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MUD STABILIZED BLOCKS PRODUCTION and USE

TECHNICAL MANUAL

Promoting community-level job creation and income-generating activities through the development of cost-effective building materials in Kyrgyzstan

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

Inclusive Sustainable Industrial Development

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MUD STABILIZED-BLOCKS: PRODUCTION and USE

TECHNICAL MANUAL

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FOREWORD

Materials, and the technologies that make use of them, tend to move forward in parallel. Since the beginnings of human civilisation, a whole range of materials, from natural fibres, to clay, limestone, rocks and wood, have been used to provide habitation and shelter. These materials were not simply exploited: they were also used in conjunction with numerous innovative techniques, such as the building of thick walls, sloping roofs, wooden reinforcements and different types of foundations. These innovations were designed to achieve the best results in the face of climatic challenges and other hazards experienced by people in different parts of the world. The development of burnt clay bricks, and then, the introduction of other building materials, including steel and cement, to produce concrete in various forms, have changed building construction in many ways. Plastics and polymers have also played a major part in the development of many kinds of new and innovative building materials. Plastics are used for doors and window frames, and other applications where they can offer a substitute for wood.

In general, such progress and innovation have flowed through into construction in the urban areas of under-developed and developing countries. While innovative materials aid rapid construction and are suitable for use in high-rise buildings, they are also energy-intensive and cannot be classed as green technologies.

In the last decade, global warming and the need for energy-efficient technology has seen the focus shift back to the consideration of more traditional techniques and has highlighted the need to employ local materials in a more systematic fashion by introducing machinery and technology.

UNIDO has initiated the Low-Cost Housing project in Kyrgyzstan, which uses mud stabilized-block technology to construct disaster-resistant housing. The project has two main thrusts. First, a large proportion of Kyrgyzstan's population is still using mud for construction, especially in the form of non-stabilized adobe bricks, and would benefit from greater use of technology. Second, the machine-made conduit-stabilized-blocks that the project focuses on are suitable for energy-efficient and disaster-resistant housing technology.

This technical manual concerns stabilized mud blocks and covers all aspects of the associated technology, such as the history of mud-brick based construction, the selection of raw materials, mix design, moulding, curing, technical specifications and their application in disaster-resistant housing.

The manual also provides close to 100 references on various aspects of stabilized mud block technology. We hope that this will help disseminate the technology among young entrepreneurs, and provide information to assist engineers and researchers in testing innovations with mud stabilized bricks made from the local clays that can be found in the various regions of Kyrgyzstan.

Dr. Amit Rai
UNIDO International Consultant

INTRODUCTION

Building materials have been used for centuries, in a variety of ways, to provide safe, climatically comfortable, and easy-to-construct habitats and shelters. People's exact choices of material have often been determined by the availability of local materials and the demands of nature.

The earliest humans may have lived in caves and used trees for housing, but eventually, they learned how to innovate and use natural materials such as soil, stone, and wood, which were readily available around them, in the building of houses and shelters. Mud and clay were among the first building materials they used because of their ease of mouldability and their adhesive properties when used with natural fibres. The adhesive quality of clay made it easy to work with and form into shapes. People used straw, grass, husks and other agricultural waste and fibres to make the structures more durable and provide the strength to cope with severe weather conditions. They added dung to such mixtures, and typically used wooden moulds to form adobe. Earth was often compacted using wooden planks to construct walls, known as "rammed" walls, and other building structures.

People also used logs, sticks, thatch, brush, stone, lime and wood for early construction purposes. In the Arctic, the Inuit used ice to build igloo homes. Uncut rocks and large stones were also employed. There are many ancient examples of "cyclopean" architecture, consisting of large uncut rocks, piled or stuck together with some form of adhesive. Numerous historical religious buildings such as temples, mosques, and churches were also built using natural raw materials.

In recent times, humans have developed more advanced and versatile composite building materials such as concrete, cement, and flowable and aerated concrete. Concrete is generally made of sand or gravel, mixed with cement and water. When the mixture dries, it becomes hard and stone-like. Before the mixture sets, it can easily be poured into moulds and formed into different shapes. Because concrete is brittle, it is often reinforced with steel or other metals. Now, even fibre reinforced concrete is used extensively in the construction of structures for specialist applications.

New technology has also made construction using metal more practical than before. Most high-rise buildings and skyscrapers are built using frames made from steel or other metals. While steel was traditionally the favoured metal for such constructions, new alloys are now sometimes preferred on the basis of their resistance to corrosion.

Light-weight concrete can be used to make buildings lighter, save materials, and make structures more stable and durable.

Plastic is another widely used modern building material. Formed from polymers, plastics can be moulded easily while in their liquid state. Compared with metal and many other materials, plastic is less dense and lower in cost. Plastic is often used for pipes and in building interiors. Nowadays, wood-plastic composite offers a new material which provides an alternative to forest-produced wood and helps save natural resources.

Modern buildings often use glass, not only for windows but as the primary exterior building material. Glass skyscrapers and other structures have become popular as a result of their aesthetic appeal. Transparent glass also allows natural light to be used to illuminate the interiors of buildings.

In spite of all these developments, which are especially relevant for those in higher income groups and urban sectors, people living in semi-urban areas and village-dwellers still use various forms of mud bricks and blocks, which are more readily available and have superior thermal and acoustic properties. As clay is widely available in most parts of the world, people in many countries use burnt clay bricks as the principal material for walls. Clay flooring and roofing tiles are also widely used. The clay thus used can be found in various traditional forms, such as hand moulded, rammed wall and burnt clay bricks.

Burnt clay bricks are a well-established material requiring little in the way of production technology. Hand moulded, unburnt bricks, however, require materials, machines, and technology, in order to produce simple, interlocking mud stabilized-blocks. These bricks and blocks can be used in disaster-resistant housing technology, and also save energy and help the environment.

This document discusses various detailed topics and technical information associated with mud stabilized-blocks, such as raw materials, mix design, the moulding process, curing methods and the feasibility of using various types of machines. One of the aims of such stabilized brick production, using the process described, is to provide training and development, using an easy-to-adopt technology, for young, unemployed people. This manual provides an introductory guide to disseminate knowledge about stabilized mud block technology, and suitably trained young people may adopt it in providing construction solutions for rural and semi-urban societies in the countryside.

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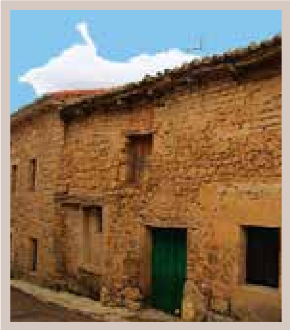
REPRESENTATIVE CLAY AND EARTH BUILDINGS



ADOBE HOUSE
EGYPT AND IRAQ

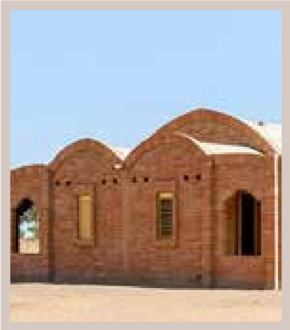
An adobe house, built using sun-dried bricks/ blocks and covered with earthen plaster. Such houses were commonly built in Egypt and Iraq, and date from around 6000-6000 BCE.

MUD HOUSE
INDIA

Traditional circular mud house with a bamboo roof. These houses are known as Bhunga and are built using mud walls with cow dung plaster. This type of construction has existed for centuries and is still used today in the Indian state of Gujarat.

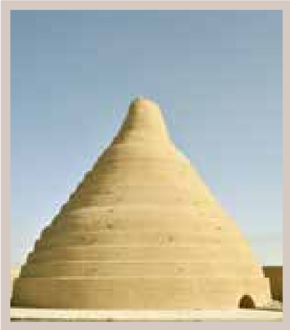
DJENNÉ MOSQUE
MALI

The great mosque of Djenné is the largest mud built structure in the world. Located in a UNESCO world heritage site in Mali, it was built during the 13th century.



PRIMARY SCHOOL
TANOUAN IBI, MALI

The Dutch firm, Levs Architecten, used compressed earth blocks from local clay mines to build the barrel- vaulted structure of this primary school in the village of Tanouan Ibi, in Mali, in 2013.



YAKHCHAL
IRAN

Iranian engineers mastered the technique of storing ice in the desert in the middle of the summer! This structure comprises a large mud brick dome, some 20m high, which was built in 400 BCE.

TAOS PUEBLO
NEW MEXICO, USA

The pueblos are considered to be some 1000 years old and are still inhabited by communities in the United States. The location has been designated a UNESCO World Heritage Site.

MUD STABILIZATION

FOR BRICK MAKING

To improve the quality of bricks, proper clay selection and mix design is essential. Careful selection of raw materials including clay, lime, gypsum, and cement, assists in the production of strong, high-quality bricks/blocks.

Mud Stabilization for brick making

The compressed/stabilized mud block is the modern descendent of the moulded mud block, more commonly known as the adobe block. The idea of compacting earth to improve the quality and performance of moulded mud blocks is, however, far from new, and it was with wooden tamps that the first compressed earth blocks were produced. This process is still used in some parts of the world.

Earth blocks are a construction material made primarily from soil. Types of earth block include compressed earth/mud blocks, compressed stabilized earth/mud blocks, and stabilized earth/mud blocks. Compressed/ stabilized mud blocks or pressed mud blocks are building materials made primarily from damp soil which is compressed, at high pressure, to form blocks. If the blocks are also stabilized, using a chemical binding agent such as Portland cement, they are known as compressed, stabilized mud blocks or stabilized mud blocks. Creating compressed earth blocks (CEBs) differs from rammed-earth in that the latter uses a larger formwork into which earth is poured and manually tamped down. Rammed earth methods result in forms that are larger than adobe or individual building blocks (such as a whole wall, or more, at any one time) and uncompressed. Compressed earth blocks use a mechanical press to form blocks from a suitable mix of partially dry inorganic subsoil, non-expansive clay, aggregate, and, sometimes, a small amount of cement. Stabilized mud blocks are built into walls using standard bricklaying and masonry techniques. The mortar may be a simple slurry made of the same soil/clay mix without aggregate, spread or brushed very thinly between the blocks for bonding. Cement mortar may also be used where high strength is required, or when construction during freeze-thaw cycles may cause stability issues. Hydraform blocks are shaped so that they can form interlocking structures.

HAND MOULD ADOBE
Using clay and locally available agro-waste

RAMMED WALL HOUSE
Using large mud blocks

MUD STABILISED BLOCK
Produced using hydraulic machines

MACHINERY AND TECHNOLOGY

FOR PRODUCING MUD STABILIZED-BLOCKS

The introduction of manual and semi-mechanized machines to produce mud stabilized bricks and blocks has improved the overall properties of the final products. Using semi-automatic hydraulic machines has also resulted in increased production capacity. Different sized blocks can be produced by changing the moulds on a single machine.

Machinery and technology for producing mud stabilized-blocks

Mud stabilized-blocks can be produced using various kinds of machines. For decades, the blocks were produced using only clay and some added agro-waste, such as straw and weeds. Over the centuries, large numbers of houses have been constructed using these hand moulded, or simple wooden moulded, un-stabilized and unburnt bricks/blocks.

The introduction of stabilizers such as lime, cement, gypsum, and fly-ash, went hand-in-hand with a need to apply some manual or mechanical pressure in order to achieve a higher density, lower water absorption, and a higher compressive strength. Using hydraulic machines to carry out the stabilization step has also made the blocks more economical to produce by reducing the percentage of stabilizing agents required, and has resulted in improved physical and mechanical properties in the finished products. Apart from the Hydraform machines adopted by UNIDO, there are many other types of machines available, in various countries, for producing mud stabilized-blocks . Manual machines for producing mud stabilized-blocks are also available and widely used in rural and village-level projects. Blocks can be produced in various sizes and shapes for a range of building types, including disaster-resistant constructions.

WOODEN MOULD
FOR PRODUCING ADOBE
BRICKS

SIMPLE MANUAL MACHINE
FOR PRODUCING MUD STABILIZED
BRICKS/BLOCKS

HYDRAFORM MACHINE
FOR PRODUCING MUD STABILIZED
BRICKS/BLOCKS

TECHNICAL SPECIFICATIONS

HYDRAFORM MACHINES

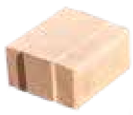
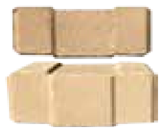
The specification and production capacity of the Hydraform machines adopted by UNIDO to promote this technology, under the project, in Kyrgyzstan, is as follows:

POWER SOURCE	3-PHASE ELECTRIC MOTOR 440V/11kW
DIMENSIONS (m)	2.95 X 1.7 X 1.7
WEIGHT (kg)	1600
HYDRAULIC POWER-PACK CYLINDERS	1
COMPRESSION CHAMBERS	1
LOADING ASSEMBLIES	1
HYDRAULICALLY POWERED PAN MIXER CAPACITY (l)	140
TOW-HITCH TROLLEY & ROAD TYRES	YES
BLOCK PRODUCTION (units/hour)	200
SPACE REQUIRED (m^2)	1500-2000
PEOPLE REQUIRED PER MACHINE (EXCLUDING SIEVING/CURING)	8
SUITABLE FOR	SITE PRODUCTION FACTORY

TECHNICAL SPECIFICATIONS

INTERLOCKING BLOCK MOULDS

Sizes of blocks that can be produced using the same machine and employing different moulds:

				
W	220	150	220	220
H	115	115	115	115
L	115-220	120-240	up to 240	240
	9-11	7-8	4-8	9-11
	1500-2000	1500-2000	1500-2000	1500-2000

SIZE (mm)	WEIGHT (kg)	PRODUCTION CAPACITY

SELECTION OF MATERIALS

Selection of high-quality clay, processing, and mix design are important factors in attaining suitable compositions to produce high-quality blocks. Selection of soils with a defined range of plasticity, and cement stabilized under set parameters, both contribute towards the production of high-quality blocks to attain the desired properties.

Soil selection and stabilization of mud stabilized-blocks

Not all soil types are suitable for earth-based construction, especially that using mud stabilized-blocks. Topsoil and organic soils must not be used. But, with some knowledge and experience, it is possible to choose from many different types of soil to produce mud stabilized-blocks. Identifying the properties of a soil is essential in producing good-quality products. Simple sensitivity analyses can be carried out after some basic training. For example, cement stabilization will be better for sandy soils, and lime stabilization for clayey soils.

Good soil choices for compressed stabilized earth blocks

The selection of a stabilizer will depend on the quality of the soil and the project's requirements. Cement is preferable for sandy soils and to achieve greater strength quickly. Lime is better for very clayey soil but takes longer to harden and to produce strong blocks.

Interlocking blocks using the Hydraform machine can be produced from sandy soil with a clay content of between 5 and 20%, and a silt content of between 5 and 25%. Blocks can even be produced from soils with a clay and silt content higher than these figures, but the plasticity index would need to be determined in order to check whether the soil is suitable for block production. Generally, soil with lower clay and silt proportions, below 10%, will be difficult to handle when it is removed from the machine. Conversely, soil with a higher clay and silt content, above about 35%-40%, will need to be blended with sandy soil to ensure its suitability.

SOIL FOR CEMENT STABILIZATION (%)

GRAVEL	SILT
15	15
SAND	**CLAY**
50	20

SOIL FOR LIME STABILIZATION (%)

GRAVEL	SILT
15	20
SAND	**CLAY**
30	35

MAIN RAW MATERIALS

TO PRODUCE MUD BASED BLOCKS

- MUD/SOIL
- CEMENT
- COARSE SAND/ STONE DUST
- WATER

TECHNICAL SPECIFICATIONS

- The soil must be free from organic material, must not contain harmful quantities of salts, and should contain sufficient clay to bind the blocks, so that they may be handled immediately after manufacture, without disintegrating. Generally, the soil should comply with the grading and plasticity requirements set out below.

SOIL RANGE A MAX	SOIL RANGE A MIN		SOIL RANGE B MAX	SOIL RANGE B MIN
10%	35%	% BY MASS PASSING THROUGH A 0.075MM SIEVE (SILT AND CLAY FRACTION)	10%	25%
15		PLASTICITY INDEX (MAXIMUM)	10	
~ 4 MPa		ESTIMATED BLOCK STRENGTH (AFTER CURING)	~ 7 MPa	

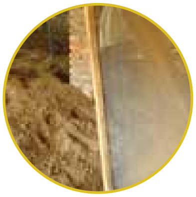
- Soils with a higher plasticity (greater than 15) are acceptable, if the material is treated with lime; laboratory testing will confirm the dose needed and additional curing time required.

- Water must be clean and should not contain any harmful quantities of acid, alkalis, salts, sugars, or any other organic or chemical material. Drinking water is normally satisfactory.

- The cement content required will typically be in the range 4-7%, by volume of dry soil, for 4MPa blocks and 7-10%, by volume of dry soil, for 7MPa blocks.

TECHNICAL SPECIFICATIONS

SOIL PREPARATION FOR STABILIZED-BLOCK PRODUCTION


1. Clay containing weeds and other organic matter should be avoided.

2. Prepare the soil using a sieve to ensure that uniform particles are obtained.

3. Soil/clay which is free from any organic matter and uniform in particle size is always suitable for stabilised block production.

VOLUME BATCHING

Initial volume batching ratios are set out below; these can be refined after the block strength has been tested, on fully cured blocks, by an approved laboratory.

ESTIMATED VOLUME BATCHING QUANTITIES FOR INITIAL TRIAL MIXES

5%	8%	PROPORTION OF CEMENT (by volume)
4MPa	7MPa	ESTIMATED COMPRESSIVE STRENGTH OF BLOCKS
1 BAG	1 BAG	NUMBER OF 50kg (33l) BAGS OF CEMENT
10	6	NUMBER OF 65l WHEELBARROWS OF SOIL
70	40	BLOCKS MADE PER BAG OF CEMENT (approx.)

TECHNICAL SPECIFICATIONS

SOIL TEST

The most commonly used soil test is to compress a 'sausage' of slightly moist (not wet) soil in your hand, then open your hand; if the sausage does not feel 'sticky' and breaks cleanly under the thumb's pressure, the soil is probably suitable for making blocks. However, it may be possible to select a higher quality of soil for block production by submitting samples of potential construction soil to a reputable laboratory for particle-size-distribution analysis. The normal proportions of the constituents of soil are shown below. Where analysis shows that the constituents of a candidate soil fall within these normal ranges, the soil can be used for block making:

S. Number	1	2	3	4	5
PARTICLE SIZE	FINE GRAVEL	COARSE SAND	FINE SAND	SILT	CLAY
OPTIMUM PROPORTION (%)	7	30	23	20	20
ACCEPTABLE PROPORTIONS (%)	0-10	20-35	20-30	15-30	10-30

In addition to selecting the right soil, a higher cement/stabilizer content in the mix will result in stronger blocks. The table below shows a summary of the ideal overall composition of blocks, including stabilizer proportions.

IDEAL COMPOSITION FOR SOIL BASED BLOCKS:

S. Number	1	2	3
MATERIALS	SOIL/CLAY/MUD	COARSE SAND	CEMENT
PERCENTAGE	30-60	40-60	8-12

PHOTOGRAPHIC DISPLAY

Ribbon pan mixer for preparation of composition for moulding blocks

Removal of environmental stabilized mud blocks from their moulds and subsequent cleaning

The hopper is filled with raw material before moulding

Full and half-size interlocking mud
stabilized-blocks

The mould is filled with materials before pressing

Moulds for making half and full-size blocks

STACKING AND CURING

TO PRODUCE MUD STABILIZED BLOCKS

Newly produced blocks always require careful stacking and curing if the desired properties are to be obtained. Proper spacing between each block, daily water curing, and timely covering of stacks helps produce blocks of a good strength.

Stacking and curing of the blocks

When first produced, stabilized-blocks are very low in strength. To attain a suitable strength, as well as other physical properties, blocks should be cured for three weeks. Cement-based stabilized-blocks reach their cured strength in three weeks, but the lime and gypsum may continue to gain strength over time, even after blocks have been incorporated into the construction. Whenever cement is used, it must be covered and cured properly. Cement needs water to gain strength (hydration) and it requires 28 days to achieve full strength. It achieves 65% of its cured strength in the first seven days, reaching about 85%-strength by 14 days. The remainder of the cured strength is obtained during the third week of formation and curing.

PLACING: Blocks should be placed on a flat surface with appropriate spacing. There should be proper spacing between all the stacked rows being cured.

STACKING: The stacked height should not be more than five feet to ensure easy handling.

CURING: Curing should start from the second day after the block has been cast.

WEATHER: In a moderate/hot climate, the blocks should be cured twice a day. If the weather is very hot, the blocks may need to be cured three times in a day.

COVERING: Keep the blocks cured and covered for at least 14 days; additional curing may help achieve higher strengths. It is advisable to cover the blocks with plastic sheets to reduce the rate of water evaporation and maintain the proper humidity. This is useful in helping lime or gypsum based blocks gain strength. To avoid rapid loss of water and growth of cracks, a plastic sheet may also be placed on the ground, underneath the stack, before stacking begins.

TRANSPORT: The stacking yard should be designed to allow the easy movement of trucks and loading of the materials in an orderly manner.

SUSTAINABILITY
AND ENVIRONMENTAL FRIENDLINESS

Mud stabilized-blocks always qualify as green building materials; clay is a traditional construction material and is widely available throughout the world, and the production of mud blocks using machine-based stabilization processes consumes less energy than producing an equivalent quantity of burnt clay or cement bricks. Moreover, use of interlocking blocks can also result in material savings when joining and plastering sections of wall.

Sustainability and the environmentalfriendliness of mud stabilized blocks (MSBs)

- Earth is a material that should be sourced locally; soil should preferably be extracted from the construction site itself or transported to the site from nearby
- Earth-based construction uses easily adaptable and transferable technology
- Earth is a cost and energy effective material
- Construction using earth requires much less energy and is less polluting than using country fired bricks

	Initial embodied energy (MJ /m3 wall)	Carbon emissions (kg CO2 /m3 wall)
CSEB Wall	631	56.79
KFB* Kiln Fired Brick	2,356	230.06
CFB Country Fired Brick	6,358	547.30

*Kiln fired bricks are often called wir- cut bricks

ENERGY EFFECTIVENESS

- Mud stabilized-blocks consume 11 times less energy than country fired bricks
- Mud stabilized-blocks are 13 times less polluting than country fired bricks

	Initial Embodied Energy (MJ/m³ of materials)	Carbon emission (Kg of CO_2/m³ of materials)
MSB*	548.32 MJ/m³	49.37 Kg of CO_2 /m³
CFB	6,122.54 MJ/m³	642.87 Kg of CO_2 /m³

*MSB produced on site with 5% cement

COMPARATIVE ANALYSIS AND ADVANTAGES OF MSBs

MSB technology has many advantages, compared with other, equivalent technologies. Its main benefits are: it is affordable, environmentally sound, user-friendly, performs well, and is versatile. However, as with any other construction product, care must be taken to ensure that good quality materials are used. Obtaining high-quality MSBs depends on access to good and locally available soil, selecting a stabilizer that will complement the soil type, and following good practice during the production of the blocks and their use in construction.

TECHNICAL SPECIFICATIONS

COMPARATIVE ANALYSIS AND ADVANTAGES

OF MUD STABILSED BLOCKS

PROPERTIES	INTERLOCKING STABILIZED SOIL BLOCK	SUN-DRIED MUD BLOCKS	BURNT CLAY BRICK	STABILIZED SOIL BLOCK	CONCRETE MASONRY UNIT
DIMENSION (LxWxH) (cm)	26.5x14x10	25x15x7-40x20x15	20x10x10	29x14x11.5	40x20x20
WEIGHT (kg)	8-10	5-18	4-5	8-10	12-14
TEXTURE	Smooth and flat	Rough and powdery	Rough and powdery	Smooth and flat	Coarse and flat
BLOCKS/m^2	35	10 to 30	30	21	10
WET COMPRESSIVE STRENGHT (MPa)	1-4	0-5	0.5-6	1-4	0.7-5
THERMAL INSULATION (W/mC)	0.8-1.4	0.4-0.8	0.7-1.3	0.8-1.4	1-1.7
DENSITY (kg/m^3)	1700-2200	1200-1700	1400-2400	1700-2200	1700-2200

BLOCK

GENERAL INFO

PERFORMANCE

Information for this chart was gathered from the Craterre publication: "Compressed Earth Blocks: Manual of Production" and GET

E NERGY EFFICIENT
A FFORDABLE
R ESISTANT
T RANSFERABLE KNOWLEDGE
H EALTHY

C OST EFFECTIVE
O PPORTUNITY
N ATURAL
S USTAINABLE
T ECHNICAL
R ENEWABLE
U SER FRIENDLY
C OMMUNITY IMPROVEMENT
T OUGH
I NNOVATIVE
O CCUPATION
N EW TECHNOLOGY

MSB
ADVANTAGES
MUD STABILIZED-BLOCKS

·1·

SANITATION

Mud Stabilized-blocks (MSBs) are ideal for water and sanitation applications. MSBs can be used to construct water tanks, linings for pit latrines, and septic tanks. Examples of above ground water tanks exist with volumes up to 30,000l, and of below ground tanks of up to 200,000l. The cylindrical shape of the final structure and the block interlock mechanism both provide good resistance to water pressure.

·2·

ECONOMICAL

MSB technology offers affordable construction. The bricks are weatherproof, meaning there is no requirement for a plaster finish on the building exterior. In addition, thanks to the interlocking design, little cement is needed between block joints, allowing walls to be constructed rapidly, with associated savings in labour. Moreover, MSB machinery is easy to transport and use on construction sites.

·3·

EASY-TO-USE

The MSB machine is easy-to-use and to maintain. After long periods of use, repairs are easy to carry out locally, using scrap material and welding. Thanks to the interlocking design of the blocks, walls are easy and quick to construct.

·4·

AESTHETIC

MSB technology is growing in popularity as a result of its aesthetic appeal and has been successfully embraced by many communities that have developed the know-how to make use of it. A further benefit is that being an earth-based technology, it fits naturally with the common and traditional methods that local communities are familiar with.

·5·

STRUCTURAL

MSB constructions have been proved to be strong and durable compared with traditional construction methods. They are suitable for the construction of multi-storey buildings and have good compressive strength.

·6·

ENVIRONMENTAL

MSB technology provides an alternative to the widely seen fired brick, whose use, at present, is causing serious environmental degradation due to deforestation and the destruction of wetlands.

·7·

EDUCATIONAL

As a new technology, this construction method can enhance the local skill-base and offers an income-generating opportunity for numerous groups of people. Developing the necessary skills is straightforward, and, given the nature of the product, can stimulate educational discussions about environmental issues.

HYDRAFORM MACHINE

The Hydraform machine, with its specially designed mould, can produce conduit blocks suitable for constructing earthquake-resistant houses. Vertical and horizontal reinforcement can be added to make them disaster-resistant. The blocks it produces can also be used as filler materials in the framed structures of multi-storey buildings.

Hydraform building systems

These are the best practice specifications for building single-storey residential housing using 220mm wide Hydraform interlocking dry stacked soil-cement blocks commonly used in South Africa and India.

BLOCK STRENGTH AND QUALITY

- Blocks below a damp-proof course must have a nominal 28-day strength of 7MPa.
- Blocks above a damp-proof course must have a nominal 28-day strength of 4MPa. For external walls subject to wind and rain, the nominal 28-day strength should be 7MPa or above.
- Cracked, weathered or damaged blocks should be discarded
- Only blocks that have been cured for 7 days, and allowed to stand for 14 days, should be used.

Compressive strength testing of Hydraform blocks

FOUNDATIONS

- Foundation trenches and foundations must be in accordance with professional engineering designs.
- Strip footing foundations should be at cast level. Steps should be 130mm to allow for the block height with a mortar joint of 15mm.

FOUNDATION WALLS

- These must be built with 7MPa blocks embedded in a mortar bed of between 10 and 15mm.
- A minimum of three courses, embedded in mortar, is required below the damp-proof course.
- The foundation wall should extend above the normal ground level to a minimum height of 150mm.
- Cross-bonding must occur at corners only.
- The foundation wall should stand for a minimum period of 24 hours before compaction of infill below the surface bed commences.
- No construction on top of foundation walls should take place for a period of 24 hours after completion of the foundation walls.

SUPERSTRUCTURE

- All block work must be carried out with thoroughly dried blocks; there must be no moisture inside the block.
- The first course of blocks above the slab or damp-proof course must be embedded in mortar. Blocks in this levelling course should be levelled in all directions, and to the same level as adjacent blocks.
- Blocks must be dry stacked in stretcher bond to lintel level, which is usually 2.1m above the level of the internal floor.
- Windows and door frames must be secured using lugs, bent to joint level.
- Reveals of windows must be plastered.
- 75mm pre-stressed concrete lintels must

be used over doors, windows and openings. Lintel bearing length on each side of the opening should not be less than 300mm.
- Gaps between block work and steel window or door frames must be filled with mortar.
- All intersections between walls must be built using alternating half blocks.
- All corners must be built using cross-bonded half blocks.
- The gap between lintels and block work above the lintel should be filled with mortar. The ring beam must be constructed at the top of the wall by embedding all block work above the lintel level in mortar. Mortar joints must be between 10 and 15mm. Brick reinforcement must be placed in all mortar joints. Brick reinforcement should comprise 2.2mm diameter longitudinal wires at 130mm separation, centre-to-centre. Brick reinforcement should overlap at corners and intersections. A minimum of four mortar joints is needed to form a ring beam.
- No chasing should be carried out in the ring beam.
- Horizontal wind bracing in the plane of the ceiling should be carried out according to a professional engineering design.

ROOF AND ROOF ANCHORAGE

- One 4mm diameter galvanized-steel-wire anchor tie per rafter must be placed through the mortar joint at a minimum of four courses below the top of the wall.
- The roof must be constructed according to a professional engineering design.

SERVICES

- Services can be wall mounted on all walls or stored in vertical rebates chased into the wall below ring beam level. Chasing must be vertical only and to a depth not exceeding 50mm.

MORTAR

- All mortar must be Class II mortar with a minimum 28 days' compressive strength of 7MPa when measured by laboratory tests, and 5MPa when measured by on-site work tests. A mix of one bag (50kg) of cement (42.5MPa) to three wheelbarrows (3 x 65l) of building sand is suggested.

Use of conducting and half mud-blocks for disaster-resistant housing technology

- Interlocking blocks can be used with dry masonry to reduce the cost of construction.
- Cement may be used in the conduit blocks, with reinforcement, to make it more stable and earthquake resistant.
- In conduit blocks, vertical and horizontal reinforcement should be used to make structures more stable.
- Horizontal and vertical reinforcement should be tied-up to pack, and enclose the building so that it can sustain even a high-intensity earthquake.

ILLUSTRATIVE PHOTOGRAPHS

COMPRESSIVE STRENGTH TESTING OF HYDRAFORM BLOCK

FOUNDATIONS

FOUNDATION WALLS

SUPERSTRUCTURE

ROOF AND ROOF ANCHORAGE

INTERLOCKING BLOCKS IN WALL CONSTRUCTION

ILLUSTRATIVE PHOTOGRAPHS

USE OF CONDUIT BLOCKS FOR WALL CONSTRUCTION

Examples of the structures made from interlocking mud stabilized-blocks produced using Hydraform machines.

Illustrative examples of associated construction practices in India.

Tying vertical and horizontal reinforcement together for a disaster-resistant house

Creating space at the join of two walls for the addition of vertical reinforcement

Filling with mortar after tying the horizontal and vertical bars together

The placing of vertical reinforcement for disaster-resistant housing

Mortar filling after the placing of the vertical and horizontal bars

ILLUSTRATIVE PHOTOGRAPHS

Use of half blocks at the corner of a wall

Joining together of horizontal reinforcement

Residential house constructed from mud stabilized bricks/ blocks with a sloping roof

Residential housing using interlocking blocks with flat roofing

Double-storey university building, using interlocking blocks with a flat roof

Community, double-storey building with a sloping roof

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CONCLUSION

The needs-assessment study, carried out as part of the low-cost housing project in Kyrgyzstan by the United Nations Industrial Development Organization (UNIDO), highlighted the importance of mud stabilized-block technology in the country. In the project, most of the information about mud blocks has been assembled to form a technical manual with the aim of sharing and highlighting the various advantages of using mud stabilized-blocks for housing construction. The manual will help entrepreneurs and students to carry out experiments and research in a more systematic way on stabilized mud blocks made using the Hydraform machine.

Mud has been used as a material for centuries. There are countless examples of its use for residential and other purposes, including brick production for construction. However, as a result of the introduction of other fast setting and more durable materials, such as cement-based products, the inherent properties and benefits of mud/clay blocks, energy efficiency, environmental friendliness and ready availability, were often overlooked.

In opting for high-strength, fast-setting construction materials, society has also chosen to favour materials that are energy-intensive and better suited to high-rise and urban construction. Yet a large proportion of the population, in any given country (including Kyrgyzstan), lives in rural areas and requires easy-to-use, affordable building materials and housing technologies. Various studies conducted on the production of mud stabilized-blocks in different countries, and under different climatic conditions, confirm that blocks can be used as filler material in framed structures and non-load bearing housing construction. The technology is simple, easy-to-adopt and suitable for production in small local centres with community participation. The products and technologies lend themselves to skills-development among unemployed young people; employment can be generated by setting up low-cost production units. UNIDO also trains people in the construction of disaster-resistant houses using stabilized mud blocks.

With the aim of disseminating the technology further, this technical manual has focused on the production and use of mud stabilized-blocks using Hydraform machines, which were the machine of choice for the project. There are a large number of organizations that continually work on mud brick/block technologies, and most of this work is cited in the bibliography as a pointer to additional information and an aid to those who wish to carry out further research work.

PROJECT OVERVIEW

UNIDO'S technical assistance project, "Development of cost-effective building material production promoting community-level job creation and income-generating activities" has two main aims. First, promoting innovative, low-cost sustainable manufacturing technologies within the Kyrgyz Republic, and, second, disseminating knowledge about cost-effective, environmentally friendly building materials that can be easily adopted by local builders for housing and irrigation purposes. The project is funded by the Russian Federation and is fully consistent with the needs and the priorities set out by the country's government. These can be found in the Kyrgyz Republic's National Sustainable Development Strategy for 2013-2017.

The main project counterparts are the Ministry of the Economy of the Kyrgyz Republic, and the State Agency for Architecture, Construction and Communal Services (Gosstroy). Within the framework of the project, UNIDO established a cooperative relationship with the Kyrgyz-Russian Slavic University, which is expected to host the project-facilitated Technology Demonstration and Training Centre.

The broad objectives of the project cover the identification and exploitation of locally available raw materials through the development of cost-effective, energy-efficient and environmentally friendly building materials and housing technologies. The scope of the project was defined with a special focus on local raw materials, medium-scale technologies, and also skills development, in order to share the benefits to create jobs and develop skills.

Transfer of know-how and technology to local manufacturers for the production of building materials was also facilitated through the establishment of partnerships with a private sector enterprise, which is a project beneficiary in terms of developing expertise in the simple operation of block making machines. The beneficiary enterprise is also expected to serve as a Technology Production Centre for local skilled workers, including young experts, students, engineers and other interested stakeholders.

This technical manual on mud stabilized-block technology provides support for the first step in the partnership between UNIDO and private companies to create the Technology Production Centre. It will also serve to promote the centre and its acceptance locally.

A training centre for environmentally friendly and cost-effective housing technologies will help ensure the long-term sustainability of the skills and technologies promoted in the project and disseminate them among local manufacturers. The project is also expected to facilitate local job and income creation, which will improve people's livelihoods, especially in rural areas.

MUD STABILIZED-BLOCKS: PRODUCTION and USE

TECHNICAL MANUAL

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

The project is funded by the
Russian Federation

Inclusive
Sustainable
Industrial
Development

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