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PRODUCTS AND INDUSTRIES BASED ON PORTLAND CEMENT

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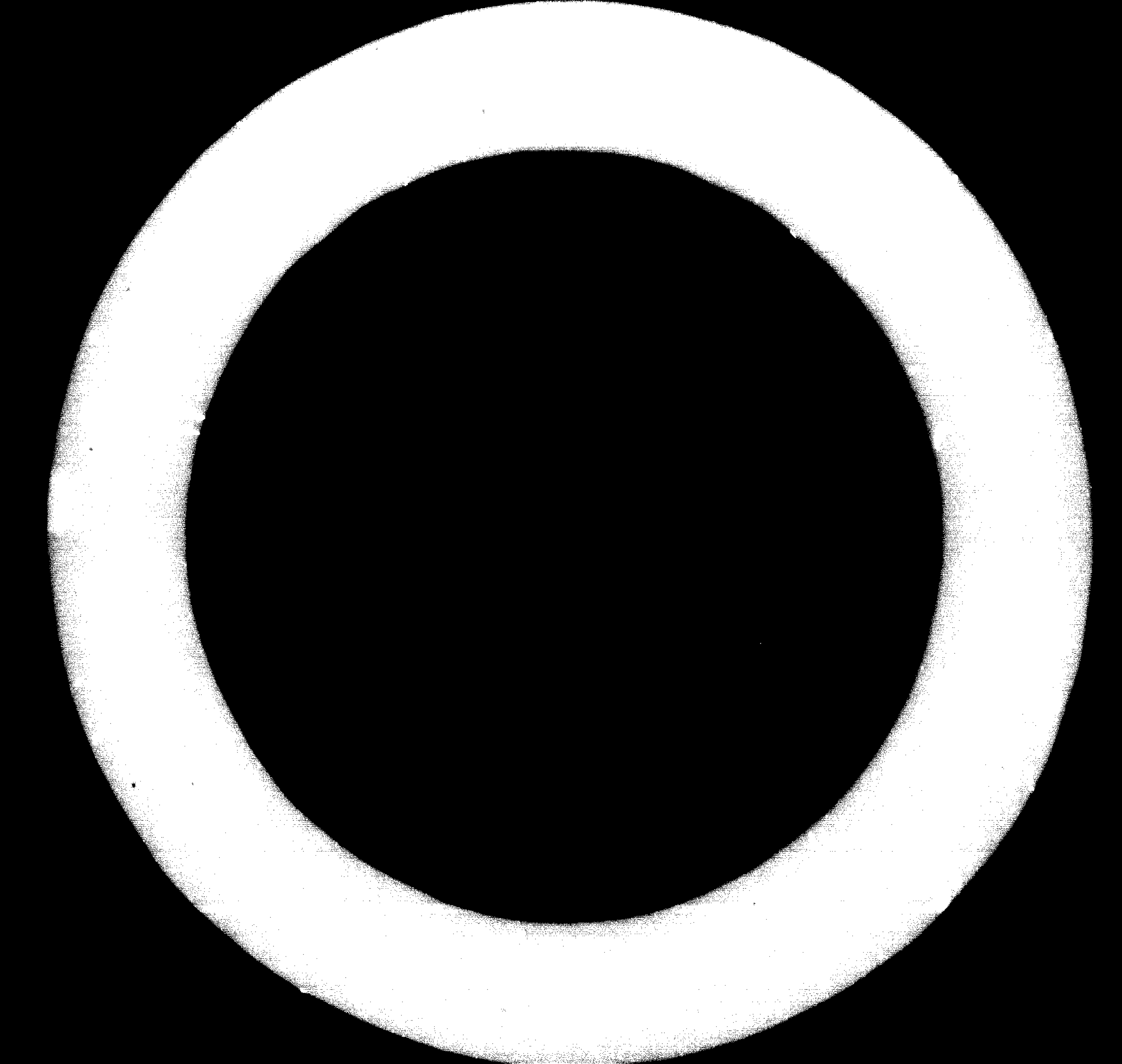

INTRODUCTION

In presenting this lecture about *Cement and Concrete Research in Future Urban Development* it seems appropriate to mention its background.

The Concrete Research Laboratory Karlstrup was established in 1960 by the Danish Cement Manufacturing Company: Aktieselskabet Aalborg Portland-Cement-Fabrik, running about 80% of the Danish cement production, i.e. about 2 mill. tons cement in 1970. The research is only to a minor extent concerned with the problems of the manufacture of the product - cement - made by the sponsoring industry. So far, it has been more orientated towards the use of the cement, that is to say: the problems in manufacturing concrete.

So much of concrete manufacturing to-day in Denmark is industrialized that the research predominantly must concern industry problems, or in other words:

process technology
product development

rather than conventional design, making, and use of concrete.

Quite much of Danish know-how in industrialized concrete manufacturing is now being exported. Danish plants or licensed plants are to be found in Western Europe, Eastern Europe, Israel, USA, Thailand, and elsewhere. As it is well known, also cement manufacturing industry is an important all over feature of Danish export.

This outlook in Danish cement and concrete industry forces the concrete research to apply a global, rather than a national view on its function as a basis for innovation of cement and concrete industry.

If we now look upon modern manufacture of cement from the point of view of concrete research there are three areas of problems to be considered seriously with regard to the development in the years to come:

The steadily increasing cement consumption in the global, social development, the corresponding trends in cement manufacture and the creation of concrete manufacturing industries.

The advance of basic knowledge on cement, its minerals and their formation during manufacture and on the characteristics of unhydrated and hydrated cement and its adhesion to aggregate particles.

YEAR	CEMENT PRODUCTION - DENMARK mill. tons	KGS CEM/CAPITA
1920	0.2	64
1950	0.7	159
1960	1.2	266
1968	2.0	425

FIG. 1

The application of basic knowledge so as to create innovation in the manufacture of cements, cement products, concrete and concrete products in a still widening spectrum of types.

THE TASK

There is no need to present extensive documentation for the fundamental importance of the manufacture of cement in modern life of people all over the world. Figs. 1 and 2 are significant expressions of what the consumption of cement, predominantly in concrete, has meant for the creation of the 20th century.

Speaking from an industrial point of view the market is prosperous also for the years to come. But in a broader sense we might say that it is prosperous in a frightening order of magnitude.

There is not yet the problem of available natural resources as with some other raw materials. Limestone and rocks with silica and alumina are still among the most widespread mineral raw materials in most regions of the world, and ways of producing artificial aggregates for concrete etc. are at hand where suitable natural sand and gravels or rocks for crushing are becoming scarce.

The main problem of the future is rather, how the production can keep up with the demand for cement and concrete for the concentrated urbanization now coming along in our countries.

J. Van Ettinger, in his book *TOWARDS A HABITABLE WORLD*, [1], issued in 1960, says:

"---- in order to ensure reasonable housing for everyone in the year 2000 it will be necessary to build 1000 million dwellings

YEAR	CEMENT PRODUCTION - WORLD mill. tons
1920	32
1950	133
1960	315
1968	509

FIG. 2

in the present century, viz. 1100 million (------) less 100 million (------).

To attain in the year 2000 a world housing stock of 1100 mil-
lion dwellings of reasonable quality, it will be necessary to build
in the forty-two years available roughly 25 million dwellings per
year. Seeing that it will take a few decennia to attain a produc-
tion of this size, it will be clear that in the second half produc-
tion will have to be considerably greater than 25 million dwellings
per year. This is especially necessary, because in the period 2000-
2050 production will also have to be considerably greater than 25
million dwellings per year and consequently a higher rate of pro-
duction must be attained at the end of the present century. In view
of the enormous arrears production must be increased as quickly as
possible and for this reason the relative increase in production in
the first part of the period has been assumed to be higher than in
the second part."

Twelve years have passed since the publication of this estima-
tion of the global habitation problem. Figs. 1 and 2 indicate that
cement industries have been aware of these perspectives, whereas
Fig. 3 indicates, how far we still are from meeting the needs. And
recent information concerning population growth and its increasing
social problems in some regions of the world definitely support the
view that we are still far from such a level of dwelling production
that we are dealing with a systematic, controlled move *"towards a habitable world"*.

On the contrary, the Danish delegation at a world conference
held in November 1969 in Bruxelles concerning big city developments
presented a survey of the difficulties involved in the urbanisation
of the Copenhagen area aiming at 2.6 mill. inhabitants year 2000.

Output of Dwelling Units per 1000 Inhabitants	1960	1968
Austria		6.8
Belgium		5.1
Czekoslovakia		6.1
Denmark		9.2
Finland	7.1	
France	7.0	8.2
Greece		12.8
Hungary		6.5
Luxembourg		3.3
Malta		6.9
Netherlands	7.4	
Norway	7.4	
Poland		5.9
Romania	7.3	5.8
Spain		7.7
Sweden	9.1	13.4
Switzerland	9.3	
USA	7.1	
USSR	14.0	9.4
U.K.		7.7
W. Germany	10.3	9.0
Many developing countries	2.0 or less	

FIG. 3 From: UN Economic & Social Council, E/C 6/12.9.12.1963
Annual Bulletin of Housing and Building Statistics for Europe, 1968, United Nations, Economic Commission for Europe, New York 1969

An East Asian delegate opposed to calling this difficult, referring to the fact that the capital of his country now holds about 10 mill. inhabitants without having any noticeable modern facilities, and it is expected to have 20 mill. inhabitants in 1990. There are no plans laid out for urbanisation and no capital available for such investments.

The importance of cement and concrete for housing and constructhis road as a heroic challenge to the environments, a daring symbol that India will firmly attempt to integrate science and technology in its future life and development. If this has been the attitude deciding the construction, we must look upon it with admiration - not least, because while driving there it is easy to imagine an antagonistic reaction from the environments which could quickly pour the statics of the rural life back over the road and make it quite obsolete.

One might think that science, research and technology more strongly are influencing the main concepts of modern life in the industrialized regions of the world than in India. But this is not necessarily true.

In recent years big companies operating in the consumption markets in USA have introduced the "systematic value analyses technique". Ad hoc expert groups are established, when a customer has a demand which cannot be met by existing products. Potential solutions are then formulated through penetrating discussions down to unambiguous definitions of the basic functions to be fulfilled, and thereafter by creative team-work in searching new ideas and technology. A special Society of Value Engineers already exists, and spectacular cases are known with big savings in costs of production and in creation of new products by utilising this approach.

Admittingly, programming of science and research could be much improved by systematic expert group's brain storming. The alarming feature in value analysis as a tool in big business' development work rather is that science is applied in a quite haphazard way and levelled in with occasional and lexical knowledge in the decisive process.

There is but little reason to cry for the freedom of academic, basic science in that romantic sense of this concept which inevitably now belong to the pre-electronic era. What must concern us is that science and technology ought to evolve a system approach to the utilization of new ideas and concepts, and not accept merely to be used as a heap of occasional information.

It seems convincingly demonstrated that value analyses can be a powerful tool, probably not least because it incorporates the creation of a favourable environment for multiplication-effects by integrating individual resources. But science-research-technology could long ago have created environments of equal or superior power, instead of so often having accepted to live with, or vainly tried to break down - if not built - insurmountable barriers of terminology and ideology between research and practice. To change this tide we must understand the problem and its order of magnitude.

Fig. 5 is a compilation of the amount of R + D (Research and Development, so used in the following) employees against the totals of employees in 26 European industry companies, covering research intensive as well as research extensive fields of business. Representatives of these firms attended a conference in Denmark on R + D problems in 1969 and offered the information here presented. The figure seems to say that research-intensive industry (for instance pharmaceuticals) tends to employ 1 or more R + D man per each 10 employees for companies of say 1000 to 10000 employees. This proportion falls off in the giant companies (oil, beer, electronics etc.) and the validity of a proportion is obscure in companies with less than 1000 employees.

Cement industry in general has much less R + D employees than 1 per 10, also outside Europe and with a few dynamic companies as the exceptions.

Fig. 6, from (2), shows the percentage of basic research expenditure to total research expenditure against total research expenditure (US = 1000) in a number of countries, big as well as smaller ones. In a number of the small countries a large proportion of the total research is basic - this will generally be synonymous with university and technical university research and work at public research institutes. At the same time the small countries have only few big companies, which are prepared to employ scientists or for that sake to apply and utilise science as a basis for R + D activites.

Cement chemistry as a part of silicate chemistry has played an important and spectacular part of university research, both in smaller and bigger countries for the last 150 years.

Cement industry has nowhere, except as minor fields of secondary investments, developed into the modern type of giant corporations (oil, steel, chemicals, electronics etc.) and comprises a good many quite small companies (less than 1000 employees). The cement industry does not belong to the research-intensive group of industry, and concrete manufacture is even much less a field of concentrated industry organization.

Thus, this is our picture: A high proportion of the basic research is public and academic and only remotely related to its application in the R + D of cement and concrete manufacture. Cement manufacture is much less research-intensive than most other fields of modern mass production. Concrete manufacture is still in the larger part of the world only in an incipient phase of industrialization.

This must be understood, if we want to make progress with regard to evolve a system approach to the utilization of science and technology or, in other words: to reinforce the efforts for the advance of basic research and its transformation into more intensive R + D.

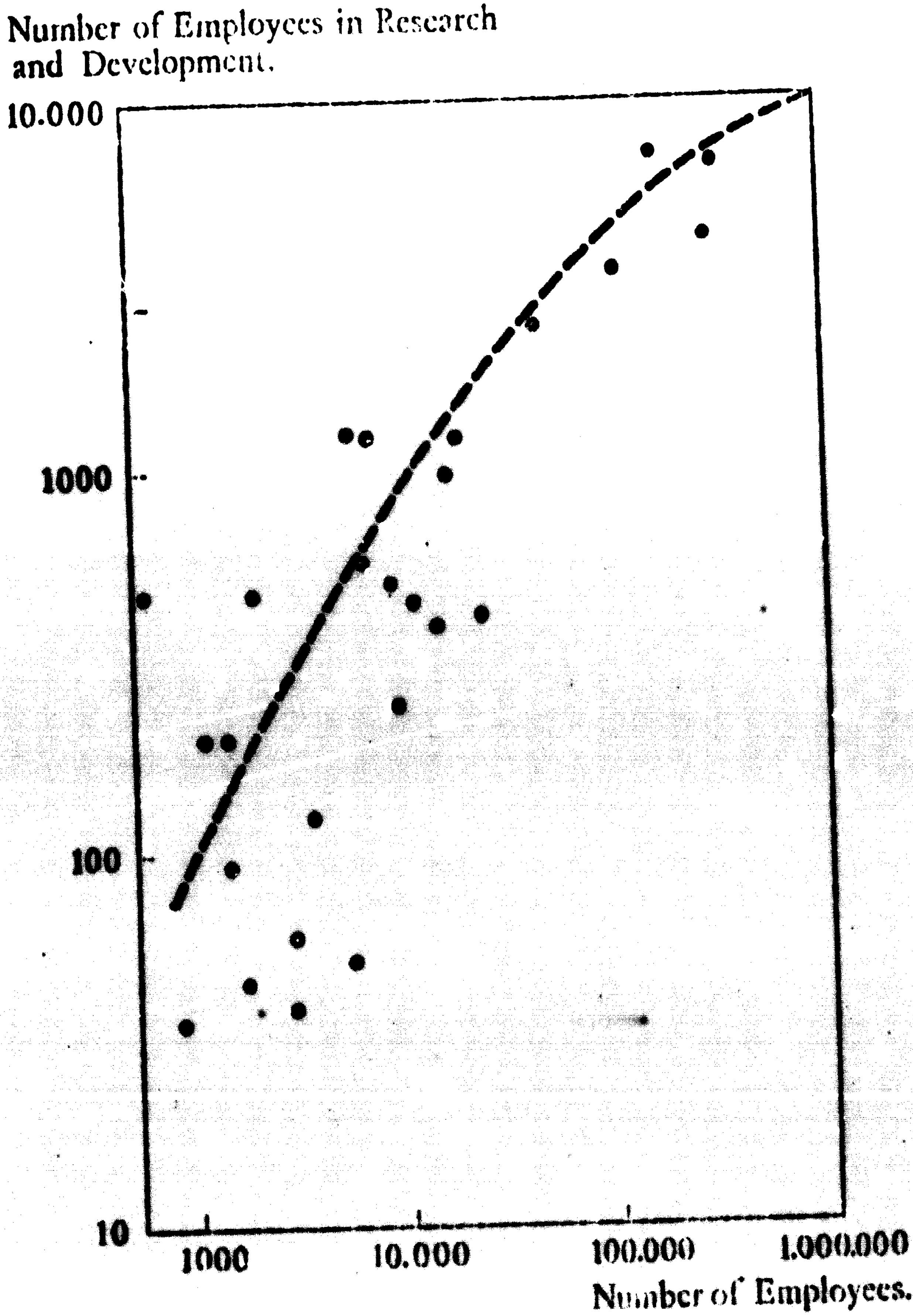

FIG. 5 Number of employees in Research and Development against the totals of employees in 26 European industry companies

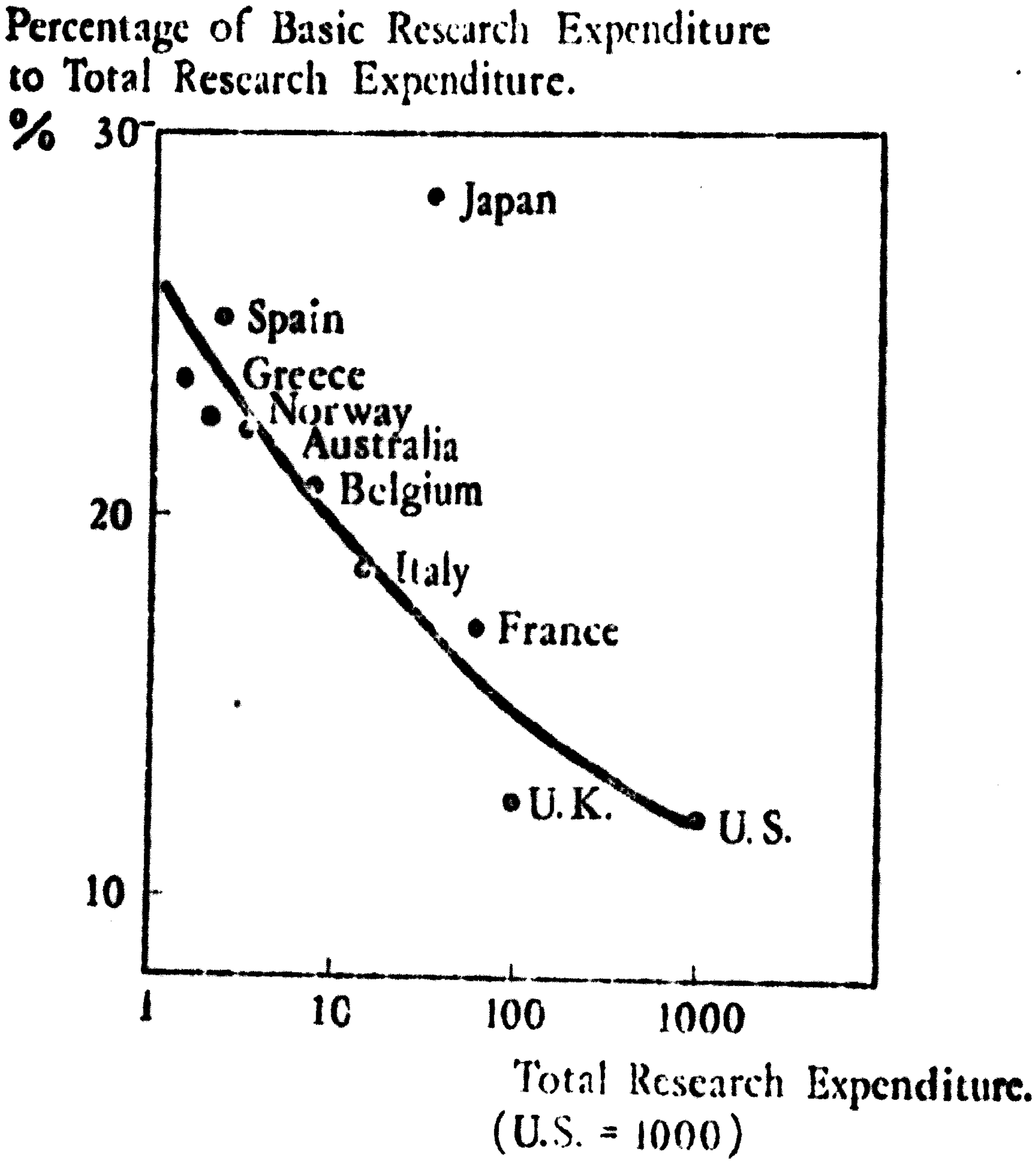

FIG. 6 Percentage basic research expenditure to total research expenditure against total research expenditure in some countries. From (2)

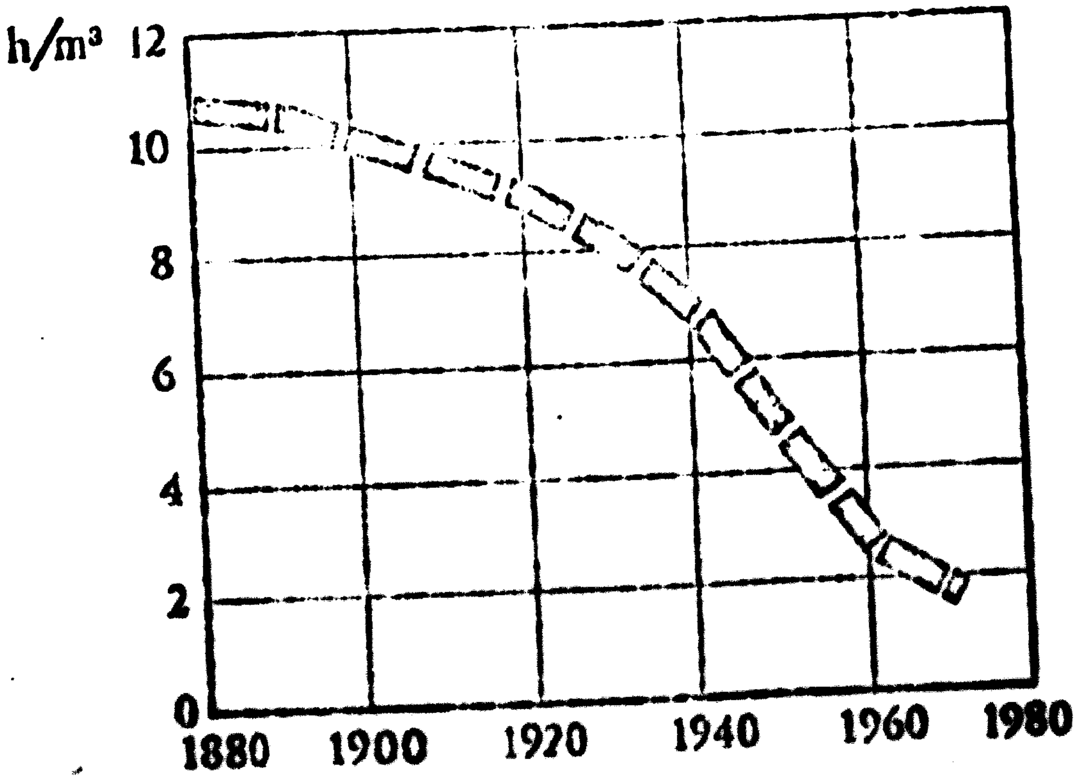

FIG. 7 Decrease in working hours on the building site per m^3 dwelling volume in Sweden, 1880-1960. From (3)

CEMENT AND CONCRETE INNOVATION

Most countries are still widely accepting that innovation within the building and construction sector must take place through slow evolution of codes of practice, standards etc. There are mainly historical reasons for this peculiar way of meeting the urgency of a rapid progress towards a habitable world.

In ancient times the modes of construction were based entirely on experience. Catastrophic accidents during and after the erection of big buildings and constructions etc. must have been numerous and of chocking effects. More recently, for instance when the cement industry grew up, the difficulties in attaining dependable qualities of cement clinkers in the burning process still called for public suspicion and strict control, also because the erection of buildings and construction was still simple handwork, often to be made by unskilled labourers. This "safeguard-policy" has been of heavy impact on research from far back in ancient time up till to-day's international committee work on standard specifications etc.

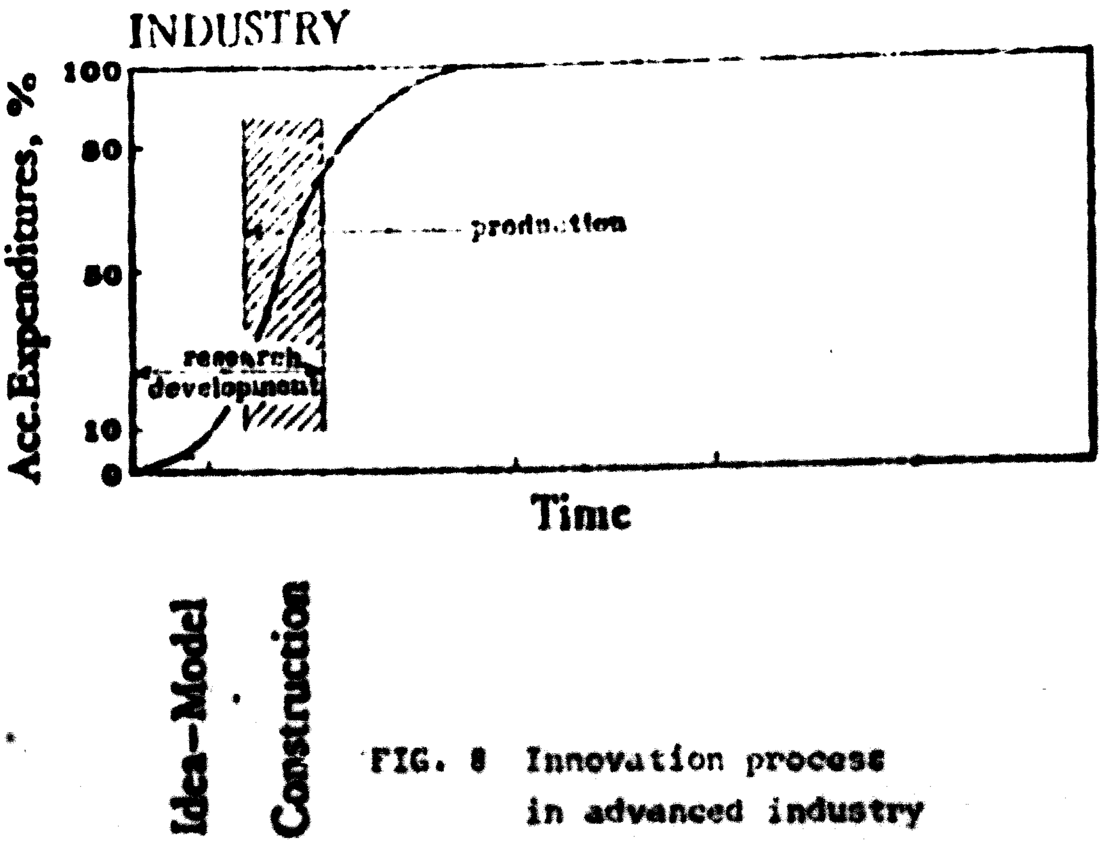

FIG. 8 Innovation process in advanced industry

Immense series of costly, empiric tests are still made despite the fact that they are only vaguely reflecting the true characteristics of building materials exposed to varying complex environmental factors. In its entity this system of traditional acceptance testing is becoming more and more a barrier of retardation against further industrialization, and this is coming in still sharper contrast to the fact that theoretical research, modern instrumentation and datamatic expertise are available for a system approach to research and development and for control purposes, like already long ago introduced in other mass production industries.

It is also to a large extent due to the historic development that rationalization rather than qualitative innovation so far has been the predominant feature of the development of concrete industries.

Fig. 7 shows the decrease in working hours on the building site per m³ dwelling volume [illegible] to 19[illegible] in Sweden [3]. Precast concrete commenced to contribute to the reduction from 5 to 2½ hour per m³ in the decade 1960 to 1969. The predominance of rationalization rather than product innovation is also characteristic of the cement industry, especially for the last 20 years and particularly due to:

1. Mechanization of excavation and transport of raw materials
2. Increase of kiln sizes (600 → 4000 ts/day)
3. Rationalization of kiln operation
4. Introduction of bulk cement transportation

The time has come to make the statement that the economic savings in these progresses since the second world war involve but little influential science and technology, which was not at hand before the war.

Fig. 8 shows an idealized sketch of the innovation process in advanced industry. The "idea-model" phase (the research) constitutes the introduction phase and often less than 10% of the total costs of the R & D investment. The further work until the marketing phase is well established as a smooth, integrated and well controlled process, fitting into the larger scheme of industrial and commercial activity. An entire product development will often last five years or less in quite a few types of industry.

Fig. 9 represents an attempt to visualize the R & D feature of the building industry - in this connection considered the alias of either cement or concrete industry. Most research, basic as well as practically aimed, is institutional and ends up in publications, lectures etc. - and in a gap of lacking communication with regard to application. However, some consultants, site-engineers, plant operators, plant constructors etc. will always try to find new ways and to pick up news from the literature, personal contacts etc. In the course of time new design, new materials, improved characteristics of materials etc. are thus brought forward.

Then comes the next gap, because the authorities depend on experiences and demand time to be convinced of the security in accepting new things.

Hereafter comes the third gap, because contractors, site-engineers, plant operators etc. must be brought to understand and accept the new ideas and procedures. First now the accumulated costs of R & D have attained about 100%, and very often 20 years have passed before the break-through in practice of a cement or concrete innovation, commenced as an idea and an investigation in a research institute.

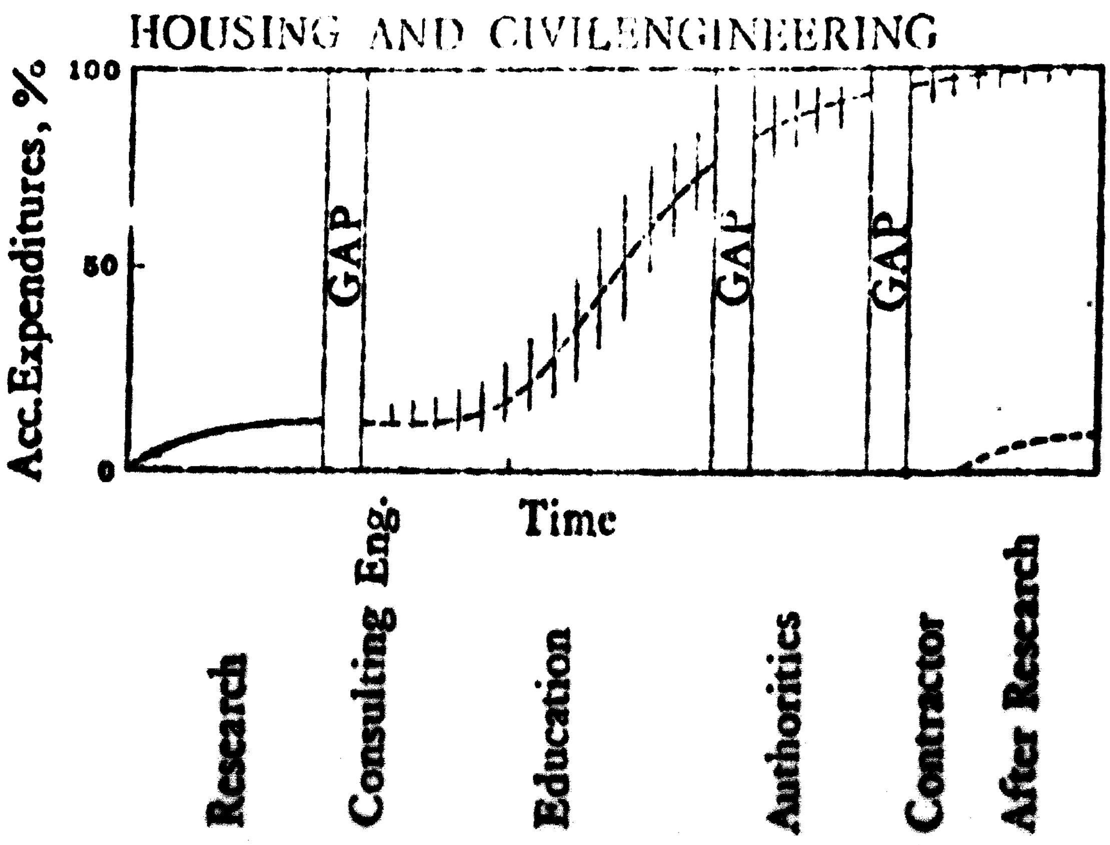

FIG. 9 Innovation process in the building industry

Then at last comes often some failures, and this is the endangering barrier against a more rapid development towards a habitable world - now research is called upon to assist in trouble shooting, to correct procedures of manufacturing or to adjust products, into which basic misconcepts may well be built-in. In fact, in numerous cases such work is what people in practice have learned to understand by the designation research, and they have been taught so much from the way many research institutes have worked.

RESEARCH - ANVIL OR HAMMER

The introduction during the forties of physico-chemical theory and experimental technique in concrete research in many respects replaced the traditional testing methods.

Thereby more meaningful and deeper acknowledgement of the nature of cement paste and concrete have been attained. But this has not resulted in powerful innovation of concrete manufacturing methods or in significantly improved characteristics of concrete products e.g. workability, strength, durability etc.

The precast concrete industry for instance is still largely based upon conventional concrete technology. The savings and capacity increase has been attained by mechanization and rationalization. Even acceleration of the hardening for instance by steam curing has been introduced quite empirically, and research has merely been utilized sporadically in this development for trouble shooting and for testing purposes, resulting in not much more than adjustments of materials' and manufacturing specifications. For labourers and civil engineers precast concrete is still largely concrete as it was on the building site in the old ages. Thus, the creation of the precast industry is due to the machinery industry, and to the engineers of design and construction.

Fig. 10 shows houses of concrete, cast on the site, in the famous English WELWYN GARDEN CITY, erected 1928-1932, about 30 miles north of London, and still a beautiful, habitable town. Fig. 11 shows a Danish urban development, erected near Copenhagen in 1969-1970. The concrete here has been manufactured entirely in factories as standard beams, columns, decks and walls according a sophisticated design, manufacturing and erection system, often designated: "system-building". But the concrete is in all important characteristics still the same material as in the Welwyn Garden City work, which was made by much more primitive means forty years ago.

Much research is now going on to develop concrete as a material. Powerful new techniques like micro-calorimetry, scanning electron microscopy etc. are put in action, but in the opinion of the writer we - the concrete research institute people - are still working far too much peace-meal, and with insufficiently clear technological aims of our work. This is delaying the possible innovation as compared with what could probably be achieved by forming strong, temporary project groups making continuous flows of information from basic and applied research to the industry's R & D work.

Efficient organization of R & D activity is well established in other fields of industry, and may well be forced upon the cement and concrete industry before long. This is because savings in the costs of materials in concrete commence to be attractive. This leads towards more efficient utilization of the cement, e.g. attempt to reduce the cement contents of concrete. This again brings the homogeneity and the level of the characteristics of cement more into focus than when conventional technique is used. At the same time cement industry is in a phase of remarkable rationalization, particularly with regard to sizes and capacities of rotary kilns. And it is not easy simultaneously to reduce the quality variations to much less than has always been quite acceptable to concrete manufacturers. Thus, the probability must be expected to increase in the years to come for failures in precast concrete manufacture, if research does not very soon mobilize considerable efforts in solving the most pertinent problems *before* failures necessitate painful and defensive investigations involving loss of prestige, controversies with authorities and retardation of further innovation and growth.

Fig. 12 is a compilation of some major fields of operation under problems for the concrete industry of to-day and tomorrow. The industry must have these things under control, technologically and economically, instead of being left to continuous trial and error of short-sightet trouble shooting. The problem outlined in fig. 12 may be transformed in the following framework of important areas of research:

CEMENT MINERALOGY. X-ray optical and electronic microscopy, DTA etc. together with data processing will soon make it possible to produce and interpretate at high rates unlimited amounts of data on mineral compositions of cement, clinker mineral textures, impurities etc. The influence of these factors on the properties of cement paste and concrete can then be attacked with great power. This research is of equal importance for the cement manufacture development.

POWDER TECHNOLOGY. Basic physico-chemical knowledge on the nature and behaviour of powdery materials have so far not been wide-

WATER

Industrial waste waters and even sea water will have to be made acceptable as mixing water in regions where fresh water supplies for domestic purposes tend to be threatened.

AGGREGATES

Selected high-quality aggregates will be demanded for special concrete of high density and strength. Resources of conventionally acceptable aggregates are being emptied in some regions and must be replaced by:

1. Crushed rock types of a wide range of qualities
2. Artificial aggregates
3. Gravels, so far considered too contaminated

MIXING AND PLACING OF CONCRETE

Automation and "flow" of manufacturing process will be aimed at by the mechanical and electronic industries involving:

mixing
transportation
placing
compaction
demoulding
registrations and controls

STRUCTURE FORMATION AND HARDENING OF CONCRETE

Savings in labour costs and innovation of concrete properties as a structural material point towards the use of:

accelerated hydration by steam, electricity and hot water curing

chemical accelerators

micro-structure reinforcements (monomer/polymers)

FIG. 12

ly applied in precast concrete technology. Hence, coming fields of intensive studies must be: Cement fineness and cement granulometry, and also more general studies of the nature and behaviour of finely ground powdery materials. Also cement manufacture is urgently needing studies of these subjects.

PASTE PHYSICS AND CHEMISTRY. The nature of fresh cement paste and its behaviour under vibration, transport etc. can now, by applying basic science and electronic experimental technique be dealt with in meaningful quantitative measures. Precast concrete innovation has an urgent need for this research, for instance to the optimizing of mix compositions, improvement of compaction, control of setting etc. Cement industry has interests in this knowledge with regard to slurry problems and false set phenomena etc.

STRUCTURE AND STRENGTH. Description of the hydration process, the structure formation and the nature of strength and of rupture in hardened concrete is now being approached by basic science supported by powerful, modern instrumentation and datamatics. This knowledge must be applied in studies with the aim to accelerate hydration, improve strength levels, control industrial manufacture processes and final products. The cement manufacture has much interest in the correlation of these studies with more accurate knowledge on cement characteristics etc.

DURABILITY. Time has come to remove the research on durability from the civil-engineering acceptance testing methodology and to apply science on ion-migration, rupture mechanics etc., aided by modern phycico-chemical instrumentation. New regions for habitation may well create unpleasant surprises with regard to deterioration problems. Important problems exist concerning de-icing deterioration, aggressivity of contaminated waters, alkali-aggregate reactivity and long-time effects of initial, plastic shrinkage.

CONCLUDING REMARKS

The intention with this paper has been to present some ideas and motivations for discussions going on in our country concerning cement and concrete research and R & D activity, both in cement industry and in the concrete industries to come.

We now find classical, post war ways of organizing institutional research with its heavy working procedures of cooperation and exchange obsolete, and not efficient as stimulation for the innovation of industry. I am convinced that the problem of 1970 is to facilitate flows of information so as to create operational entities of our knowledge on:

basic natural science
silicate chemistry
cement and concrete technology
cement manufacture
concrete manufacture
electronics and data processing

Naturally, exceedingly many aspects of this philosophy have not even been touched upon in the preceeding analyses despite the fact that we can see before us a rising wave of turbulent development both regarding the inherent problems of science and research and concerning the ways by which to make our achievements useful for technology and constructional enterprise. This is the basic challenge in the present situation.

And the problem of habitation to people belong to us in common, although there are degrees of differences with regard to actual technical levels, food consumption and so forth. This means that ways of improving the rate and efficiency of making concrete the soonest possible should be made available to all people.

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