industry) should be a sector of dynamic development, with a growth rate exceeding that of the whole economy (i.e. the growth of GDP). Sectors having dynamic growth rates usually need government attention; this especially applies to construction for reasons given in the following paragraphs.

Construction accounts for approximately half of all fixed capital investments, and new construction is required for most development projects. In particular, new manufacturing facilities and new housing must be constructed to ensure the development of industrial production and to overcome the housing shortage.

The shortage of building materials and the lack of an adequate transport system (roads, railway lines, harbours, airports etc.) have often been an obstacle to the expansion of construction. Therefore the construction of roads, bridges, railway lines, harbours and facilities for the building materials industry is an important step towards increasing construction output itself.

A well-balanced increase in construction output helps to satisfy the needs of the population, because it improves the housing situation, creates new jobs in new factories, reduces unemployment and promotes further building activity.

Construction is a labour-intensive activity. As such, assuming a given fixed capital outlay, it employs comparatively more workers than other economic sectors. The construction industry also has a mission to fulfil, owing to the fact that many workers come from rural areas, for whom the construction site is the first organized working place. Many of these workers leave construction after a certain period to become employed by other industries. Thus, construction has in a sense a training and educational role in the overall industrialization process of a country.

The construction sector involves many different types of workers (masons, carpenters, plumbers, painters etc), and enterprises, and is a purchaser of the products of many other industries (steel, aluminium, plastics etc.). The growth of the construction industry therefore has widespread positive effects, whereas a slump in construction has far-reaching negative consequences.

The public sector's demand for construction is high and government intervention has become necessary in many fields. Public buildings, schools, hospitals, roads and airports are directly financed and contracted by central, regional or public authorities. With regard to new housing, public authorities also play an active role. Government policy in increasing or reducing construction works expenditure strongly inflences the economic climate in the construction and building materials industry.

Construction is both a concentrated and a small-scale activity. Central government or large, private industrial projects are carried out through the concentrated efforts of the construction industry; local development projects are the result of small-scale construction activities. Hence the construction industry takes an equal share in major central development projects and in furthering local development aspirations, including self-help in the non-monetary sector.

II. ECONOMIC DEVELOPMENT, INDUSTRIALIZATION AND APPROPRIATE TECHNOLOGIES IN THE CONSTRUCTION AND BUILDING MATERIALS INDUSTRY

Economic and structural changes

According to the situation of the construction and building materials industry, developing countries belong to the following three categories: countries with high government income; newly industrializing countries with construction export aspirations; and other developing countrries with different levels of GDP.

Most members of the Organization of Petroleum Exporting Countries belong to the first category. In these countries, expenditure on construction has increased rapidly and a flattening of the growth curve (at a high level of construction activity) is taking place. Extremely quick growth has been achieved by inviting foreign firms to carry out major works and by employing foreign workers to increase the domestic labour supply. Different measures have been taken to protect and promote the domestic construction industry, and in some countries a partnership of foreign and domestic firms is required or preferred.

The domestic construction industries in some newly industrializing countries have reached a high degree of development within a short period of time, and now these countries are bidding for construction contracts abroad.

In the first two categories (and even more so in the third) domestic architectural and engineering designers lack sufficient capacity and experience to solve all design problems. Design and consulting offices of developed countries are invited to fill the gaps.

The third category includes countries with very different levels of GDP: on the one (lower) end perhaps embracing the Sahel countries and on the other (nigher) end some Latin American countries (e.g. Brazil). In countries with a low GDP *per capita*, construction and the building materials industry still face the problems that were common for most developing countries a decade ago. In countries where the GDP *per capita* has grown quickly over the past 10 years, both construction and the building materials industry have developed quite remarkably.

In the past decade in most developing countries government departments (ministries) and agencies have been established to supervise industry (including the building materials, and perhaps also the construction, industry) and industrial development; housing and urban development; and the protection of the environment.

Governments have made considerable efforts to educate and train the present and future staff of these public bodies and to introduce modern methods of planning, programming and supervision in these fields.

It has often been stated that inadequate banking and financing facilities hamper the flow of funds (savings) into construction and slow down the growth of fixed capital formation, and hence of the construction industry. Again it can be stated that during the past 10 years in certain countries spectacular progress has also been achieved in this field; in others the situation still remains unsatisfactory.

Foreign trade also presents some new features in addition to the traditional ones. In many developing countries the production of cement and other building materials has substantially increased. However, foreign trade in building materials is still a major source of supply, and companies in developed countries have often established subsidiaries to carry out construction projects in developing countries.

The introduction of building systems in developed countries has led to a new form of foreign trade. In system building the whole structure is lightweight, and therefore components of complex integrated buildings can be shipped from one country to another.

The process of industrialization and the use of appropriate technology

The industrialization process in developed countries cannot simply be copied in developing countries, though for the modern (both domestic and international) subsector it could be a basis for the choice of appropriate technologies.

In the traditional domestic subsector, appropriate technology has a different meaning. Here the decisive factors are small scale, capital investment and the maximum use of domestic (local) resources. Technical solutions applied in developed countries often lead to inappropriate technologies for the small-scale domestic industry. Therefore other solutions have to be invented or existing ones adapted to local circumstances.

The tasks of the construction industry are different enough to call for very different technologies. Major industrial development projects, for example, require modern industrial methods; big urban agglomerations (there are many of them in developing countries: Bombay, Buenos Aires, Cairo, Calcutta, Mexico City, São Paulo and Seoul to mention only a few) call partly for new industrialized housing, commercial and other buildings, and partly for low-cost housing; small settlements and industrial development projects require simple but improved construction technologies using local raw materials and skills.

Hence there is not just one appropriate technology for one product. On the contrary, several technologies can be considered to be the most appropriate at the same time, depending on the scale of operations and other factors.

The selection of appropriate technologies depends on factors changing with time. The relation between the prices of various materials, labour, machines and other input factors changes, and this changes the cost (price) relation of different technologies.

Based on the experience of developed countries the main fields of industrialization in the construction sector are the following: prefabrication, mechanization, introduction of research into the building process, changing pattern in the production and use of building materials and components, new design methods and standardization, changes in the manpower employed and up-to-date management methods. The same holds true for developing countries, despite certain important differences.

The main objectives of the development of the industrialization process are as follows: to increase the productivity of labour; to increase the output of the construction industry; to make good use of local resources, including local raw materials, and agricultural and industrial wastes; to reduce the weight of the building structure and as a complementary objective to decrease the volume of materials to be transported in relation to the building volume; and to transfer as many processes as possible from the changing building sites to off-site factories.

In developed countries much effort is devoted to energy conservation, a problem of less importance as yet in many developing countries.

It has often been stated that prefabrication has always been part of construction. The Japanese tatamis and the stones pre-cut to standardized dimensions are just two forms of prefabrication. However, prefabrication in our age has a new, previously unknown feature: it is based on modern mechanized processes.

Since the first buildings were erected, they have been either heavyweight or lightweight. To the first category belong stone, clay, bricks, concrete, to the second timber and fabrics. Mechanized manufacturing methods have been introduced in both categories, and the prefabrication of both heavyweight and light-weight components is part of the industrialization process.

A wide variety of prefabricated (reinforced) concrete products exists: masonry blocks, beams, lintels, paving stones, curbs, flooring tiles, fences, railway sleepers, street lampposts, large wall and floor panels, stairs and staircase components, components for frames, retaining walls, pipes, bridge components etc. In many developing countries factories have been established for these products. A further development of prefabricated (reinforced) concrete components can be expected, which will require higher cement production. Pre-stressed concrete products are also finding growing applications.

A controversial aspect of prefabrication concerns the production and use of large reinforced concrete panels. In Europe (both Eastern and Western) this has been a revolutionary new housing technique introduced after the Second World

War The highest outputs have been reached in the Union of Soviet Socialist Republics and other socialist countries of Eastern Europe, where large panel construction became the basic means of reducing or eliminating severe housing shortages. The main advantage of this technique has been the high productivity of labour. practically the same number of workers produce twice as many flats.

Large panel construction in developing countries has acquired some special characteristics. In a hot climate external walls usually do not contain thermal insulation but consist merely of a single layer of reinforced concrete. Factory buildings do not require heating (as they do in Europe), and can therefore be of very simple structure. Large panel construction also leads to positive changes in developing countries with regard to the productivity of labour and new housing output. Moreover, in developing countries special care has to be taken to avoid the monotonous unimaginative appearance of buildings and residential areas; the successful realization of many projects proves this to be attainable. Large panel construction techniques seem to be a useful method of providing new housing in developing countries mainly for a high density urban population with a severe housing shortage. On the other hand, it cannot be regarded as the only means of industrialization; many other means also produce positive economic results.

Prefabrication and the serial industrial production of building components other than those of reinforced concrete–form part of the overall industrialization process. Some of the components that can and should be industrially produced are doors, windows, partitions etc.

The introduction of prefabrication, mainly that of large pre-cast concrete panels, may produce certain conflicts. Building designers consider that the use of large panels restricts the design process. Designers at least during a transition period–would prefer techniques that facilitate an individual approach for each building. Component manufacturers, on the other hand, prefer to produce standardized components in large quantities. The preferences of the designer therefore conflict with those of the component manufacturers. However, through mutual understanding a satisfactory compromise can be reached. Governments should actively support the introduction of industrially made building components, thereby eliminating conflicts between participants in the construction process and speeding up the development of prefabrication. Appropriate technologies for small-scale production using local materials have been introduced in many countries.

Asbestos cement products, mainly pipes and corrugated roofing components, are also of paramount importance for many developing countries. Several developing countries have already started to manufacture asbestos cement products, though often with low outputs using machinery that is not sufficiently up-to-date. Owing to the good technical properties of asbestos cement (impact resistance/resistance against atmospheric and bio-corrosion), the development of this industry should be supported.

Mechanization plays an essential role in industrialization and in many construction processes that must be carried out at the building site, such as the construction of roads and railway lines, and finishing processes within buildings, partial prefabrication, for example the painting of doors and windows in the workshop, is preferred. Building machines have the following uses:

earth-moving, construction of roads, railways, bridges, dams, foundations; mixing, compacting and curing of concrete; horizontal and vertical transport of materials and components; hand-operated processes (painting etc.); and the manufacture of building components.

The manufacture of building machines requires a certain overall experience in machine building, existing production facilities for crucial parts (electric and diesel engines, ball bearings, pneumatic parts, wire cables, steel castings etc.) and a market of sufficient size for such machines. Most developing countries do not meet all these requirements, and therefore have no building machines industry. In the near future, they will probably be able to establish only a few factories to manufacture a small range of building machines. Some simple building machines (hoists, conveyor belts etc.) on the other hand can be and are produced in many developing countries.

In India, for example, facilities have been created for the production of big construction machines, such as road rollers, hot-mix plants, paver finishers, stone crushers, pre-stressed concrete equipment, concrete vibrators, air compressors, excavators, motor scrapers, dozers, motor graders, earth compacting machines, building cranes, dump cars, mixers, conveyors etc.

For the small-scale domestic industry, small machines are economical and appropriate technologies can be implemented with simple low-cost equipment. In this category simple scaffolds, hoists, mixers, presses etc. may be mentioned.

The need to ensure the continuous operation of building machines is often overlooked. Because of the lack of spare parts or adequate maintenance, machines are left standing. Therefore, whenever building machinery is acquired from abroad, spare parts and maintenance and repair facilities should be provided.

The number and variety of building machines used in industrialized construction is so large that highly organized maintenance and repair shops equipped like machine factories are required. When such maintenance and repair shops are built, promoters of industrialization are often tempted to convert them into machine-building factories, although the maintenance and repair of building machinery could suffer as a result. Without attempting to dissuade any country from producing building machines, top priority must be given to good maintenance and repair of the existing stock.

In view of the major importance of mechanization and of the high cost of machinery, which if owned by one contractor may be idle for long periods due to lack of continuity of operations, the establishment of equipment and plant hire services should be promoted.

A changing pattern in the production and use of building materials and components may be a major factor in industrializing of construction. Some general trends in this changing pattern are as follows:

(a) The overall cost of building materials and components expressed in percentages of construction costs tends to grow as a consequence of moving on-site processes to off-site factories (prefabrication);

(b) The proportion of materials extracted directly from nature decreases, while the share of materials and components that reach their final form of application after several production cycles increases;

(c) The share of traditional building materials (stone, bricks etc.) in the overall cost of materials tends to decrease, with plastics usually benefiting by this change;

(d) Among traditional materials, the share of cement is growing, while that of bricks is diminishing.

It is estimated that when the GDP in a country was below $390 *per capita* (1965 data) or cement consumption below 148 kg *per capita*, cement consumption grew quicker than GDP. Beyond these values, the growth rate of cement consumption decreases. Since most developing countries are below these limit values, cement production should grow at a higher rate than the economy.

The production and use of bricks do not follow uniform trends. In most developed countries, the production of bricks no longer increases, but often decreases; in developing countries an increase may still be desirable.

Construction uses but part of the steel output. The correlation between GDP and steel consumption in the construction industry is unclear. The data seem to show that the share of construction in steel consumption tends to decrease gradually because in developed countries an increasing part of the steel output is used to manufacture durable consumer goods.

No definite clues can be obtained from studying the use of timber in construction. However, it is clear that the share of various boards (particle board, wood-wool board, fibreboard etc.) in timber-based products is growing. Moreover, in oil-producing countries, bituminous felts and asphalt are used for many purposes (flat roofs, roads etc.). On the other hand, the manufacture and use of plastics has not yet gained ground in the construction industries of developing countries, but there are obviously great possibilities for expansion. The specific circumstances of developing countries (climate etc.) have to be given serious consideration.

Economic development is reflected in buildings of more and more complex structure involving a wider range of building materials, components and equipment. In developed countries the number of different products used in building amounts to nearly 100,000. In this paper the principal types of products could be mentioned only briefly. It must be stated, however, that growing complexity in the production and supply of building materials, components and equipment is a normal part of the development process.

As previously mentioned, appropriate technologies in developing countries very often differ from those adopted in developed countries. Developing countries should make use of their local materials and agricultural and industrial wastes. In some cases the technologies used in developed countries cannot be considered appropriate for developing countries because of the scale of production. It may be necessary to produce equipment of smaller production capacity requiring less capital investment. Such is the case for the small-scale manufacture of cement, lime and other building materials.

Development trends in the production and use of building materials and components require the establishment of new factories.

The development of prefabrication, mechanization, production and transport of building materials and components all widen the range of background activities of the construction industry. To be able to transport the growing quantity of building materials and components to the building sites, transport equipment has to be improved. The development of more lightweight building materials and components to a certain extent alleviates the increasing strain on the transport system.

Prefabrication, mechanization and the use of up-to-date building materials and components are technical characteristics of industrialized construction. However, industrialization has a further characteristic feature, namely the use of up-to-date management and programming methods. Flow-line methods have been introduced as an adaptation of conveyor production in construction. The critical path method and similar network programming techniques are easily adaptable for use in the construction industry. The complexity of operations calls for an extensive use of computers, as is usually the case in the management of large construction firms. Therefore the introduction and extensive use of modern management and programming methods should be aimed at and encouraged.

Building activities were for long based on trial and error, with practical successes and failures contributing to knowledge in this field. During the last century, and especially in recent decades, construction has relied increasingly on scientific research and mechanical and civil engineering know-how. Building research institutes founded first in developed and later in developing countries are becoming more and more active in the industrialization process. They do not have to concentrate exclusively on basic research. On the contrary, their main task in most countries is to follow research and development (R and D) in other countries and to adapt the results to conditions in their own countries. Building research institutes are sponsored by Governments, whereas research in the manufacturing industry may be left in the hands of industrial enterprises, because construction is a decentralized activity spread over large areas. Construction enterprises lack the necessary resources for maintaining their own research units. An exception is Japan, where construction enterprises have established their own research institutes.

Developing countries often have natural resources (raw materials) that up to now have not been used for manufacturing building materials and components, but which could be used for that purpose. Research (exploration of resources and quality control) is needed to make good use of such raw materials, e.g. for the production of cement, lime, gypsum, lightweight aggregates (pumice, perlite, vermiculite etc.), glass blocks etc. The climate and other factors (e.g. termites) prevailing in developing countries must be studied to make an appropriate selection of materials and structural components. There are many construction problems in developing countries (roofing, ventilation etc.) for which no ready-made solutions are available. Though many of these problems have already been carefully studied, mistakes are still frequently made.

Industrialization and appropriate technologies can be achieved in many ways. It is therefore very important to screen the different solutions in order to be able to choose techniques appropriate for a particular country. Research institutes and information centres produce the knowledge needed to make correct decisions and take part in the implementation of these decisions. Industrialization and the use of appropriate construction technologies require designs that take into account the results of science and research in this field. To achieve this, up-to-date technical regulations and standards based on performance criteria have to be worked out. Functional and practical buildings requirements have to be defined. Since the conditions prevailing in developed countries are different from those in developing countries (climate etc.), the requirements may also fundamentally differ. The requirements must therefore be assessed for each particular country or region.

III. GOVERNMENT POLICY AND INTERNATIONAL ACTION

The development of construction and the building materials industry calls not only for a policy on the selection of appropriate technologies, but also for a comprehensive development policy. Government and international action related to appropriate technologies should also be planned in a wider framework.

Government regulation of demand is essential to the sound development of the construction industry. The appropriate central and regional (local) authorities handle planning and programming problems on different levels. The central authorities' organization has to be of a complex character because it has to comprise government supervision of industry, the construction industry and technical progress; regional and urban planning; housing; and protection of the environment.

Governments should ensure a sufficiently stable demand for construction. Stable demand is ensured, among other things, by long-term housing, industrial development and land policies. Government-sponsored road, railway and harbour construction also makes construction demand more stable.

Governments should also find the means to create good financing and legal conditions for the construction industry. This includes up-to-date and sufficiently simple building legislation (e.g. for building permits), contracting procedures, access to funds and foreign exchange. Governments should formulate (with the participation of the construction industry) a technical policy on the industrialization of construction, especially that relating to the domestic industry. They should support R and D and capital investments to promote this industrialization process and the use of appropriate technologies in the various subsectors.

Building is one of the economic sectors where the establishment of a state-owned national building research institute may be necessary in most developing countries. Quality control and standardization should also be government responsibilities to a certain extent. Co-operation with R and D institutes in developed countries should be encouraged.

Governments should take measures to protect the domestic construction industry and domestic value added, and also the use of local resources for th production of building materials. This should not, however, take the form of overzealous protectionism that drives up prices and consequently damages the country's interests. It should rather consist of reasonable support given to the development of the domestic construction and building materials industry and the use of appropriate technologies.

The appropriate technologies to be applied in the construction and building materials industry of developing countries can be selected from advanced technologies in developed countries. First, in the building materials industry it is often necessary to organize production on a smaller scale than in developed countries; equipment for smaller plants must therefore be developed. Secondly, it is important to promote the exploration and use of local materials and the use of industrial and agricultural wastes. Thirdly, mechanization and prefabrication should be supported and adapted in scale and sophistication to the special circumstances of developing countries.

Education and training at all levels (workers, technicians, architects, civil engineers, site managers etc.) should be supported, always keeping in mind the aspects of the industrialization process and the use of appropriate technologies (e.g. in university curricula etc.).

International action and co-operation should be supported by Governments in all the above-mentioned fields. International action on both a bilateral and a multilateral (governmental and non-governmental) basis should be undertaken in all branches of the industry. With regard to the construction industry, such actions have failed to make a sufficient impact. In most cases they have been project-oriented, aimed at new housing, new urban infrastructure (water supply etc.) and new industrial complexes, including in some cases new factories in the building materials industry (cement plants).

Therefore, emphasis should in future be laid on the development and industrialization of the construction industry itself and the use of appropriate technologies. Measures described in the previous paragraphs (e.g. research, quality control, education, training etc.) could be promoted by international action initiated and supported by Governments.

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Mechanization of construction and choice of appropriate technology in civil engineering

J.W.S. De Graft Johnson[*]

The construction industry in developing countries

The construction industry in developing countries is generally characterized by a few, usually foreign, contractors who execute most of the major infrastructural works as well as larger buildings. There are usually a number of medium-sized local contractors who carry out repairs and supervise the construction of smaller houses. The Government is generally the major client, and this at times becomes a constraint on the selection of appropriate technology. In addition, many developing countries undertake major construction works more as prestige projects, many of which are not subjected to detailed analysis which would permit the adoption of the most appropriate technology. Many developing countries have establshed technical institutions and some include a national consultancy agency for undertaking designs for all government projects. However, these organizations have for the most part not achieved high degrees of efficiency and productivity, and most of them incur losses when similar private organizations are making profits.

In most developing countries, the availability of trained personnel is far below requirements, and the scope of training is not sufficient to enable graduates to acquire skills which would facilitate the adoption of the appropriate technology. Projects are planned, designed, and executed by personnel from developed countries, or by local staff trained in using techniques similar to those available in developed countries. A large number of developing countries have not established the necessary research organizations to undertake the compilation of available technologies and their cost implications. This is particularly crucial as such factors as climate and diet will influence productivity when labour-intensive technologies are used.

Many developing countries use predominantly imported materials in construction. Thus, materials resources in most developing countries are not fully exploited. In some cases materials production plants dependent on imported raw materials have been established, and this has led to expensive products. Generally, all major construction equipment is imported.

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[*] Director, Building and Road Research Institute, Kumasi, Ghana.

Another problem is caused by replacing human labour with machines. The extent to which some of the relatively more capital-intensive machines replace labourers is reflected in the table.

This is a subject on which research should be undertaken, the findings of which could be used to establish the ratio of labour to machines needed to achieve optimal performance in construction operations.

TABLE 1. REPLACEMENT OF HUMAN LABOUR WITH MACHINES

Type of machine	*Number of labourers replaced*
Excavators, 0.15–3 m^3	20–160
Motor-scrapers, from 6 m^3	50–120
Bulldozers, from 80 hp	70– 90
Motor-graders, 60–120	30– 50
Machines for earth compaction, 4–25	20– 50
Building cranes, 30–80	30– 40
Dump-cars, 3–5 m^3	20– 30
Motor-cranes, 5	10– 20
Mixers, 250–750	5– 20
Conveyors, 4–15	3– 5

Source: Building Research numbers 2 and 3, Research Institute of the Building Industry, Prague, 1963.

Criteria for choice of appropriate technology at project level

A detailed consideration of the choice of appropriate technology for a single building construction operation may, for example, cover the construction of a building, a foundation or a wall. The choice of appropriate technology can be based mainly on either economic or social considerations.

Generally, in engineering feasibility studies, economic considerations are given a higher priority. The alternatives for undertaking a specific building operation using various combinations of labour, materials and equipment should be identified. The cost of the resources used will depend on their availability in a country or in a specific location. Thus, relatively plentiful resources will have low prices compared to relatively scarce resources.

Three distinct types of costs relevant to the selection of appropriate technology in building construction can be identified.

(a) Financial or market costs, the costs usually taken into account by government budgeting agencies and contractors or managers in an industrial operation;

(b) Foreign exchange costs pertaining to payments for imported goods and services and, less obviously, to costs represented by any reductions in the foreign exchange receipts of the country;

(c) National economic costs.

National economic costs differ from (and are usually lower than) ordinary financial costs for two principal reasons. Firstly, financial costs such as taxes are not real costs when viewed from a national standpoint. Taxes are essentially transferred payments. Secondly, market prices may be artificially suppressed or inflated so that such price distortions characteristically appear to encourage the choice of inappropriate technologies. The type of prices which are typically so distorted are wages of local labour, especially unskilled labour; interest rates; and foreign exchange rates.

Market wages, in many developing countries especially for unskilled labour, tend to be distorted upward by such devices as legally imposed minimum wages that lift market wages above the levels justified by labour productivity.

In some developing countries, the Government tries to help consumer borrowers by placing a ceiling on interest rates. The distortion of foreign exchange rates is reflected in the international over-valuation of national currency which is typical of developing countries. Most developing countries tend to establish and maintain low rates of exchange on foreign currencies. Such exchange rates encourage the choice of technologies that require a relatively high proportion of imported resources and a relatively low proportion of domestic resources. If technologies that are in keeping with national costs are to be selected, there is a need to use prices that are consistent with national costs, which may be different from market prices. They are commonly called shadow prices.

The costs of using given technology are usually calculated using shadow prices to identify the technology that is appropriate in the sense of minimizing costs to the developing nation. Furthermore, such cost minimization is sought in order to maximize the net economic benefits to the nation of completing the building project. Net benefits may be thought of as the increase in the present discounted value of a real output aggregate such as net national product. Since the gross benefits minus costs equal net benefits, the flow of net benefits from a given building project is maximized by minimizing the cost to the nation of constructing it.

By comparing the present discounted values of the net benefits, it is possible to assess the relative merits of alternative technologies over different time spans.

The selection of appropriate technology is also based on minimizing the outflow of scarce foreign exchange. Comparing alternative technologies by this criterion does not involve shadow prices; rather, foreign exchange flows can be measured in a monetary unit, and the net flows over the relevant span of years can be discounted back to the date of project initiation. Generally, the more labour intensive a technology, the less foreign exchange is required and thus the more appropriate the technology is by this criterion.

A building construction project consists of a number of individual building operations or sub-projects for which a corresponding range of alternative technologies ranges must be determined. Therefore in order to identify the appropriate technology for a whole building construction project, a list of the various building operations for which a level of technology is identifiable must be prepared. The next step is to identify and list the alternative technologies for each building operation, be they traditional ones currently or formerly in use or more advanced technologies. Such alternatives may be found by investigating the possibility of:

(a) Using the latest results of government, academic and private research;

(b) Improving auxiliary construction materials and adapting them to new uses;

(c) Developing and using indigenous building materials;

(d) Using current technology to increase the productivity of labour and capital resources by eliminating lost time or waste of materials;

(e) Improving, for a given mix of labour and capital, the productivity of the workers by increasing their motivation, reallocating tasks, personnel or by alternative methods of payment;

(f) Maximizing capital, without changing the labour and capital mix, by replacing one unit of capital equipment by an alternative and more productive piece of equipment;

(g) Changing the mix of labour and capital.

The next step is to compute the discounted cost of carrying out each specific building operation using several alternative feasible technologies. The appropriate technology for each operation will be the least-cost alternative and for the total project it will be a combination of individual appropriate technologies.

Engineers, planners and decision-makers should know the implications of their choices and should have specific knowledge of various techniques and productivity data on all the building operations. Some data are available on manual techniques, but useful information on intermediate technology is rare. In order to help planners and designers choose technology for various building operations, the supply of data on intermediate methods now being used needs to be increased and new intermediate technology construction methods for the building industry developed.

In considering the choice of technology for a housing programme for the rural and urban sectors, it must be realized that factor endowments in the rural and urban sectors will differ. Therefore, the methodology outlined for determining the appropriate technology will yield different levels of technology and the technology suitable for the urban sector will probably be more capital-intensive than that for the rural sector. If a technology intermediate between these two levels can be chosen for both, it will probably promote a more unified and integrated economy.

If, on the other hand, two different levels of technology are applied, the economy will be dualistic. In macro-economic terms, aggregation of the output arising from the application of appropriate technology in these two sectors will be maximized in the sense that it will contribute most to the growth of the national product. However, since it will also promote a dualistic economy, it will not alleviate poverty and unemployment, particularly in the informal sectors.

What Governments can do

The following suggestions should be considered:

(a) Every country must first of all seek to build up its own scientific and technological capabilities by establishing the necessary scientific and

technological training institutions covering both middle-level and highly trained professional staff;

(b) Methods should be developed for costing and administrating projects which will encourage the use of appropriate technologies, and induce private contractors and other agencies to adopt them;

(c) Training courses in developing countries tend to rely on handbooks and teaching materials from highly industrialized countries. The compilation of handbooks on more appropriate technology would be a first step towards making available to technical institutes and universities offering courses in building technology and construction, training materials in the selection and adoption of appropriate technologies;

(d) A number of developing countries have not established the necessary institutional arrangements for controlling construction costs and for promoting the selection of appropriate technology. Indeed, in many, the existing structure encourages excessive costs since consultants are usually paid on the basis of a percentage of the project;

(e) If national social and economic interests are to be served, it must be recognized first that public participation in technological decisions is imperative. Political institutions must be so constituted that public participation is possible in order to avoid a situation whereby elite interests swamp the welfare of the majority. Government action, should therefore be directed towards establishing the necessary administrative institutions to formulate realistic national, social and economic goals, reflecting the basic needs of the people, and such institutions should actively encourage full public participation in their activities.

Annex I

SELECTED DOCUMENTATION PUBLISHED OR COMPILED BY UNIDO RELATING TO THE SUBJECT

Information sources on building boards from wood and other fibrous materials. UNIDO guides to information sources no. 9. 1974. 82 p. (UNIDO/LIB/SER.D/9)

Information sources on the cement and concrete industry. UNIDO guides to information sources no 2. rev. ed. 1977. 90 p. (UNIDO/LIB/SER.D/2/Rev.1)

Austrian experience in up to date low cost construction. Paper prepared by H. Stoecher for the Joint Consultation on Prefabrication for Industrial Construction, Warsaw, 1975. 1975. 41 p. diagrams. (ID/WG.211/1)

Brick making plant: industry profile. Development and transfer of technology series no. 10. Prepared by I. Knizek. 1978. 55 p. tables, diagrams. (ID/212)

Development of appropriate technology for small-scale production of Portland cement in least developed countries and regions. Paper prepared by H. Boeck. 1976. 28 p. tables, graph. (UNIDO/IOD.48)

Development of building materials industries in the developing countries. Interregional Seminar on Building Operations in Low-Cost Housing Construction, Rotterdam, Netherlands, 1976. 1976. 13 p. table. (UNIDO/IOD. 19)

Also published in French.

Establishing low-cost housing manufacturing plants. Paper preared by R. Behrens for the Meeting of Top-Level Industrialists on Factory Establishment Projects in Developing Countries, Vienna , Austria, 1976. 1976. 9 p. (ID/WG.237/6)

Fundamentals for success in the establishment of cement projects. Paper prepared by A. Afify. 1975. 25 p. (UNIDO/ITD.361)

General principles and practice of low-cost housing, based on Hungarian experience. *Ad hoc* Expert Group Meeting on Industrial Construction in Developing Countries, Vienna, Austria, 1974. 1975. 41 p. tables. (ID/WG.196/6)

Improved packaging for cement and mini cement. Paper prepared by H. Visvesvaraya for the Expert Group Meeting on the Utilization of National Technological Institutions in the Developing Countries for Industrial Development, Port of Spain, Trinidad, 1977. 1977. 24 p. graph, diagram. (ID/WG.246/1)

Industrial construction in developing countries. Report of the *Ad hoc* Expert Group Meeting on Industrial Construction in Developing Countries, Vienna, 1974. 1975. 56 p. (ID/WG.196/9)

Low-cost prefabricated elements for small-scale industrial structures in Poland. Paper prepared by A. Lendzion *and* K. Borsuk for the Joint Consultation on Prefabrication for Industrial Construction, Warsaw, Poland, 1975. 1975. 19 p. diagrams, illus. (ID/WG.211/2)

Manufacturing guide. Lime industry. Prepared by F. Sobek. 1975. 69 p. graphs, tables, diagrams. (UNIDO/ISID/INQ.3)

Production of doors, windows and frames. Paper prepared by E. Minarelli for the Technical Course on Criteria for the Selection of Woodworking Machinery, Milan, Italy, 1978. 1978. 24 p. (ID/WG.277/9)

Recent trends in the development of building materials and construction industries.

Symposium on Construction Policies and Industrial Building Systems in the Arab Countries and Iran, Vienna, Austria, 1978. 1978. 12 p. (UNIDO/IOD.206)

Technologies from developing countries. Development and transfer of technology series no. 7. 1978. 35 p. (ID/208)

- Door and window frames from magnesium oxychloride cement and sawdust, pp. 9–10.
- Building materials production, p. 17.
- Asbestos tiles from asbestos cement factory wastes, p. 17.
- Manufacture of clay flooring and roofing, p. 17.
- A process for avoiding warping and cracking of tiles made from plastic clay, p. 18.
- Brick making, pp. 18–19.
- Sintered fly ash lightweight aggregate, p. 19.
- Lime sludge based masonry cements, p. 19.
- Equipment for construction, pp. 20–21.
- Grinding mill for cement and other industries, p. 35.

The advantage of wood as a construction material. Paper prepared by R. Williams for the Joint Consultation on Prefabrication for Industrial Construction, Warsaw, Poland, 1975. 1975. 10 p. tables, graph, illus. (ID/WG.211/7)

The role of a developer in the low-cost housing programmes for developing countries. Paper prepared by Z. Wolak for the Joint Consultation on Prefabrication for Industrial Construction, Warsaw, Poland, 1975. 1975. 23 p. (ID/WG.211/4)

Papers issued for the International Forum on Appropriate Industrial Technology, New Delhi and Anand, India, 20–30 November 1978

ID/WG.282/21	Paper, cardboard, corrugated cardboard, polyethylene shrink and stretch film for a better packaging. 57p. S. Mulitsch di Palmenberg
ID/WG.282/47	Choice of appropriate packaging technology. 40 p. M. R. Subramanian
ID/WG.282/48	Production of glass for containers and for the building industry. 21 p. A. Szczytowski
ID/WG.282/49	Opportunities for technical co-operation between developing countries for producing building materials. 31 p. N. R. Hill
ID/WG.282/64	Packaging: an integrated part of economic development in developing countries. 21 p. Z. Zackiewicz
ID/WG.282/71	The role of national institutions and raw materials problems in building materials industries. 20 p. N. R. Hill
ID/WG.282/105	Appropriate technology for bricks and ceramics: aims and approaches. 11 p. I. Knizek
ID/WG.282/65	Technologies from developing countries. 251 p.

- Cement from rice husk ash, p. 54.
- Foam concrete, pp. 55–56.
- Masonry cement from waste lime sludge and Portland cement, p. 57.
- Cementitious binder from waste lime sludge and rice husk, pp. 58–59.
- Manufacture of plaster of Paris, p. 60.
- Funicular shell roof, pp. 61–62.
- Lightweight aggregate from urban sewage slime, p. 63.

Corrugated roofing panels from agricultural residues, p. 64.
Wood wool boards, pp. 65–66.
Corrugated roofing sheets from coir waste or wood wool, p. 67.
Resin/natural fibre composites, p. 68.
Building lime from sugar press mud, pp. 69–70.
Manufacture of pozzolana clays, p. 71.
Lime burnt clay pozzolana mixture, pp. 72–73.
Burnt clay pozzolana (reactive *surkhi*), pp. 74–75.
Large size clay products with improved strength, pp. 76–77.
Clay flooring and roofing tiles, pp. 78–79.
Manufacture of ceramic floor tiles, p. 80.
Production of wall tiles from unrefined china clay, p. 81.
Production of floor tiles from red burning clay, p. 82.
Production of acid-resistant bricks from red burning clays, p. 83.
Soil-cement brick making machine, p. 84.
Coconut-pith expansion joint filler and building board, pp. 85–86.
Utilization of fly ash, pp. 87–88.
Locally available low-grade materials for the construction of rural roads, pp. 89–90.

Technical information compiled by the Industrial Inquiry Service (IIS) and the Industrial and Technological Information Bank (INTIB)

Copies of these compilations are available to requestors from developing countries only. The reference number must be quoted.

Aluminium doors and windows. (IIS file no. 6647)
Asbestos. (IIS file no. 8398)
Brick and tile manufacture. (IIS file no. x4014)
Calcium silicate bricks. (IIS file no. 6731)
Composite boards. (IIS file no. 6800)
Glass micro-balloons. (IIS file no. 8391)
Hinges. (IIS file no. 5205)
Joints. (IIS file no. 7650)
Lime kilns. (IIS file no. x3663)
Manufacture of clay bricks. (IIS file no. 6362)
Portland cement clinker. (IIS file no. 5995–96)
Rubber. (IIS file no. 5228)
Sheet glass. (IIS file no. 6030)
Vermiculite. (IIS file no. 5433)
Wallpaper and coated paper manufacture. (IIS file no. 6788)
Waste gypsum utilization. (IIS file no. 8046)

Annex II

WORKING GROUP PARTICIPANTS AND OBSERVERS

Participants

Z. A. Abbas, Government Official, Public Works, Bandung, Indonesia.
H. U. Bijlani, Chairman and Managing Director, Housing and Urban Development Corporation India, New Delhi, India.
J. W. S. de Graft Johnson, Director, Building and Road Research Institute, Kumasi, Ghana. (Chairman of the working group)
P. O. Grane, Industrias Betcel S. A., Buenos Aires, Argentina.
N. R. Hill, Neville R. Hill Consultancy Services, Portsmouth, United Kingdom.
I. O. Knizek, Consultant, Mexico D. F., Mexico.
R. C. Mangal, Director, Central Building Research Institute, Roorkee, India.
G. C. Mathur, Director, Regional Housing Centre, New Delhi, India.
B. B. Kshetry, Deputy General Manager, Nepal Food Corporation, Kathmandu, Nepal.
A. Mier y Teran, Expert, Ministry of Public Works and Human Settlements, Mexico D. F., Mexico.
J. P. Meric, Director General, Centre d'Etudes et de Recherches de l'Industrie des Liant Hydrauliques, Paris, France.
E. K. Mundi, Director, Director of Public Works, Research and Investigations Centre (CRETP), Yaoundé, United Republic of Cameroon.
F. Neghabat, Director, Building and Housing Research Centre, Tehran, Iran.
H. H. Persson, Consultant, Royal Institute of Technology, Stockholm, Sweden.
G. Sebestyén, Director, Building Research Institute, Budapest, Hungary.
A. Shadmon, Senior Consultant, Jerusalem, Israel.
Å. Skarendahl, Åke Skarendahl Konsultbyrå, Djursholm, Sweden.
J. Storaas, Head of Division, Norwegian Agency of International Development, Oslo, Norway.
P. B. Singh Tuladhar, Architect, Department of Housing, Building and Physical Planning, Ministry of Public Works and Transport, Nepal.
H. C. Visvesvaraya, Director General, Cement Research Institute of India, New Delhi, India.
D. L. Wright, General Manger, Intermediate Technology Industrial Services, Rugby, United Kingdom. (Rapporteur of the working group)
F. Yagiz, Director, Research and Development Department, Turkish Cement Industry Company, Ankara, Turkey.

Observers

A. M. Al Kadhili, Director, Technical Department, State Organization for Construction Material, Ministry of Industry, Baghdad, Iraq.
O. P. Ratra, Assistant Director (Plastics), National Buildings Organization, New Delhi, India.

A. V. R. Rao. Joint Director (Building Materials), National Buildings Organization, New Delhi, India.
P. Rossner, Deputy Director, VEB ZAB, Dessau, German Democratic Republic.
B. M. Sedalia, Consultant, New Delhi, India.
H. G. Schleife, Commercial Attaché, Embassy of the German Democratic Republic, New Delhi, India.

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