1
1978

HOUSING & BUILDING RESEARCH
JOURNAL

HOUSING & BUILDING RESEARCH INSTITUTE
MIRPUR, DACCA, BANGLADESH

HOUSING AND BUILDING RESEARCH JOURNAL

Vol. 1, No. 1, 1978

Housing And Building Research Journal

The Housing and Building Research Institute, Dacca, has been established to find ways and means to utilise local materials in construction more effectively and economically and improving quality of construction and technique.

Towards these aims, the Housing & Building Research Institute has been continuously paying its attention and extending its services to meet the needs of the construction industry by helping it in improving its standard. Besides, studies on some basic techno-economic problems of immediate benefit to the country have been undertaken and progressed satisfactorily. Their results and findings in many cases are found to be encouraging. As research is a continuous process, studies are being carried out to get more effective results. However, to the common builders, architects and engineers the findings and results of the studies already done will be of interest and value. It has, therefore, been decided to bring out, for the first time, a publication of the Institute, containing its activities. It is hoped that this may create interest amongst the builders and awarness of the Institute to utilise its resources.

This publication being the first of its kind by the Institute, perhaps bears the blemishes of the rudiments and the Institute will welcome gratefully constructive suggestions to improve its quality.

(M. A. Khan)
Director
Housing & Building Research Institute,
Mirpur, Dacca.

All communications for publication should be addressed to the Editorial Board, Housing & Building Research Journal, Housing and Building Research Institute, Darus-Salam, Mirpur Dacca-18, Bangladesh.

Housing And Building Research Journal

Vol. 1, No. 1, 1978

CONTENT

Housing and Building Research Journal *Volume 1, Number 1, 1978*

Experimentation with Double Curvature Shell Roof as Low-Cost Roofing Element

KAZI ATA-UL HAQUE
Housing and Building Research Institute, Dacca

Abstract

The double curvature funicular shell carries load in membrane state by pure compression. Shear and tensile stresses being absent, practically no reinforcement is needed in the shell and the compressive stresses also are very low.

Thus it is possible by the help of this type of shell to obtain 'strength through the form' and to utilise this aspect of nature in economising comsumption of scarce materials like cement, steel and timber for low-cost housing.

Experimentation of the shell has been carried out in the Institute for practical use in the field on the basis of simplified but accurate enough informations so far available in this regard. Studies are still continuing on its further improvements and newer ideas and technique to achieve economy and simplification of the technique.

1.0. Introduction :

ROOFING of a building costs about 25% to 30% of the total cost. Saving in this item alone will appreciably help in reducing the cost. Active study and experimentation have been carried out from sometime past on this particular topic at the Institute. Several means, leading to this objective has been conceived of and acted upon. Construction of funicular double curvature concrete tile roof is one of such attempts which appears to be suitable in local conditions.

The shell of double curvature is such type of construction in which maximum benefit is obtained structurally from its shape and the funicular shell of double curvature, is the most efficient of all shells. Shells of eggs, nuts and the human skull are common examples of double curved shells in nature. With the introduction of such a shallow shell, scopes have been widened for minimising the cost of roofing houses and industrial structure by obviating the need of reinforcement and the usual thickness of reinforced concrete roof itself as the double curvature funicular shells carry load in its membrane state by pure compression.

To make the most use of this aspect of nature of obtaining 'strength through the form' theory of Double Curvature Funicular shells was developed which found its wide applications in roofing different types of houses and industrial structures in some developed countries.

Based on the same theory, attempts have been made at the Institute to construct roofs with funicular double curvature concrete tiles which have shown promising results.

2.0. The Shape of D.C. Shell.

A simple frame, geometrically similar to the ground plan of any desired structure, is made of wood and a piece of flexible hessian is stretched tight across it and a uniform layer of wet concrete is placed on it. The hessian, thus covered with wet concrete sags little and assumes the shape of funicular surface corresponding to the load. When the concrete sets, the shape of funicular surface so formed is inverted, it will now carry loads by pure compression provided it is stiffened by edge beams.

3.0. Principle/Theory of D.C. Shell.

In designing this funicular double curvature shell, it is usual practice that corresponding shape is to be found for an assumed condition of stress in the shell i.e. membrane compression under uniform vertical loading. Shear and tensile stresses being absent, no reinforcement is needed in the body of the shell and the compressive stress also are very low.

3.1. Surface of the Double Curvature Shell.

Height of different points in the shell may be found out from the following relationship between real and fictitious stresses acting on any element of the doubly curved shell and its rectangular projection on a horizontal plane and is expressed

$$\frac{d^2z}{dx^2} + \frac{d^2z}{dy^2} = -\frac{w}{N}$$

where,

x and y are cartesan co-ordinates measured on the horizontal plane.

z=height of the shell, middle surface at any point.

w=vertical load per unit area of the curved surface.

N=membrane compressive stress.

This is the equation of a doubly curved funicular shell but the solution of the differential equation is a very lengthy and complicated one and it takes the form as quoted below for rectangular ground plan.

$$Z = \frac{16wa^2}{N\pi^3} \sum_{n=1,3,5\ldots}^{\alpha} \frac{1}{n^3}(-1)^{\frac{n-1}{2}} \left(1 - \frac{\cosh\frac{n\pi y}{2a}}{\cosh\frac{n\pi b}{2a}}\right) \left(\cos\frac{n\pi x}{2a}\right)$$

where a = half length of the shell

b = half width of the shell

x,y = co-ordinates of the grid points from the centre of the shell.

The exact equation to the shell of rectangular ground plan has been approximated for the sake of simplicity into the following form and is accurate enough for setting out the funicular shell of rectangular ground plan.

$$Z = \frac{5}{8}\frac{w}{N}\frac{1}{a^2+b^2}(a^2-x^2)\ (b^2-y^2)$$

$$\text{or}\quad Z = \frac{Z_{max}}{a^2b^2}(a^2-x^2)\ (b^2-y^2)$$

where, Z_{max} =maximum rise i.e. rise at the centre of the shell.

Thus the ordinate for shells of rectangular ground plan may be found from the exact equation to the shell so approximated as above.

But the technique of sagging fabric is the most useful and powerful tool that agree closely with the results that obained by the mathematical solution.

3.2 Action of Funicular Shell.

Shallow funicular shell behaves as two independent systems of arches at right angles and it is easily verified that the total vartical load at any point will be shared between the two systems of arches in the ratio of their curvatures. As the membrane state is statically deter minate, the arches can be considered to be hinged at the two ends and the crown for the purpose of calculation (three hinged arches). The horizontal thrust of the arches calculated in this manner will agree with the value of "N" as obtained from the formula.

3.3. Stress in the Shell under Load.

It can be shown in the following lines that the stresses in the shell under heavy loads no where exceed the permissible stress of the material. The value 'N' for 4' x 4' shell with 4" rise at the centre under load of 300 lbs/sft will be 93.75 psi of horizontal projection.

For example,

w=300 lbs./sft.

N= ?

Z_{max} = 4"

$$Z = \tfrac{5}{8}\ \frac{w}{N}\ \frac{1}{a^2+b^2}\ (a^2-x^2)\ (b^2-y^2)$$

$$= \tfrac{5}{8}\ \frac{w}{N}\ \frac{1}{2a^2}\ (a^2-x^2)\ (a^2-y^2)\quad \text{when } a=b$$

$$\text{or,}\quad Z_{max} = \tfrac{5}{8}\ \frac{w}{N}\ \frac{1}{2a^2}\ a^4\quad \text{at } x=0,\ y=0$$

$$\text{or,}\quad N = \frac{300 \times 5}{16}$$

$\therefore$ N=93.75 psi.

And real stresses S_x and S_y will follow from relationship.

$$N_x = S_x\sqrt{\frac{1+q^2}{1+p^2}} \text{ and } N_y = S_y\sqrt{\frac{1+p^2}{1+q^2}} \text{ and } N_{xy}=S_{xy}$$

where $p=\frac{dz}{dx}$ and $q=\frac{dz}{dy}$

Maximum value of real stress occur at four corners and their value is 99.00 psi.

4.0. Application of Double Curvature Shell.

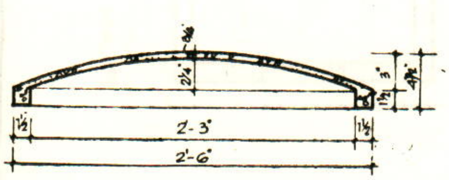
A full scale room incorporating double curvature funicular shell in its roofiing system has been constructed at the Institute and the roofing system is based on the use of simple roofing unit comprising 2'-6" square doubly curved concrete tiles and partially precast reinforced concrete beams plan and section of the units/room have been shown in the figure (Fig. 1).

4.1. Description of D.C. Tile Unit.

The precast doubly curved shell unit is 2'-6" square and is only ¾" thick. It has been provided with four lightly reinforced R.C. edge beam 1½"x 1½". The body of the shells is of cement concrete of 1:2:4 mix with maximum size of aggregates restricted to 3/8". The edge beams of the shells have been reinforced with one 1/8" dia m.s. wire in each side (Fig-below).

From the point of view of handling and making, 2'-6" square tile seems more convenient and has been adopted.

D.C. tiles were cast itself by the technique of sagging fabric.



Section of 2'-6" D.C. Tile

4.2. Partially Pre-cast Beams (Ref. Fig. 1)

The following types of load have been taken into consideration for partially pre-cast R.C. beams :-

i)	Live load	30 psf.
ii)	Waterproofing	30-45 psf.
iii)	Weight of concrete tiles concrete in haunches and beams.	50 psf.

Pre-cast portion of the beam has been properly designed and provided with reinforcement according to the design requirement.

5.0. Equipments and Process of Making D.C. Concrete Tiles Partially Precast Beam / Roof.

5.1. An inexpensive wooden frame made of garzan wood and a piece of hessian as shown in Fig. 2 (1-5) are only simple equipments used. The hessian is recovered and re-used about 10 to 12 times.

5.2. A masonry platform 2'-2" x 2'-2" x 3½" high of bricks were laid flat and to make smooth and level plaster has been done on the top.

A square wooden frame of garzan wood with four pieces each 2'-6¼" x 2'-6¼" in cross section was made clear dimension of which has been kept 2'-2¼"x 2'-2¼".

On the outer sides of the frame 1/16" thick and 2" long headless nails have been fixed. Hessian cloth was then mounted on this frame in such a manner that it was held taut by the nails.

The frame was then placed on the masonry platform and the hessian cloth remained tighty stretched. Later, another frame of 2'-4" x 2'-4" clear inner dimension was placed on the first frame to hold the concrete and to act as a gauge.

Concrete of 1:2:4 mix with 3/8" down graded aggregates were poured in this form and compacted to a depth of 3/4" thick and the entire form with the compacted concrete resting on the hessian cloth was lifted and placed on four rigid supports. The hessian cloth then sagged under the weight of wet concrete. Thus the shell of double curvature was formed and cast itself without the edge beam.

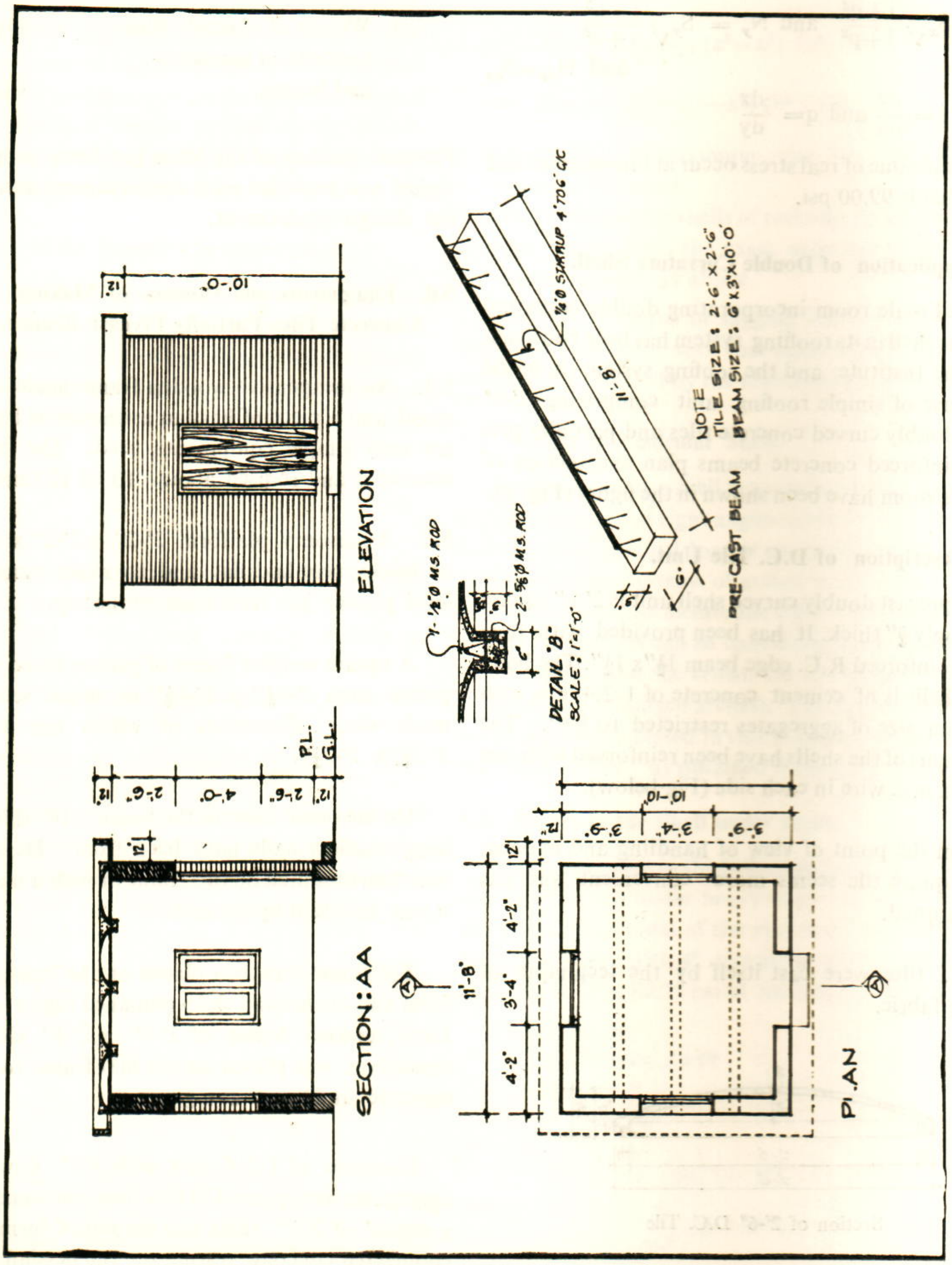


Fig. 1. Plan and Section of a room (136.33 stt).

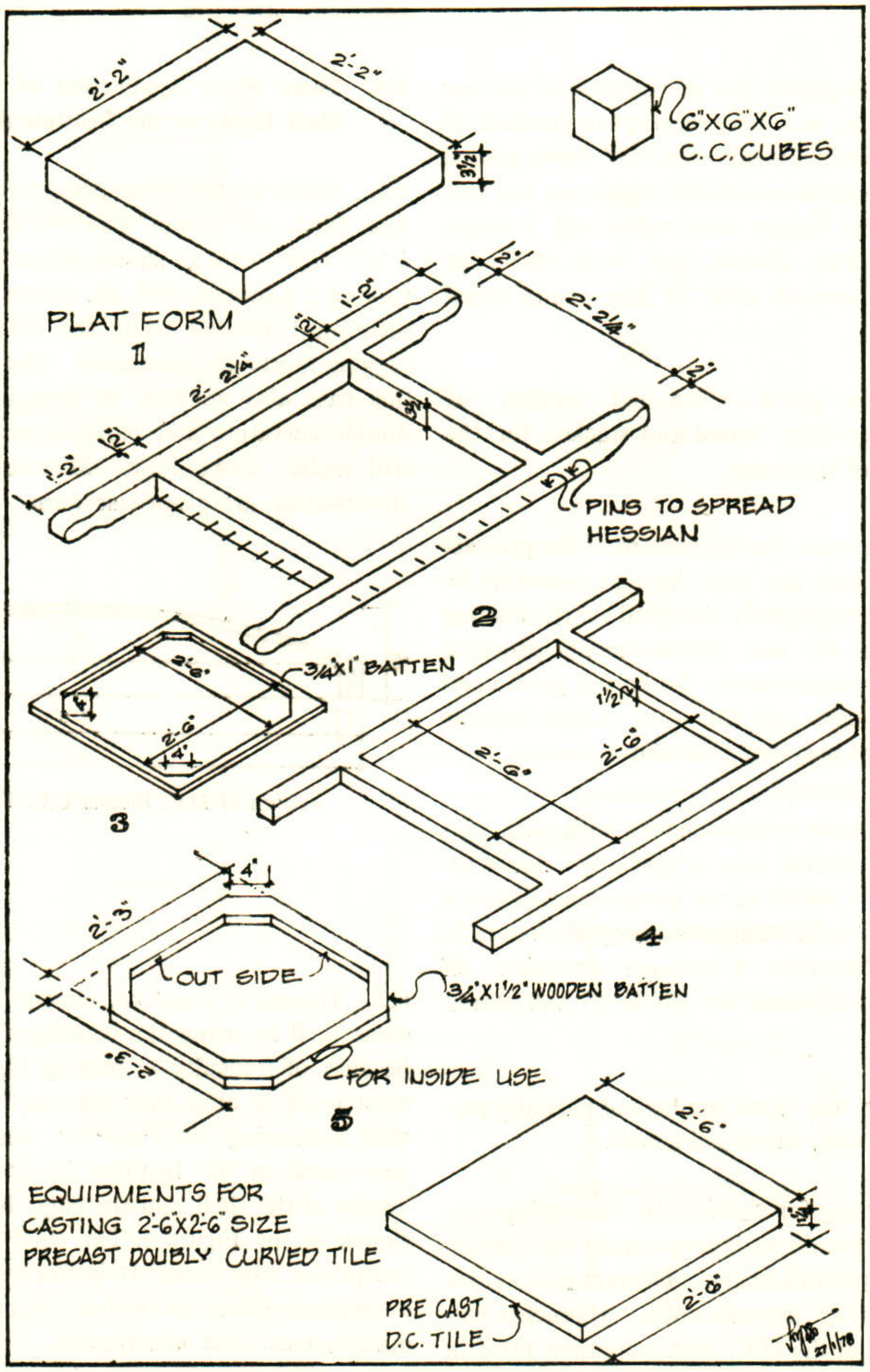


Fig. 2. Equipments of making D.C. Tile

Subsequently the formwork for the edge beam was next set up as shown around the raw shell which is 3" longer each side than the dimension of the outside of the shell.

The frame was placed just the outside of the raw shell and 1/8" dia. m.s. wire was kept in position all around Concrete of 1:2:4 mix with 3/8" down graded aggregate was poured in and the edgebeam was cast in this way. The frames were taken off 3 hours after casting. The desired shell with the edge beam was then inverted after 24 hours and cured for 14 days.

Repeating the process, required number of concrete tiles were cast, cured and stacked for the use in the roof of the room.

5.3. For convenience, the dimensions of the pre-cast portion of the beam has been kept as shown in the Fig. 1. It has been properly designed for the loading as mentioned in 4.2 and reinforcements provided according to the requirement. To ensure good bond between the pre-cast and the cast in-situ-concrete stirrups were kept projecting the above portion.

The cage of main reinforcements with such stirrups was then placed into a specially made re-usuable form of 3 pieces on the ground and concrete was then poured in it, compacted properly and cast. After 24 hours the sides of the form were taken off and the beam was cured for 14 days and stored properly.

In the similar way three numbers of partially pre-cast beam were cast, cured and stored.

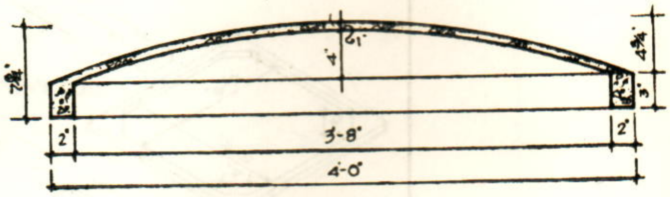
5.4. The shuttering for cast-in-situ concreting consists of wooden planks with props under the portion of the partially pre-cast beam. The precast concrete tiles were laid on the pre-cast beam. Haunches between the crown of the D.C. tiles were then filled in with cement concrete of 1:2:4 mix with 3/8" down graded aggregate and compacted properly.

The detailed plan and section of the roof have been illustrated as above. (Fig. 1)

5.5. Care was taken, while handling/hoisting the precast beam to support the middle third points till the concrete in the haunches was set and attained sufficient strength.

6.0. Some More Application of Double Curvature Shell Roofs at the Institute (Fig. 3 & 4).

6.1. Small unreinforced precast funicular shell one inch thick and about 4'x4' in size provided with 3"x2" edge beam as shown below have been used in roofing a house of 395 sft. plinth area. The above mentioned process using the technique of loaded sagging fabric has been used. The roofing system in this case also consists of such funicular shells of double curvature and partially precast beam and is still under observation. Materials consumed and specification are given else were.



Section of D.C. Precast C.C. Tile (4'-0" x 4'-0")

6.2. Though it is not convenient to cast large funicular shell by using the technique of sagging fabric because of difficulty in turning big shells over into erect position after they are cast, yet one such big shell measuring 10'-5"x14'-8" was attempted few years back in the Institute in the similar way, the details of the shell and the edge beam of which are shown in the Figure 4. The shell was unre-inforced except the edge beam. It is freely supported resting on masonry pillars on the four corners and is without maintenance since constructed.

The structure itself is still existing with sign of cracks at the centre and the corner. Maintenance of the shell has been undertaken and further observation of its behaviour is under way.

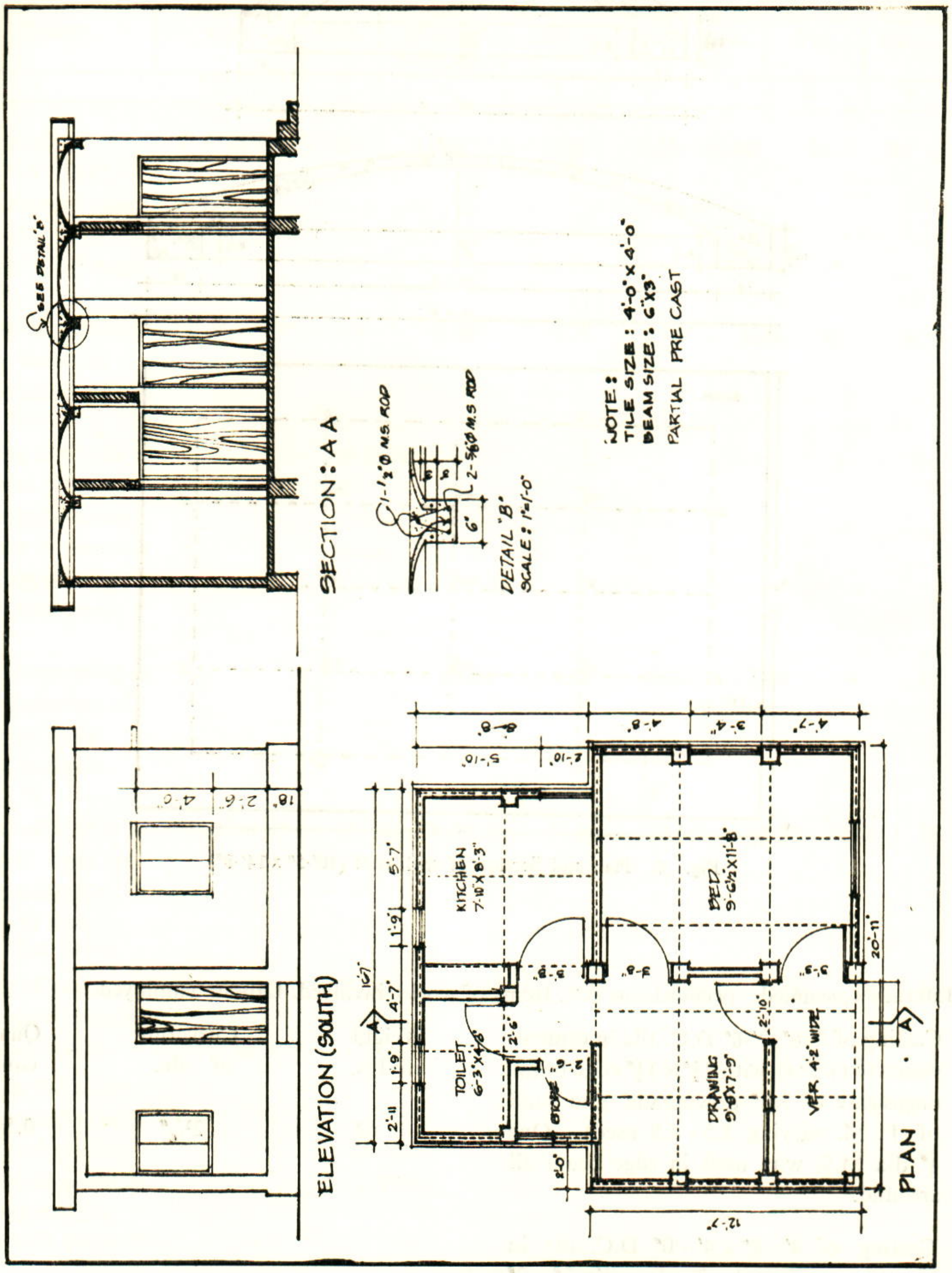


Fig. 3. Plan and section of a house (395 sft.) with D.C. shall roof.

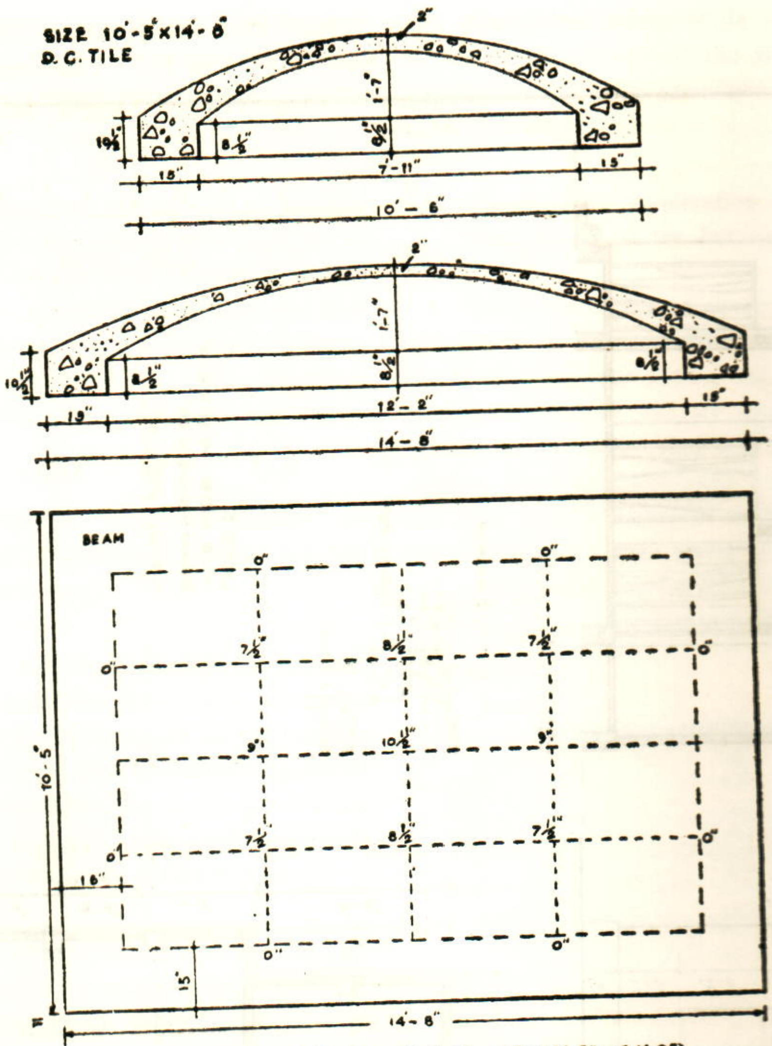


Fig. 4. Plan and Section of shell roof (10'-5" x 14'-8")

7.0. Materials consumed, specifications etc.. Items of works involved, Labour employed.

	Weight in lbs.	Curvature of tile.	Quantity of concrete
7.1.1. Casting of 2'-6"x2'-6" D.C. tile in cement concrete (1:2:4) with 1½" x 1½" edge beam (aggregate of 3/8" downgrade and sand of F. M. varying 1.5 – 1.8 used). One ⅛" dia M.S. wire used in edge beam all arround.	62	2¼"	0.583 cft.
7.1.2. Casting of 4' - 0" x 4' - 0" D.C. tile in cement concrete (1 : 2 : 4) with 3" x 2" edge beam (aggregate of 3/8" downgrade and sand of F.M. varying 1.5—1.8 used & one ¼" dia M.S. Rod used in edge beam all arround.	248	4"	2.33 cft.

7.2. Items of works involved for (a) the room (136.33 sft.) (b) the house (395 sft.)

(Ref. Fig. 1 & 3) 1 Labour=(8 man—hour)

Items	Dimension	Nos.	Volume of concrete cft.	Cement cft.	Sand cft.	Aggregate. cft.	Mason No.	Labour No.	Rod Mistry No.
1	2	3	4	5	6	7	8	9	10
1. Casting of 2′-6″x2′-6″ D.C. tile in cement concrete (1 : 2: 4) with 1½″ x 1½″ edge beam)	2′-6″x2′-6″	20	11.67	2.50	5.00	10.00	20	20	2
2. Casting of partially precast beam in cement concrete (1: 2: 4)	12′-5″x6″x3″.	3	3.50	0.75	1.50	3.00	6	6	6
3. Hoisting D.C. tile & partial precast beams and placing the same in position including placing planks with props etc.		20 Nos. tile 3 Nos. beam.					3	9	
4. In-situ concreting in filling haunches of beams etc. with cement concrete (1 : 2 : 4)			20.34	4.36	8.72	17.44	4	12	1
5. Casting of 4′-0″ x 4′-0″ D.C. tiles in cement concrete (1 : 2 : 4) with 3″x2″ edge beam.	4′-0″x4′-0″	23 Nos.	53.60	11.50	23.00	46.00	30	30	3
6. Casting of partially precast beam in cement concrete.	10′-4″x6″x3″ 9′-2″x6″x3″ 7′-4″x6″x3″	5 Nos. 1 Nos. 1 Nos.	5.83	1.25	2.50	5.00	14	14	14
7. Hoisting D.C. tiles and partially precast beams and placing the same in position including placing planks with props etc.		23 Nos. 7 Nos.					6	18	6
8. In-situ concreting in filling haunches of beams etc. with cement concrete (1 : 2 : 4)			45.00	9.64	19.29	38.57	12	36	8

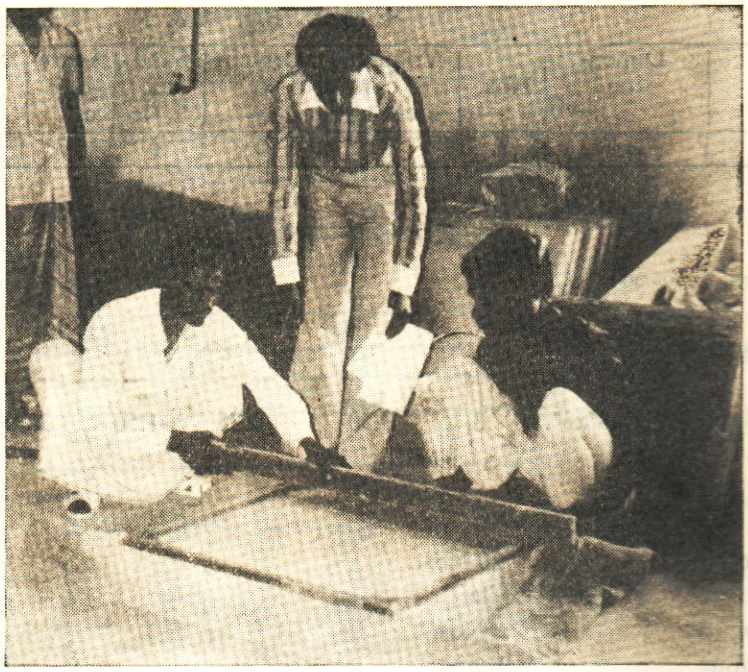


Fig. 5. Casting of funicular D.C. Shell in Process (ref. Fig. 2.)

Fig. 6. Casting of funicular D.C. Shell on Process (ref. Fig. 2.)

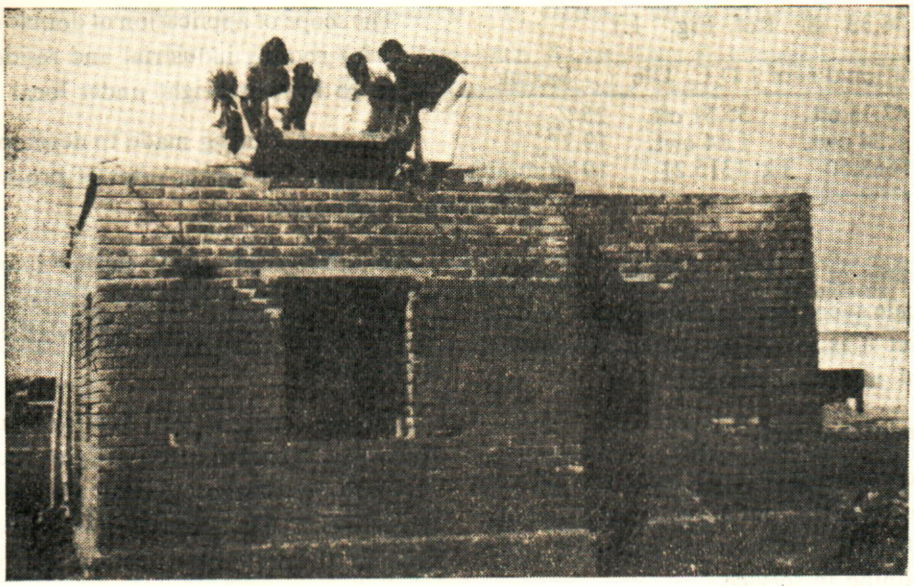


Fig. 7. Construction of funicular D.C. Shell roof in process

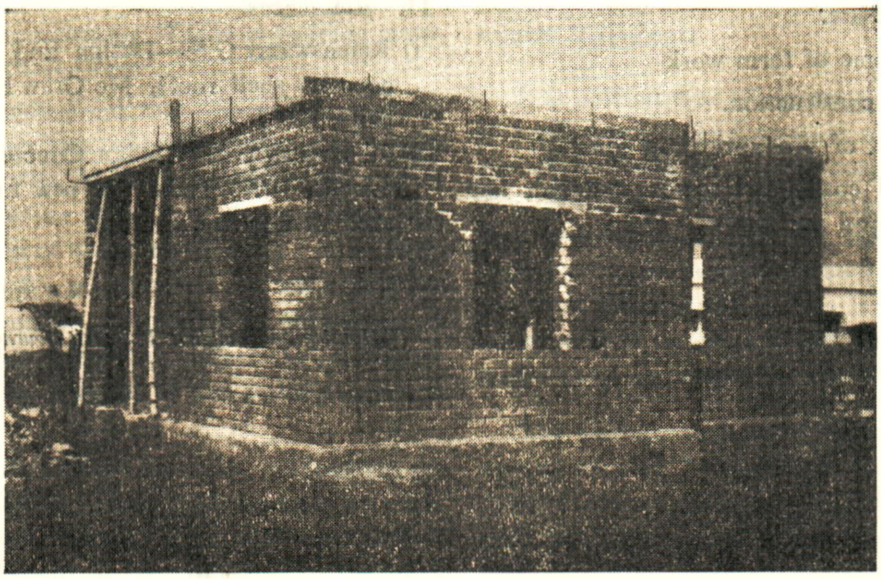


Fig. 8. Funicular D.C. Shell roof after completion

Comparative statement of material consumption

(136.33 sft. Ref. Fig. 1.)

Item	Conventional roof	D.C. Tile	Saving
Concrete—	47.33 cft.	35.51 cft.	25%
Steel —	1.34 cwt.	1.14 cwt.	19.7%
Cost —	Tk. 1663.50	Tk. 1315.21	19%(about)

8.0. Test.

Full programme of tests on individual shell unit as well as full scale such tiled roofs could not be completed as yet but it is in process to be subjected to static, sustained and shock loads.

8.1. Test on individual unit.

Tests on individual shell units were carried with the shells supported at the four corners. As in application, the condition of the tests are far more severe than those obtaining in service.

i) Minimum failure load sustained by the shell. 250 lb/per sft. (av.).

ii) The failure initiated by cracking of R.C. edge beam and the shell has adequate reserved strength against overloads.

iii) In the impact load test, no sign of distress was observed when a load of 30 lbs. was dropped from a height of 5′-0″.

9.1. Benefits.

The special features of this type of roof as against conventional type are.

i) least volume of form work

ii) speed of construction.

iii) advantage of pre-fabrication (quality)

iv) saving of costly and scarce materials like cement, steel and timber.

9.2. Concluding Remarks.

The scope of application of double curved funicular shell for roofing industrial and residential structures seems to be very bright under local conditions.

Efforts are being made to develop masonry erect/steel mould for higher rates of production, economy and efficiency.

Suitability of constructing intermediate floors with precast funicular shell supported over in-situ-concrete ribs forming a grid waffle is also being investigated.

Besides, being in very low compression, no reinforcement is needed in the body of the shell for which it is also possible to build the shell with locally available bricks. The Institute has already initiated programme towards this direction and have made good progress.

10. Acknowledgement.

The work has been done as part of the normal programme of research/experimentation at the Housing and Building Research Institute.

The author is grateful to his officials Messrs. Lutfur Rahman, Mirza Mahbubul Haque, M.A. Sadeque, Hasan-uz-Zaman Khan and other staff who are closely associated with execution of experimentation of the programme.

11. References.

i) Ramaswamy G.S.—Design and construction of concrete shell roofs, Mc Graw Hill Book Company, 1968.

ii) Ramswamy G.S.—Indian Concrete Journal September, 1960. Theory of new funiculor shallow shell of double curvature.

Housing and Building Research Journal *Volume-1, Number-1, 1978*

Study of Efflorescence in Brick and Mortar

A.U. Ahmed, A.K.M. Khorshed Alam and B. Monir
Housing & Building Research Intitute, Dacca.

Abstract

In the present investigation some case study has been conducted to determine the cause of efflorescence and the effective treatment for remedial measures of this harmful phenomena. It is observed from the experimentation that in most of the cases the efflorescence occured due to presence of calcium carbonate which may be derived from soluble hydroxides of calcium.

Introduction

Efflorescence is a white deposit which may occur on the surface of any masonry wall and is caused by the crystallization of soluble salts present in the materials of the building components. Flood and Wests[1] defines the term efflorescence as the production of flowers, forming a layer of crystals on the surface of a wall due to drying out of salts, loss of water from a crystal and formation of powder on the surface of the crystal. Handisyde[2] make a distinction between efflorescence and crypto-floresecence. Crystal formation on the surface of a material is termed as "crypto-florescence" and may occur due to some soluble salts which crystallize just inside the surface pores. Magnesium sulphate is particularly liable to the crypto-florescence. The general phenomenon of the crystalization of salts in building materials is called "florescence".

It is now understood that the phenomenon of florescence occurs because of the presence of certain soluble salts in the building materials themselves. The porous structure of brick or masonry work aids in the penetration of water into its body. As a result, these soluble salts get dissolved in water and are carried to the surface of the material (efflorescence) or some distance inside the surface (crypto-florescence) where they remain, as the water evaporates out.

Schanpp[3] states that the salts responsible are generally magnesium and vanadium sulphates. Presumably Mg and V comes from clay and sulphate from sulphur present in the coal used in the brick fields.

Goodwin[4] states that the efflorescences occurs due to the presence of sodium sulphate, carbonate, bicarbonate, silicate, potassium sulphate, calcium carbonate, calcium sulphate, magnesium sulphate and other salts such as chlorides, nitrates and also salts of vanadium, chromium and molybdenum.

Ritchie[5] mentions mortar as a source of efflorescence, sodium carbonate is the main constituent in the mortar mixture. It is also stated that the presence of relatively large amounts of Na and K salts, usually as sulphates in mortar indicates that portland cement is the source of efflorescence.

It is also recognised that in most cases brick is the source of efflorescence and caused due to the presence of soluble salts as most of the clays originally contain soluble ingradients.

It is obvious that efflorescence would be reduced to a minimum if the formation of most of the free hydroxides could be avoided during the curing process. Molony[6] B. (el) reported that the formation of free hydroxides during the hydration of cement concrete may be completely suppressed by curing the sample in steam at 185°C. This is also achieved when equal parts of cement and diatomite are used in the mixture and the sample is cured at 90°C for 20 hours.

The calcium carbonate[7] efflorescence is a more serious problem because it is extremely difficult to remove. It appears usually as a white bloom diffused over certain areas and in the worst cases it forms a hard white crust. Any of the methods which may be at all effective such as washing down with acid or chipping off frequently alter the texture of the block to such an extent that it is necessary to treat the entire wall area and not merely the affected regions. In the present paper the authors have under taken experiments to investigate the cause and suggest effective treatment for remedial measures of this harmful phenomena.

Experimental

Chemical Analysis :

Qualitative analysis have been carried out for each of the samples collected from the following buildings where the phenomenon of efflorescence were present.

(a) Building of the Department of Bio-Chemistry, Dacca University, Dacca.

(b) Building of the Planning Commission, Sher-e-Bangla Nagar, Dacca.

(c) Building of Building Research Institute, Dacca.

The results are presented in Table-1.

Table I

Chemical analysis of sample :

Samples collected from	Constituents
Building of the Department of Bio-Chemistry, Dacca University.	Ca^{++}, CO_3^{--} and traces of SiO_2 and Na^+.
Building of Planning Commission at Sher-e-Bangla Nagar.	Ca^{++}, CO_3^{--}, traces of SiO_2
Building of Housing & Building Research Institute, Mirpur, Dacca.	Ca^{++}, CO_3^{--}, traces of SiO_2

X-ray powder diffraction photographs of the samples were obtained with the help of Philips X-ray Gencrator of type PW 1130/00 using CuKα radiation. The d-values (interplanar distances) of the samples are given in Table II.

Table-II

d-values in Å (Angstrom) of the collected samples:

Bio-Chemistry of Dacca University	Planning Commission of Sher-e-Bangla Nagar	Building Research Institute, Dacca.	Reference sample of $CaCO_3$ (E.Merck)
4.27 vvw			
3.85 ms	3.85 ms		3.86 ms
3.60 vvw			
3.28 vvw	3.27 vvw		3.37 vvw
3.03 vvs	3.03 vvs	3.05 vs	3.03 vvs
			2.66 ms
2.49 ms	2.49 ms	2.50 s	2.49 s
2.26 ms	2.26 ms	2.29 s	2.28 s
			2.20 vw
2.09 ms	2.09 ms	2.10 s	2.09 s
			2.02 vvw
1.92 ms	1.91 ms	1.92 s	1.91 ms
1.87 ms	1.87 ms	1.88 vw	1.87 s
			1.70 vvw
1.60 vw		1.61 vw	1.62 vvw
			1.60 w
1.51 vvw	1.52 vvw	1.52 vw	1.52 vw
1.44 vvw	1.44 vvw	1.44 vvw	1.43 w
1.42 vvw	1.42 vvw		1.42 vw

vvs= Very very strong vvw=Very very weak
vs = Very strong. vw =Very weak.
ms = Medium strong. w =Weak.

Wick test of the bricks for observing efflorescence :

Each brick from different manufacturers were placed on end in a shallow flat-bottom non-absorbent dish by deeping minimum clearance of 2″ between two concentrive bricks. Distilled water was than poured to depth of 1″ so that it surrounds each brick by one inch only. The arrangement was allowed to stand in a well ventilated room at about (15°-20°C). When the water has been absorbed and the bricks appear to be dry, an equal amount of water was again poured into the dish and further drying period was allowed. At the end of 5 days, the bricks were removed and dried in an oven at 105°C for about 18 hours. The results were shown in Table III.

Table III

Wick Test of the Bricks :

Location	Indication of bricks	Size	Observation after 5 days immersion in water	Observation after complete curing	Observation after 10 days immersion in water	Observation after complete curing
Chittagong	P.B.L.	9.4"x4.1"x2.7"	Nil	Nil	Nil	Nil
	C.B.C.	9.1"x4.5"x2.9"	Very slight	Very slight	Very slight	Very slight
Khulna	A & C	10.1"x4.3"x2.9"	Nil	Nil	Nil	Nil
	M.M.	9.1"x4.5"x3.0"	Nil	Nil	Nil	Nil
	Royal	9.3"x4.7"x3.0"	Nil	Nil	Nil	Nil
	K.B.69	9.5"x4.7"x3.0"	Nil	Nil	Nil	Nil
	H.M.P.	9.3"x4.6"x2.8"	Nil	Nil	Nil	Nil
Dacca	MULTICORD	9.9"x4.6"x2.9"	Nil	Very slight	Slight	Slight
	TEN HOLE	9.6"x4.6"x2.7"	Nil	Nil	Slight	Slight
	M.C.M.	9.8"x4.5"x2.7"	Nil	Nil	Moderate	Heavy
	S.B.C.	9.1"x4.3"x2.6"	Nil	Nil	Nil	Slight
	B.B.S.	9.5"x4.5"x2.7"	Slight	Slight	Moderate	Heavy
	N.U.B.	9.5"x4.5"x2.7"	Slight	Moderate	Heavy	Heavy
	N.H.N.	9.5"x4.6"x2.6"	Slight	Slight	Moderate	Moderate
	M.C.W. 12 Hole	9.5"x4.6"x2.9"	Nil	Slight	Slight	Slight
	10 Hole	-do-	Nil	Slight	Slight	Slight
	MULTI CORD	-do-	Nil	Moderate	Moderate	Moderate

Nil—No perceptible deposit of efflorcesence.
Slight—Not more than 10% of the area of the bricks covered with a thin deposit of salts.
Moderate—A heavier deposit that under slight and covering upto 50%.
Heavy—A heavy deposit of salts covering 95% or more.

to use of hard water during the construction of buildings.

It has also been observed from the results in Table III that efflorescence was absent in the hard burnt bricks where the salts of more active metals such as Na, K, Mg may decompose with the formation of a complex compound with silicates. It is therfore advisable to the brick manufactures to burn their bricks to a optimum temperature to avoid the efflorescence. Excess of lime in cement is the another source of efflorescence where $CaCO_3$ deposited as a crystalline substance. The mechanism of formation of $CaCO_3$ is as follows :

$$CaO+H_2O=Ca(OH)_2 \quad \text{(soluble)}$$
$$Ca(OH)_2+CO_2=CaCO_3+H_2O \quad \text{(crystal)}$$

Discussion :

From the results in Table I, it has been observed that the efflorescence is caused due to the presence of soluble salts which may present originally as impurities in the cement mortar and the bricks that is used for brick works.

Further, the results in Table II indicate that the X-ray diffraction patterns of the collected samples are the vary similar to that of the reference sample of calcium carbonate (E. Merck). This may result due

Suggestion

Precautions in the selection of clay for brick manufacture.

The following precautions may be taken in the selection of clay for the manufacture of bricks.

(a) Brick manufacturers should pay great attention to the selection of raw clay for its manufacture and always reject the clays which contain appreciable amount of soluble salts. In some cases the soluble salts can be removed by lixiviation and this lixiviated clay can be used for the manufacture of brick.

(b) Hard fired class (full heat)of brick will contain a minimum amount of soluble salts and the chances of efflorescence are small, such efflorescence as does occur being washed away during the first rainy season.

(c) Vitrification of bricks is the another method to avoid effective efflorescence. The clay may be mixed with requisite quantity of sodium chloride which at slightly higher temperature, will fill up majority of pores and act as a check to the capillary tendency of the bricks.

Remedy of Efflorescence.

1. Damp proof courses and flashings of roof drainage should be so designed and constructed to prevent entry of water into the body of the brick work.
2. The use of mortar of suitable texture containing very little or no soluble salts shall be used.
3. Avoidance of the use of bricks with highly soluble salts content or soft porous bricks in very exposed positions. Use of a hard fired brick for facing work is recommended.
4. Protection of the brick-work against contamination with salt bearing materials during building operations.

Removal of efflorescence in the existing masonry work.

Efflorescence may be removed by brushing off repeatedly until crystallisation ceases on the surface of the masonry works. Washing of the visible crystals by water are also in practice although it does not effect a permanent cure because the salts pass back into the brick-works with water which is absorbed during washing. Application of acids and other chemicals may create additional supply of efflorescence salts. No suitable method has yet been discovered for the permanent removal of the efflorescence.

References :

1. Flood and Wests : An Elementary Scientific and Technical Dictionary, Longman, Green & Co. Ltd. London (1962)
2. Handisyde, C.C : Building Materials, Science & Practice, the Architectural Press. London (1967)
3. Schanpp, W. : External Walls, Grosby Lock Wood & Son Ltd. London (1967).
4. Goodwin, M.J. : National Research Council of Canada, Building Note No. 8 (1950)
5. Ritchie, T. : Canadian Building Digest No.2., Feb.,1960. National Research Council of Canada.
6. Molony. B., Hashem M.A. and Hoffman E. Constructional Review, Vol. 35(9), 35(1962)
7. Calcium Carbonate Effloreseence on concrete masonry Constructional Review, Vol.36(8), 14 (1963).

Possibility of Mechanisation in the Building Industry in Bangladesh.

LUTFUR RAHMAN
Housing and Building Research Institute, Dacca

Introduction :

During the last few decades of enhanced construction efforts throughout the world, various types of tools, equipments and machines have been developed for use in the housing and building works. These machines can provide increased speed and quality in the construction operations.

The achievement of efficiency as well as increased productivity in construction activities necessitates the appropriate use of labour and equipment. In many of the highly industrialised countries as well as the developed countries, because of the level of technology, the availability of capital and highly skilled labour, availability of a steady housing market, increased efficiency and productivity has been achieved with increased mechanisation.

The term 'mechanisation' in building industry means economic utilisation of different machines and equipments in the construction of buildings. In a densely populated country like Bangladesh, we have enough unskilled labours but there are shortage of actual skilled labourers. Here, the unskilled labourers can only be utilised in the building of small houses. But for larger constructions such as in the construction of big factories, high rise multistoried buildings and bridges etc. the effective utilisation of modern machines can bring great economic benefits.

On the other hand, all construction operations require three vital elements—namely labour, materials and equipments. The appropriateness of construction operation depends on the right choice of types and amount of materials, the number and characteristics of tools, equipments and plants. The building industry is highly technologically flexible in the sense that it has available to it a range of potentially efficient techniques of different capital intensity from which to choice.

Using Machines in Construction Operations :

Considering three stages of building construction such as the foundation, wall construction and erection of the roof we can see that mechanisation can bring considerable economy in the whole process of construction. Let us consider the case of foundation of a building, for laying the foundation we are to test the soil conditions of the construction site including determination of the bearing capacity of soil for which soil samples are to be collected by making proper use of the drilling machines.

Also for casting the foundation of the building or bridges, if a mixer machine is used in the process of mixing the mortar then the quality of thematerials become far more better than these produced by ordinary labourers.

In the case of construction of the wall of any building or some other structure the machine made bricks in Bangladesh are comparatively better in quality and accurate in dimensions than the hand moulded bricks, consume less mortar in the construction of walls, there by brings economy. On the other hand the machine made bricks looks very nice and the walls made of these bricks appear more decent.

In the Housing and Building Research Institute, Dacca, among its various functions and research activities, we are trying to produce a low-cost walling material named the soil-cement blocks. 6% cement with properly graded sand mixed soil being converted into blocks with the help of a Cinva-Ram-Block machine. Such soil-cement blocks are

Fig. 1. Precast D.C. Tile roofing elements

Fig. 2. Soil tests being performed with tri-axial machine

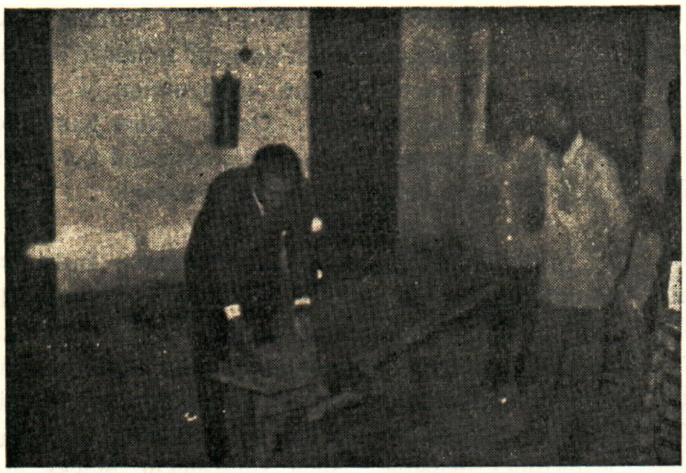


Fig. 3. Soil-Cement Blocks are being produced with Cinva-Ram Block Machine

of considerable strength. But, the major portion of our country is effec ed by heavy rains for 6 to 8 months in a year and as the water absorbtion capacity of these soil-cement blocks are comparatively greater than the burnt bricks, therefore, the practical use of these soil-cement blocks for constructing the outer walls is not so economical in the major portion of Bangladesh particularly the rain affected zones.

Attempts are being made to improve the quality of such blocks as well as to increase the efficiency of of the Cinva-Ram-Block Machine :

M.s. rod which is used in buildings, bridges etc. is itself a machine made-material and before using this m.s. rod, it is being tested by the Universal Testing Machines for different properties :

In case of R.C.C. roof casting works, the mortar, m.s. rod etc. can be lifted more easily by machines like crane, lifters etc. than by head loads. Also entire carriage of different construction materials like bricks, sand, cement, m.s. rod etc. to the construction site is being done more easily and economically by machines, trucks etc. Steel guarders, steel beams, joists etc. of roof truss of the factories usually lifted and fitted with the help of cranes and other mechanical device.

If we use prefebricated building components or elements for the construction of larger building or bridges or for mass production of same type buildings, we must use lifting machine or crane for lifting and fitting fixing the prefebricated building components properly and economically.

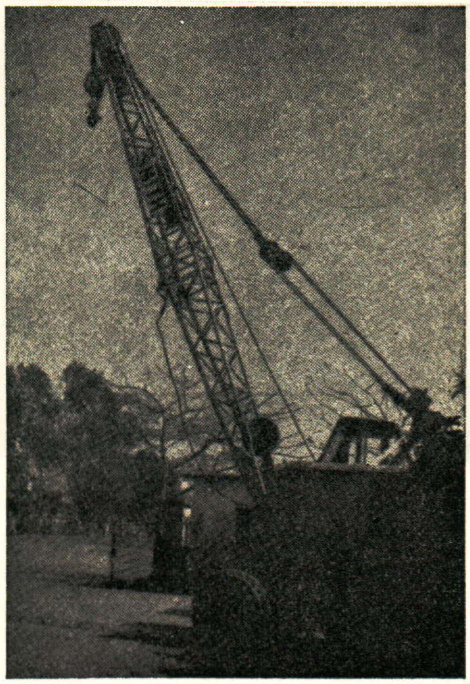


Fig. 4. Precast R. C. C. poles erected by Crane

In the Housing & Building Research Institute, Dacca, in the Structural Division we have taken up research programme-"How to minimize the cost of building construction by using different types of prefebricated roofing tiles and elements. Under this programme we have already constructed a one-roomed house with D.C. Tiles in the roof; one complete building with bedrooms, bath, kitchen, burandah with

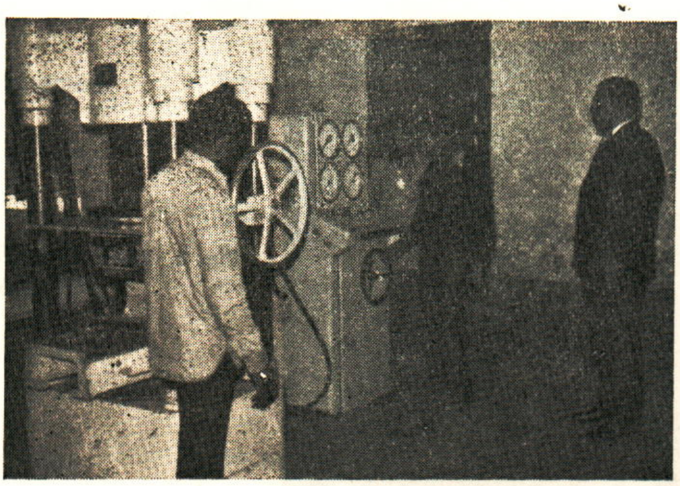


Fig. 5. Universal Testing Machine testing the compressive strength of concrete cubes

Fig. 6. Precast R.C.C. poles erected by crane

Fig. 7. Precast roofing elements and their economical uses in the roof of building

Fig. 8. Precast roofing elements and their economical uses in the roof of building

D.C. Tiles roofing; for which load tests would be made. And works on producing other types of prefebricated roofing tiles are in progress.

In order to identify the relationship between capital and labour costs some of the factors which have to be taken into account in the study include:—

(1) the availability of foreign exchange for the purchase of the simple tools and equipments.

(2) availability of local skills and energy to operate the mechanical equipment.

(3) the need to import spare parts for the maintenance of mechanical equipment.

(4) the chracteristics of labour productivity on the susceptibility of labour training in the use of equipments.

(5) the effect of good organisation on productivity.

It is not possible to determine accurately the extent to which the rational use of equipment influences building productivity as measured in man hours per square meteres of construction. Some of the information on the increase in productivity for some of the building operation through the use of simple machines has been compiled by the Central Building Research Institute of India which might be used to compare with similar data else where is given bellow :-

Increase in productivity with mechanisation

Operation	Increase in productivity
1. Mixing concrete using concrete mixer	0.7 times
2. Transportation mixed concrete in skip hoist	9.0 times
3. Compacting concrete by using vibrator	3 to 4 times
4. Tamping lime concrete tirracing using tamping machine	20 times
5. Floor grinding using polishing machine	0.6 times
6. Providing chases in brick work for electrical wiring using an electrical chaser	15 times.
7. White, colour washing using spraying pump.	10 times.

Some of the information on the extent to which some of the more capital intensive machines replace labour is given below. This data can be used to establish the choice of labour in relation to machine.

Replacement of human labour by machines.

Type of machine.	Nos. of labours Replaced.
1. Excavator, 0.15—3m³	20—160
2. Motor scrapers from 6m³	50—120
3. Dozer from 80 H.P.	70—90
4. Motor graders, 50—120 HP	30—50
5. Machine for earth compaction, 4—25 metric tons	20—50
6. Building cranes, 3—8 tons	30—40
7. Dump car	20—30
8. Motor crane, 5 tons	10—20
9. Mixer, 250—750 litres	5—20
10. Conveyors, 4—15 metres	3— 5

It must be expected however, that in some developing countries, the growth of mechanisation will be to some extent inevitable. This is because of increasing cost of labour, the general level of productivity and the general increase in the level of technology. However the type and the extent of mechanisation must be carefully selected to correspond to the expects of construction operation for which it is required and also to relate to the availability of national and in some cases regional resources.

Conclussion:

There is a school of thought that due to the availability of aboundant labour force in Bangladesh we need not go for mechanical process of building constructions which are in fact labour eleminating devices. But, considering the quality of output obtained from the machines and reduction in construction times and cost—we understand that introduction of mechanisation in the field of construction activities will not only save time but will also bring economy and decency in the buildings and houses.

In fact, mechanisation in Building Industry have already started in Bangladesh and many machines and equipments have been obtained from various friendly countries. The P.W.D. and Housing Directorate and other agencies making use of many 'time and labour saving'—construction equipments in various construction projects particularly in the urban areas. But it will be advantageous for the National Government to take necessary steps to introduce further mechanisation in our construction efforts throughout the country.

Acknowledgement

The Author expresses his gratefulness to Mr. A.K.M. Khorshed Alam, Senior Research Officer, Housing and Building Research Institute, for his constant guidance and valuable suggestions during, the course of this study.

Housing and Building Research Journal, 1 (17—22) 1978.

Housing and Building Research Journal *Volume-1, Number-1, 1978*

Chemical Properties of Building Materials

A.K.M. KHORSHED ALAM AND A.U. AHMED
Housing and Building Research Institute, Dacca.

Introduction :

Chemistry is an experimental science concerned with the composition and properties of matter. Modern explanation of the chemical properties of matter are used on well established concepts of the atoms and molecules. All matters are presumed to consist of exceedingly small fundamental particles called atoms, which retain their identity in all chemical changes. Atoms may form relatively stable combinations with one another thus forming a molecule and chemical changes or reactions involve changes in these molecules. It is necessary to consider the general structure of atom in order to develop a concept of the factors which govern the properties of materials. For example, when a material is stressed, the attractive forces between the atoms resist the stress and keep the materials from deforming and pulling apart. Electric conductivity arises from the mobility of electrons associated with the parent atoms. Oxidation of metals is caused by the diffusion of metal atoms or of oxygen atoms through the surface layer to form the oxide product. These phenomena are best explained by considering a model of an atom.

The prime effect of the structure of the atom upon the properties of engineering materials results from inter atomic forces. These forces may be conveniently divided into strong or primary bonds which are again divided into ionic bonds, covalent bonds and metallic bonds. Since melting point and boiling temperature are a rough indication of the strength of the inter-atomic bonds a qualitative relationship exists between thermal stability and mechanical strength. For example in the refractory materials such as ceramic products, glaze tiles, fire bricks etc. covalent and ionic bonds are generally present which causes their more abrasive properties. The influence of the structure of the atoms upon the chemical properties has gone without elaboration. The chemical differences between elements are primarily dependent upon the number of valency electrons. Moreover, all chemical reactions involve the formation and disruption of bonds.

The study of the structure of molecules and crystal and their co-relation with properties of substance is one of the central theme of the subject of chemistry. Furthermore, the properties of materials depend upon the arrangement of their atoms.

Chemical composition and properties of materials :

The chemical composition of a material plays an important role in its properties. The engineer or a scientist should know the exact composition of the material that are being used for construction purpose and these must coincide with the standard specifications, so as to obtain the maximum efficiency. For example, pure iron is soft and brittle but it forms various solid solutions with the variation of the presence of carbon and traces of other metals thus forming a product having different physical properties from that of soft iron. Only the presence of 0.3% carbon in iron makes it a tuff and durable compound of their kind. It has got many other modifications with the variation of its compositions.

One must have a firm idea of the underlying principles that govern the properties of all materials. To have a clear conception of the properties of the materials it is necessary to know the composition of the material, grain size, crystal shape and bond strength. Many of the physical properties such as specific gravity, thermal conductivity, thermal expansion, electric resistivity etc. have a direct bearing with the composition of the material concerned. For example brass and bronze, cast-iron and steel, brick and concrete have got different physical properties with the variation of their composition.

Physical Properties of Material ;

Materials	sp.gr.	Thermal conduc. cal./cm. °C.sec.	Thermal exp. in/ in/°F	Electric resist. ohm.cm.
Brass (70% Cu-30%Zn)	8.5	0.3	$11x10^{-6}$	$6.2x10^{-6}$
Bronze (95% Cu-5%Zn)	8.8	0.2	$10x10^{-6}$	$9.6x10^{-6}$
Cast iron	7.7	—	$5x10^{-6}$	—
Steel	7.86	0.12	$6.5x10^{-6}$	$16.9x10^{-6}$
Brick	2.3	0.0015	$5x10^{-6}$	—
Concrete	2.4	0.0025	$7x10^{-6}$	—

Corrosion :

Corrosion is the deterioration and loss of material due to the chemical attack. Many examples of corrosion of materials are in daily evidence. The conditions that promote corrosion involve both chemical and electronic changes. Obviously, the mechanism of corrosion must be understood to minimize the corrosion. This can be done in two ways: 1) by avoiding severely corrosion conditions or 2) by providing protection against corrosion.

Most corrosion occurs through the interaction of the two processes of solution and oxidation.

Corrosion by solution :

The simplest corrosion is by means of chemical solution where the material dissolves as molecules thus forming a solution. For example, a rubber hose through which gasoline flows is in contact with hydrocarbon solvents and silica refractories come in contact with iron oxide slag that dissolves the silica. The following generalizations may be made about chemical solution:

1) Small molecules and ions dissolve most readily. The components of asphalt, for example will dissolve more readily than the components of a highly polymerised plastic. Similarly, alkali and halide ions have greater solubility than more complex silicate ions.

2) Solution occurs more readily when the solvent and solute are structurally similar. Organic materials are most soluble in organic solvents, metal in other metal liquids and ceramic materials in other ceramic melts.

3) Presence of two solutes may produce greater solubility than the presence of only one.

4) The rate of solution increases with temperature.

Corrosion by Oxidation :

Direct oxidation that results in the formation of an oxide which occurs more readily at high temperatures. However, oxidation is the removal of electrons from an atom and therefore, it may involve the formation of numerous types of reaction products.

For example, the oxidation of iron to ferrous ions

$$Fe \longrightarrow Fe^{++} + 2e^- \quad ......(a)$$
$$Fe^{++} \longrightarrow Fe^{+++} + e^- \quad ......(b)$$

and to ferric ions can be explained by the above equations. These reactions are most common in rust formation. Rust is ferric hydroxide and is formed according to the reaction—

$$4Fe + 3O_2 + 6H_2O. \longrightarrow 4Fe\ (OH)_3$$

Thus, for this type of corrosion both oxygen and moisture must be present.

Different metals have different oxidation potentials in as much as the energy required to remove electrons varies from metal to metal. Most corrosion occurs through the interaction of the two processes of solution and oxidation.

Durability of Building Materials, Corrosion and the Remedial Measures :

Durability :

Durability is a measure, in an inverse sense, of the rate of deterioration of a material or component. The BSI Code of Practice defines durability as the quality of maintaining a satisfactory appearance and satisfactory performance of the required function. This parameter is measured in the code in terms of the minimum number of years of satisfactory life: there are four gradings for structural components and whole buildings and three gradings for non-structural components, finishes and decorations.

Durability Factors :

Many attempts have been made to isolate casual factors of deterioration. Atkinson[1] has reviewed these attempts and has summarised the factors as follows:-

(i) Environment factor—such as, weather factors (air temperature, humidity, rainfall, etc.) pollution, insect and fungal attack, soil aggression.

(ii) Usefactor—'fair wear and tear' and excessive damage,

(iii) Design factor—design detailing and selecting the correct materials for the design or designing appropriate to the materials available.

(iv) Workmanship.

Deterioration :

The most significant elements of weather which are responsible for deterioration of materials are moisture, temperature, solar radiation, atmospheric gases and the salt laden winds. In some regions, sand and dust storms occur and in industrial areas atmospheric pollution can effect the durability.

Moisture :

In areas of continuous high humidity, some materials may retain sufficient moisture to have deleterious effect, while in drought zones they may deteriorate or fail to develop their potential properties because of dehydration.

Many ionic substances crystallize from water solution with water molecules and ions built into a crystal lattice. These crytalline substances are called hydrates. Examples are $CaSO_4$ $2H_2O$, $CaCl_2$ $6H_2O$, $CuSO_4$ $5H_2O$. The tenacity with which these water molecules are held by the central metal ion in hydrate varies considerably from element to element when a hydrate is heated to a suitable temperature, the water of hydration passes off leaving an anhydrous. The word anhydrous means without water or deprived of water. The process is known as dehydration.

Moist conditions encourage insect attack of organic and porous clading materials. A very dry atmosphere, on the other hand, can result in the premature drying of cement products before the curing has taken place.

Temperature :

A change in temperature can cause reversible changes in physical properties such as hardness, rigidity and strengthening. It can also result in permanent changes in properties resulting from chemical degradation. Most chemical reactions responsible for breakdown of plastic sheets are initiated by ultraviolet radiation, but the rate of deterioration is largely dependent on temperature.

Temperature variations also cause dimensional changes to occur, which in turn, can lead to spliting, warping or crazing of components.

Atmospheric Gases :

Because of its high concentration in the air and its high reactivity, the gas potentially most damaging to various materials is oxygen. However, most of these oxidation reactions proceed very slowly, even at temperatures occuring in the tropics where reaction rates may be three or four times of those observed in temperate regions. Ozone (O_3), which is an unstable modification of oxygen, is very much reactive towards organic compounds.

In the industrial areas, sulphur dioxide may be present in sufficiently high concentration to attack materials containing lime or carbonate and to cause corrosion of metals.

In contrast, the presence of carbon dioxide in the atmosphere is generally beneficial in reacting with lime and with the lime content of cement products to form a protective carbonate skin. However, if carbonate is allowed to proceed as far as the steel in reinforced concrete, this is deleterious because the alkalinity of the concrete and hence its capacity to inhibit corrosion of the steel is destroyed.

Winds :

High winds can cause deterioration by impinging rain, salt, sand or dust upon exposed surfaces. Degradation of coating is usually more severe on the elevation of buildings which bear the brunt of storms.

Two or more elements acting togather almost invariably produce greater deterioration than if they were acting independently, that is they have a synergistic effect. For example, ultraviolet radiation can break down polymer chains to produce low molecular weight materials which might be soluble in rain water; materials which have been irradiated oxidize more readily than those which have not been so exposed; some plastics which have been softened by heat may be more easily eroded by sand storms; ozone cracking occurs more quickly when the material is under mechanical stress, caused for instance, by dimensional changes due to temperature variations.

Structural use of Metals - Their Corrosion and the Remedial Measures :

Steel is the most important structural metal and is used for reinforcing concrete and as structural frame work.

Concrete re-inforcement :

Steel when embedded in concrete is surrounded by an alkaline environment, usually having a pH greater than 12.5, an *alkalinity* which gives adequate protection from most forms of corrosion. Reinforcement can corrode through inadequate protection and the effect can be observed in three stages: the concrete will crack along the line of reinforcement, rust-staining will also become apparent and eventually spalling of the cover and thining of the reinforcement will occur, leading ultimately to structural weakening of the building. It is important to know what stimulates these undesirable effects and how they can be prevented.

Alkalis can react with the acidic gases in the atmosphere, particularly sulphur-dioxide and carbon dioxide. The penetration of these gases into concrete can lead to the lowering of the pH of the protective environment. The rate and extent of reduction in pH is dependent upon the case of ingress into the concrete of these acidic atmospheric gases, which depends on the pore size and structure of the concrete. Thus the steel must be placed at a distance from the surface of the concrete greater than the maximum depth of penetration of acidic gases, to ensure long-term protection against corrosion. Similar reductions in pH of the concrete can be produced by rainwater leaching the alkalis from it; the concrete must have low air-permeability and low water porosity. It is therefore essential, in order to impart long-term protection to steel in concrete, to ensure, by providing adequate concrete cover, that the quantity of alkali surrounding the reinforcing bars is sufficient to maintain a high pH.

The ingress or incorporation of aggressive ions, particularly chloride, into the concrete may also cause break down in the protection of the alkaline environment. Chloride may be introduced from the environment in marine exposure, as additions to the concrete to accelerate the setting in cold climates, in precast work where maximum use of moulds and form work is demanded, as contamination of aggregates, or in the mixing water.

In hot climates it is unlikely that chloride will be needed to accelerate the setting of concrete, thus chloride attack on reinforcement is most likely to occur in marine areas and where aggregates or water with a high level of chloride contamination are used.

If the cover is porous, salt spray and moisture will be absorbed into the concrete and as the concentration of chlorides increases, attack on the steel reinforcement will begin. It is therefore, necessary, as with carbonation and leaching of alkalis to protect the reinforcement by an adequate barrier of good-quality concrete which restricts excessive absorption of spray and thus hinders the migration of chlorides to the steel. Chloride corrosion in marine environments can therefore be reduced by ensuring that the concrete surrounding the steel is of high quality, i.e. with a low permeability and porosity, which will restrict migration of chloride ions into the concrete. The first and most important method of combating the corrosion of reinforcing steel is to ensure that the concrete has a high resistance to the ingress of acidic gases and water and that it provides an adequate depth of cover to the reinforcement. Only aggregates with the minimum of chloride contamination should be used in concrete, with the mixing water as chloride-free as is obtainable.

Site condition and design criteria occasionally create situations incompatible with good practice and in these circumstances the inherent corrosion resistance of the reinforcement can be increased with advantage by the application of protective metallic coatings, or by the use of reinforcement of alloys with greater corrosion resistance.

Cadmium and zinc coatings appear to have been most successful for protecting reinforcement; zinc has been the more popular.

Reinforcement in hot-dipped galvanise—the metallic coating is alloyed to the steel, forming a continuation of the reinforcing layer of zinc which is less prone to pitting corrosion than the iron and forms an artificial anode. Galvanised steel has a major disadvantage in that the zinc will react with alkalis liberated during the set of the concrete to produce hydrogen. The gas then collects as bubbles at the steel/concrete interface severely reducing the bond strength. The rate of gas evolution can be significantly reduced if prior to embedment, the galvanised bar receives a passivating treatment in a chromate solution and the bond can be increased by the use of deformed bars.

Structural frame work :

Steel is the most commonly used metal for framework and the principles of atmospheric corrosion apply to such structures. Corrosion will be encouraged by the presence of water vapour in the atmosphere and will be aggravated by bi-metallic contact and the presence of aggressive components such as chlorides and sulphates. These basic principles have to be borne in mind by the designer, who should minimise as far as is practicable the problems which they may cause. The structure must be protected from exposure to water vapour and aggressive gases and must also be as free as possible from bi-metallic contacts.

High atmospheric humidity, condensed water and hygroscopic dusts are most likely to cause corrosion of structural steel work, in particular, where they are allowed to accumulate in the spaces between adjacent components. In this situation differential oxygen concentration cells which will promote corrosion in the crevice can be established. It is, therefore, important to eliminate all crevices at the design stage. The close contact of two metal flats can create a capillary gap which will attract and trap water. Where flat sections have to be connected, the joint can be longitudinally welded, so sealing the crevice and improving the benefits of any subsequent protective coating.

Paints and coatings :

The most common method of protecting structural frames is by painting, which gives a barrier coating between the bare steel and the environment. This coating must have a reasonably long life but it will be less durable than the structure. So, maintenance at intervals will be necessary. The designer must allow for this and provide easy access for workmen to clean and repaint during the planned life of the structure. If this is not done, protection will be lost and the exposed steel subjected to continuous attack. The same problem occurs at joints where paint cannot penetrate and therefore a more permanent protection by the use of sealants is required. Sharp corners present problem of reduced cover and should be rounded so that uniform application of the coating may be achieved.

Metallic coatings are effective in protecting structural frame work; the most widely used metallic coating is zinc and this can be applied as either hot-dipped galvanising prior to construction, or metal spray after construction. Similar treatment can be given with aluminium. Aluminium spraying has proved particularly successful in heavily polluted industrial environments, 0.3 Kg/m^2 (1 oz/ft^2) coating having 13-year life, while the same coating weight in zinc can last 3 years before significant (5%) rusting occurs. (Ref. Over Seas Building Notes No. 137). Steel used in most steel structures have only small additions of alloying elements within a normal range of compositions. These will rust and an unacceptable degree of corrosion will occur if they are not protected. A new range of steel commonly known as weathering steel, combining up to 2% of alloying elements including copper, nickel and phosphorus, is now available. They have a significantly higher resistance to atmospheric corrosion than the conventional steel, which makes them particularly attractive to the designer. They form under favourble conditions, an adherent protective rust film which reduces the long-term corrosion rate to a low level. Rates of attack on these steels in aqueous condition are higher than for low-alloy steels and particular care in eliminating water traps is necessary when they are used without protection. Buildings incorporating these steels must be designed to prevent rust-staining of their facades, because soluble iron compounds are formed during the initial stages of rusting.

Surface coatings :

The dividing line between plastics and surface coating is very diffuse; for instance emulsion paints are in fact polymeric materials in the form of an emulsion instead of being in the solid state. However, the essential differences between the two areas of study are that surface coatings are of necessity thin and that they are always in contact with other materials. In other words, an examination of surface coatings, whether in the form of paint or of pre-formed film, involves a study of systems rather than of single material. Unsatisfactory performance of paints and surface coatings can therefore be the result of failure of the coating material itself or of incompatibility between the coating and the substrate; for example, a paint film may be insufficiently flexible to withstand the moisture movements of an applied timber component but it may perform satisfactorily on a metal surface.

In common with other organic materials, paints are subject to degradation by solar radiation; binders and plasticisers decompose and volatilise or are leached out by rain, leading to cracking of the film; pigments tend to fade. Apart from the inherent tendency of paints to be decomposed by wheathering, there is also the problem of work-manship which is much more difficult to control than the factory production of pre-formed films, although even these have to be applied with care for satisfactory performance.

Asphalt and Bitumen :

On roofs and other exposed places, the visco-elastic properties of bituminous materials are seriously affected by repeated wetting and drying, while-heat brings about softening and blistering. Again, ultraviolet radiation leads to embrittlement and the production of water-soluble materials which can be leached out by rain; felt or fibres may rot or undergo deterioration due to moulds, or be attacked by termites. High winds cause felts to crack and tear and they can be abrased by sand stroms. The problems of flat roofs in the tropics, as well as in the temperate regions, have received a great deal of attention and have led to the development of highly specialised technical industry. Modern roof coverings are sophisticated systems employing bituminous felt, plastics sheet or film, metal foil, asbestos and glass fibre reinforcement and mineral granules in numerous combination. Such systems are prone to weathering to greater or lesser extent and need thorough evaluation.

Rubber :

Natural rubber is used only to a limited extent in tropical building. Where it is exposed to solar radiation, it rapidly oxidises on the surface with consequent cracking. Ozone is very destructive, causing hardening, embrittlement and severe cracking.

Synthetic rubbers are generally less prone to oxidation and are more commonly used than their natural counterpart; for instance, neoprene and other synthetic elastomers are sometimes used in the form of sheets gaskets and pipe joints.

Timber :

Large moisture movements in timber can cause cracking, splitting, warping and raising of the grain. Susceptibility varies greatly within the range of timbers available in various locations but many instances of excessive moisture movement do in fact result from inadequate seasoning. More worring is the susceptibility of timber to wet and dry rot and to attack by insects such as termites and beetles. Many protective treatments have been devised but in some instances the chemicals used have a short life as they are quickly leached out.

Use of Metals for Weather-Proofing Roofing :

Metals have been used for roofing for many centuries. Today the designer has a wide choice including aluminium, zinc, galvanised steel, copper and stainless steel. From this range it is possible to select the most appropriate metal for a specific purpose, but the designer must be aware of the performance of different metals and continually bear in mind the purpose of the building. its location and its estimated life.

The most important consideration in selecting a roofing system is probably its long term performance. In the case of a metal roof this is closely related to its corrosion-resistance and the compatibility of the metals used with their fixings, other building components and other materials in contact with the roof. For example, the life of galvanised steel, which is dependent on the zinc thickness and the severity of exposure, can be predicted and related to the life of a building. Thus, a steel roof galvanised with 0.6 kg/m^2 (2 oz/ft^2) zinc coating in an industrial atmosphere, would have a life of about seven years until significant rusting occurs, while unprotected steel would corrode at a rate of about 0.13 mm (0.005 in.) per year. If the same galvanised steel roof were in a rural environment, it would probably last 30-40 years. An alternative choice of metal may be stainless steel. If type 316 alloy were chosen, the expected life span in urban or rural are as would be far more than 40 years. It is therefore, important to relate the life span of the roofing material to the estimated life span of the building. Aluminium has a low density and is very useful for light weight roofing, if certain precautions are taken. Its corrosion resistance depends on the formation of a self-sealing inert oxide film, the degree of protection achieved dependent on the alloy composition. Pure aluminium and medium-strength alloys are more resistant to atmospheric attack than the high strength copper containing alloys, particularly where there are both moist conditions and industrial pollution. The same applies to marine exposure sites. The direct washing of aluminium by rain water is beneficial and should lead to high durability, but the persistence of condensation, particularly under the roof, can lead to accelerate corrosion. Compatibility with other metals and building materials is also important.

Zinc and galvanised steel are widely used for roofing and their durability will be directly proportional to the thickness of the zinc. Zinc is less prone to chloride induced pitting corrosion than steel and corrodes at a lower rate. Heavily polluted moist industrial atmospheres are the most aggressive, promoting a corrosion rate thirty to forty times as great as an unpolluted atmosphere. Zinc, like aluminium, can corrode when in contact with other metals, particularly copper and it should only be allowed to come into contact with galvanised or stainless steel. Corrosion is also induced by contact with damp mortar and concrete and as with aluminium, zinc should be protected if this is likely.

One or two general points may be made to avoid corrosion of roofing metals. Horizontal areas where water can remain stagnant, crevices and junctions of metals which may lead to bi-metallic corrosion should be avoided. Roof spaces should be designed to prevent condensation, either by ventilation or by other means. Contact with incompatible building materials should be avoided.

Mechanism of Corrosion :

Major materials used by the construction industry are cement, aggregate, ceramic products, timber and metals. A significant proportion of the total value of materials used in construction is accounted for by metals, so it is wise to use them as economically and sensibly as possible. A knowledge of their performance as structural and service elements and their durability when used in construction, is necessary to achieve optimum performance of the materials.

Modern architects and designers use metal to perform many functions in buildings; for example structural frame work and reinforcement, as materials for services, weather-proofing and finishes. Unfortunately, most metals, if not adequately protected, will corrode, thereby limiting their serviceability and spoiling their appearance.

Metals and Corrosion :

Most metals are valuable to climatic influences which result mainly in corrosion is the term which means deterioration and loss of material due to the chemical attack in the environment. Many examples of corrosion of materials are in daily evidence, rusting of iron is such an example. The conditions that promote corrosion involve both chemical and electronic changes. Therefore, the mechanism of corrosion must be carefully understood with a view to minimize this destructive effect, partioularly on metals. Corrosion is favoured by high humidity conditions which retard evaporation from rain-wetted surfaces and also permit condensation on surfaces which are not exposed to rain.

The Mechanism of Corrosion :

Corrosion occurs where an electrolytic cell is established. This can be brought about by the presence of two different metals, both in contact with an electrolytically conducting solution, or by two portions of the same metal in contact with an electrolyte where there is a concentration gradient or a temperature gradient across the cell. In addition to the presence of an electrolyte, the metals which form the electrodes of the cell must be connected via an external electronic conductor for corrosion to occur. Examples of electrolytic corrosion can be found where copper bearing alloys are used with aluminium for external components, where steel pins are used in the hinges of aluminium window frames and where copper or brass fittings are in contact with zinc or galvanised tanks. Similarly, corrosion may occur from the action of copper-bearing water, such as the rain-water overflow from new copper roof-clading, on to aluminium or zinc components. Water alone can be instrumental in attack but the rate of corrosion will be greatly increased if dissolved salts are present; for instance chlorides, such as common salt, quickly corrode copper. A tropical marine environment, with salt laden winds and possibly sea-spray, can therefore provide conditions which are extremely corrosive towards metals. Moreover, hygroscopic salts deposited on metal surfaces will act as moisture trap.

It has already been indicated that the permeability of poor quality concrete can result in corrosion of metal reinforcement. The result of this is to reduce the effective cross-section of the reinforcement, but more evident is the fact that the corrosion products tend to occupy a greater volume than the original metal. Internal stresses are thus set up, leading to cracking and spalling of the concrete cover.

Apart from uniform corrosion over a metal surface, localised attack or pitting often takes place. The depth of pitting is dependent upon the severity of the localised attack which, in turn, is the result of of interaction between protected and unprotected areas of metal. As the ratio of protected to exposed area increases, corrosion processes produce more localised but more severe and deeper attack. While uniform attack produces significant quantity of corrosion product the strength of the component is unlikely to be affected in the short term, whereas penetrative localised attack can lead to a significant reduction in cross-sections of the component, with corresponding loss of strength, very quickly and the presence of corrosion may not be evident until rupture has taken place. Even more catastrophic is the failure caused by stress corrosion cracking which invariably occurs without warning. This takes place when a metal is under tensile stress in a corrosive environment. Fine penetrating cracks are produced and these reduce the sound cross-sectional area of the metal until the tensile force present is sufficient to fracture the remaining unaffected metal. In this instance, the outer surfaces and sides of the cracks in the metal are usually, though not always, protected by an oxide film, whilst the deformation at the tip of the crack produced by the stress continuously exposes fresh unfilmed metal on which very severe attack is concentrated.

Reference

1. Over Seas Building Notes No. 137.

Ferrocement Grain Silo

A.Q.M. SHAHIDULLAH, MIRZA MAHBUBUL HAQUE,
MD. HASANUZZAMAN KHAN AND
KAZI ATA-UL HAQUE
Housing and Building Research Institute. Dacca.

1.0 Introduction

Ferrocement construction in one form or other has been in practice in Bangladesh for sometime past, usually dictated on the consideration of economy. The use of the material was, however, limited, until very recently, to the construction of some elements of a building due to insufficient knowledge of proper technology and scientific evaluation of the material.

At the initiative of Bangladesh Planning Commission a small project was initiated in Housing & Building Research Institute in January 1977, the aim of which was to ascertain the performance of ferrocement grain silo under local condition. Accordingly a small ferrocement silo with a capacity of 80 maunds of paddy was constructed in the Institute premises, the performance of which is still under observation.

The problem of food storage is emerging as a major problem in Bangladesh calling immediate attention. Increased supply of food grains, such as rice, wheat etc. resulting from augmented production, have created an unprecedented demand for storage facility where production areas are still unprepared to store this new abundance adequately. Every year quite a good quantity of our food grains and other perishable products get damaged or wasted due to lack of adequate storage facilities and practices. Weather, insects and rodents attack the grains causing heavy damage. Facilities are needed to protect these products which are vulnerable to temperature, humidity, rain, wind and attack of rodents etc.

2.0 Scope of study and investigation

The experimentation is intended to see wheather the silo constructed with ferrocement can provide facilities needed to protect paddy which, like many other agricultural products, is sensitive to rain, humidity, temperature, wind and attack of pest animals, bacteria and fungi etc. The study includes observation of the resistivity of the silo to mechanical agents like shock, its thermal conductivity and possible moisture migration within its range. Also under observation is the entrance of moisture, attack of rodents in case the silo is not filled upto the brim and the lid is not airtight.

3.0 Composition and material properties of ferrocement

Ferrocement is one form of reinforced concrete made of,—

Reinforcing Mesh	:	Chicken wire or similar diameter steel mesh. The wirediameter ranges from 0.02" to 0.06" and mesh size varies from ⅜ inch to 1 inch. The volume of mesh should be 4 to 8 percent.
Cement	:	Ordinary portland cement.
Sand	:	Well graded and fine natural sand.
Water	:	Commonly used fresh water.

Ferrocement is the densely reinforced mortar formed into a thin shell and it behaves as a composite materials. The properties of ferrocement depend on the combination of steel, the form of fine steel wire and dense high strength mortar. As credited to it, the ultimate success of ferrocement depends very much upon the quality and placement of the mortar. Due to the introduction of steel fibres or wire mesh the effective tensile strength of mortar (as measured by the cracking or ultimate load) improves significantly

3 to 4 times. The wire mesh reinforcement increases the resistance to impact and prevents complete collapse of the structure if it happens to develop crack. It is due to the fact that the reinforcement produces some effective ductility and as such any damage on the structure can easily be localised.

Among the other advantages of this material is that thin structures ranging from 0.4 to 1.6 inches having relatively high tensile strength up to 4000 pounds /sq. inch can be constructed with it and it shows essentially a quasi-crack-free homogenious behaviour. However, the fracture strength of ferrocement depends solely on the load carrying capacity of the mesh reinforcement and the variation in cement-mortar does not affect the tensile strength. The factor that distinguishes ferrocement from reinforced concrete is the considerably higher specific surface of its reinforcement. This limits crack to much finer widths and multiplies tensile strength. The geometry and shape of the mesh wire also influence cracking and certain type of mesh are found to be unsuitable for ferrocement construction.

In the case of a ferrocement silo, like many of its applications, the impermiability of the material is the most important consideration. The mortar should be properly compacted and cured.

Permiability depends very critically on water-cement ratio. It is very low, almost imperiable, when the water-cement ratio is less than 0.4. Any increase in the value sharply raises the permiability.

4.0 Merits of the ferrocement structure :

It has been agreed that the most noteworthy advantages are :

Strength :	High compressive and tensile strengths.
Resistence to mechanical agents :	By dint of its great flexibility ferrocement can tolerate impact, shock and explosion of comparatively high magnitude.
Resistence to chemical agents :	Ferrocement structures, unlike steel and alloys, attains high resistivity to most chemical agents. Special surfaec treatment might be necessary in a very few cases.
Sound and vibration Absorbance :	Owing to its relatively high density and mass, ferrocement absorbs sound and dampens vibration better than any other commonly used huk material.
Durability :	Ferrocement structures attain better longevity, as they do not rot, rust, corrode or crack easily.
Thermal conductivity :	Heat conducting capacity is very low about 1/6 of that of steel.
Crack arrest :	Due to the dispersed reinforcement cracks are arrested and their widths are limited and they are no bigger than micro-cracks in dimension.
Maintenance :	It does not require maintenance at all, as the material is highly resistive to rot, rust heat, cold and other elements that necessitates preventive maintenance.
Ease and economy of repair :	Damage is localised and damaged areas can be cheaply and easily repaired by mortar. The repaired section becomes as strong as the original section if carefully done.
Cost :	Ferrocement application is relatively inexpensive due to the fact that the cost of the materials used are low in developing countries. Moreover, the volume of materials used is comparatively small and this reduces the transportation cost,

Adaptability to any shape : For purpose of construction the wire mesh can easily be formed into the desired shape which may be flat, curved or dome shaped.

For loading purpose the silo has been provided with a wooden ladder. One lid made of ferrocement material is also provided at the top with padlocking arrangements so as to preclude thefts. Brief account of the materials, labour and total construction cost is furnished below :—

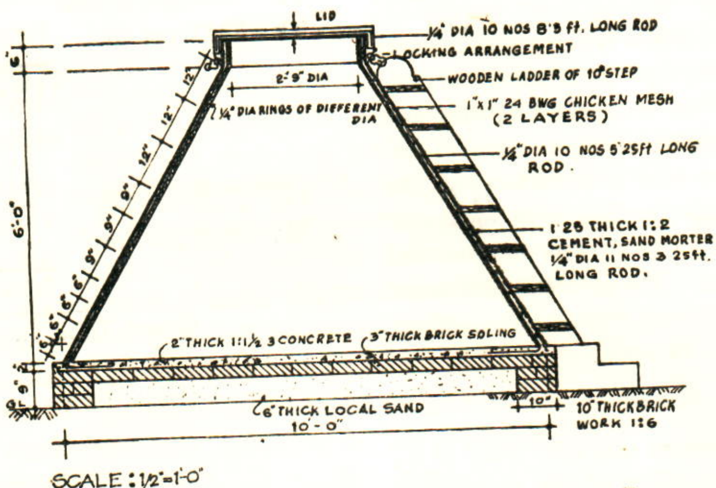


Fig. 1. Cross-section of the ferrocement silo

5.0 Construction of the Silo

The silo has been designed to take normal and natural loads. Principle of construction and design was so chosen that the experimental model may fit the requirements of the villagers. With 10 ft. base dia. 2 ft. 9 inches top dia. and 6 ft. vertical height, it has been shaped conical. Volume (internal) of the silo is approximately 212 cft. It has the capacity of storing 80 maunds of paddy, 115 maunds of rice or 105 maunds of wheat. Thickness of the silo has been kept 1.25 inches taking into account temperature, humidity and average rainfall of the country.

Base of the silo is built on a sand filling of 6" thickness above which there is a 1" thick brick soling. It consists of a single layer of 2" thick (1 : 1½ : 3) concrete. The walls are reinforced with ¼ dia m.s. rods and one layer of 1 x 1 BWG wire mesh on internal and external faces. The mortar is hand mixed and is applied as a thick paste using trowels and fingers.

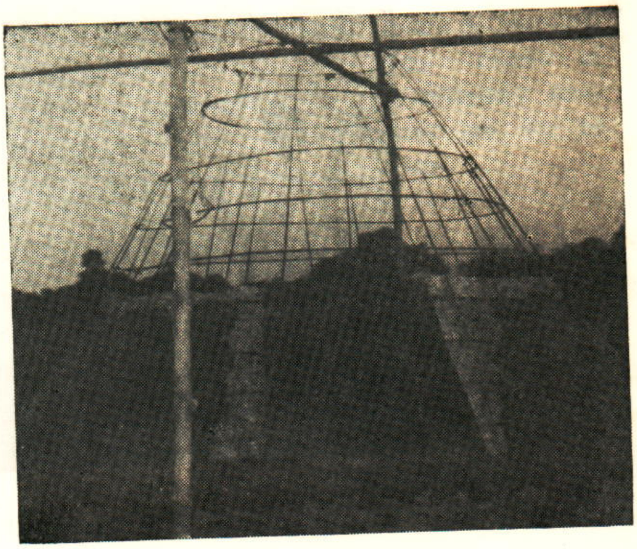


Fig. 2. Paste of mortar is being placed over chicken netting reinforcement

6.0 Total Taka Required

6.1 Materials

1.	Cement	12 bags	Tk. 62.00 per bag	Tk. 784.00
2.	Coarse sand	40 cft.	Tk. 2.00 per cft.	Tk. 80.00
3.	First class bricks	750 Nos.	Tk. 600.00 per 1000 Nos.	Tk. 450.00
4.	24 BWG chicken mesh	416 sft.	Tk. 1.22 per sft.	Tk. 507.50
5.	24 BWG G.I. wire	3 pounds	Tk. 11.00 per pound.	Tk. 33.00
6.	Tarja shutter	187 sft.	Tk. 0.50 per sft.	Tk. 93.50
7.	Barrack bamboo	2 Nos.	Tk. 20.00 per Nos.	Tk. 40.00
8.	Local sand.	35 cft.	Tk. 1.00 per cft	Tk. 35.00
9.	¼" dia m.s. rod	76 pounds	Tk. 3.50 per pound	Tk. 266.00
10.	Garjan timber	3 cft.	Tk. 70.00 per cft.	Tk. 210.00
				Total Taka 2,499.00

6.2 Labours

1.	Skilled labour	11 Nos.	Tk. 25.00 per day	Tk. 275.00
2.	Unskilled labour	20 Nos.	Tk. 10.00 per day	Tk. 200.00
				Total Tk. 475.00
				Grand Total Taka 2,974.00

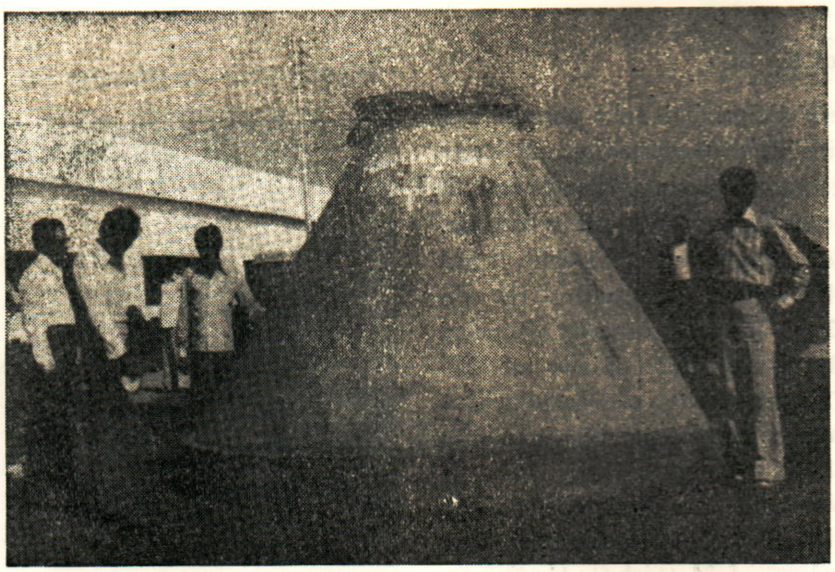


Fig. 3. Ferrocement grain silo after completion

6.3 Time of Execution

First week of January, 1977.

6.4 Comparative construction cost of silos of same capacity built with different materials and methods :

Sl. No.	Description of the silo with storing capacity	Performance	Cost in Taka	Remarks
1.	Ferrocement silo : (80 maunds of paddy)	Longevity is very high as it does not rot, rust, corrode or crack easily, silo is capable of bearing shock & impact of large magnitude and protecting grains from possible adversities of nature. Ferrocement silo does not require maintenance at all. Grains stored in f.c. silo undergoes no significant change in its starch quality, physical and chemical properties etc.	2974.00	It is suitable for developing countries where the farming community is handicapped by financial constraints.
2.	Bamboo mat silo of same capacity :	Durability varies between 5 and 8 years. Obviously the silo is not self protective; to guard against possible destruction by man and animals it is to be housed under a roof. Measures are also to be taken against the hazards of weather.	500.00	Separate shelter is needed for protection.
3.	Straw-rope silo of same capacity :	Most often the silo is meant for seasonal storage of grains and as such maintenance is not generally needed. Involves low level of technology and cost. It is vulnerable to hazards of weather and animal attack and calls for careful attention.	Nominal	Unsafe & insecure. High degree of precautionery measures are to be taken.
4.	Conventional masonry godown of the same capacity :	Masonry godown is very sound in its structure and it is most durable. The silo require nominal maintenance.	7000.00*	For its structural soundness it is safe secured.

*As per P.W.D. Rate Schedule—effective from Dec. '75.

7. Performance of the Silo

7.1 Routine observation.

Date	Time	Humidity		Temperature			Grain Condition.		Remarks
		Atmospheric	Inside the Silo.	At the top of grains °C	Av. of the lower levels. °C	Atmospheric °C	General condition/ Av. moisture content (M.C.)	Growth of insects/ rodents.	
14-5-77	9-00 A.M.	72%	82%	--	29.5 Empty Silo.	31	15.1% at storage time	Insects observed.	Insects were present in paddy at the time of procurement.
29-5-77	8-30 A.M.	80%	85%	27	29	—			
	1-30 P.M.	70%	70%	31	33	32	Normal	Increasing slowly.	
7-6-77	11-00 A.M.	67.5%	75%	32	35.5	31	Av.M.C. 14.2%	-do-	
9-6-77	8-00 A.M.	85%	92%	25	34.5	24	—		
	1-30 P.M.	80%	70%	32	35	31.5	Av.M.C. 14.5%	-do-	
13-6-77	12-45 P.M.	71%	80%	33	36	32	—	-do-	Insects have been identified as 'Alphibius' type, less harmful to paddy.
18-6-77	9-30 A.M.	78%	86%	26	35	30	—	Growth rate decreasing	
	1-30 P.M.	70%	76%	33	35	32			
23.6.77	8-00 A.M.	75%	82%	25	32.5	26	Av.M.C.		
	1-00 P.M.	70%	70%	32	35.5	31.5	14.62%		
26.7.77	9-00 A.M.	94%	84%	25	34	27	14.68%		
	12-30 P.M.	76%	80%	34	34.5	—			
9-8-77	9-30 A.M.	84%	86%	26	34	25		Decreasing rapidly.	
25.8.77	10-00 A.M.	88%	86%	33	34	30		-do-	Grains are dry and normal.
7.9.77	12-30 P.M.	78%	72%	30	35	29		-do-	Decrease of growth thought to be due to the fact that in F.C. Silo oxgyen becomes scarce and carbon dioxide increases preventing growth of insects.
28.9.77	12-45 P.M.	82%	54%	—	35.5	29		-do-	
6.10.77	12-45 P.M.	—	70%	31	34	32		-do-	
20-10.77	8-00 A.M.	88%	65%	26	32	28		—	
	2-00 P.M.	75%	68%	30	33	32		—	

Date	Time	Humidity		Temperature			Grain condition		Remarks.
		Atmospheric	Inside the silo	At the top of grains °C	Av.of lower levels. °C	Atmospheric °C	General condition/ moisture content.	Growth of insects/ rodents.	
5.11.77	12-30 P.M.	58%	63%	37	32	28	Av.M.C. 13.4%	Growth stopped.	No insecticides or fumigents applied at any stage.
20.11.77	10-00 A.M.	88%	84%	29	33	30	—	—	
26.1177.	10-30 A.M.	—	75%	28	34	27	—	—	
27.1.78	10-00 A.M.	40%	52%	22	28	25	—	—	
4.2.78	1-30 P.M.	52%	50%	20	27	24	—	—	
15.2.78	1-30 P.M.	55%	50%	26	25	—	—	—	
24.2.78	8-30 A.M.	65%	56%	23	26	22	—	—	
	1-30 P.M.	60%	55%	24	26	28	—	—	
12.3.78	9-00 A.M.	57%	48%	25	29	27	—	—	
	2-00 P.M.	55%	50%	26	29	29	—	—	
18.4.78	8-00 A.M.	92%	75%	24	30	25	—	—	
	12-00 A.M	85%	65%	25	30	28	Average M.C.11.73%		

7.2 Summary of observation, interpretation of data and inference :

Before loading, the silo has been subjected to the following tests of crushing and impact load tests in order to ascertain its structural soundness and resistive capacity against possible mechanical agents that may damage it in rural areas. The tests were performed after 14 days of curing.

The tests were :—

i) Compressive strength tested with the help of a 'Concrete Test Hammer' has been found to be within the range of 500 to 1500 p.s.i. at an inclination of 45° with horizontal direction, at different points on the silo.

ii) It was found capable to absorb the impact of a halfbrick (41b-weight) when put in oscillations from a rigid support, and that of a full brick when dropped from a height of 20 ft. at the mid-slope.

External surface of the silo has been kept covered with rags moistened with water for 7 days, at a stretch, and it was found that the inner surface was not invaded by the moisture. This confirms its resistence to rain and water logging.

On May 5, 1977 the silo was filled with 80 maunds of paddy, to a height of 4'-6" above the base. It was covered with lid and locked (not sealed with cement-mortar etc.) A summary of the observation on various aspects of performance of the silo, as recorded during a period of about one year of storage is as follows :—

a) Temperature

The temperature inside the silo was recorded at different points of two different levels. (i) On the top of the paddy. (ii) 30 inches above the base.

In general, the temperature readings obtained at the lower level were fairly constant at arround 35°C during May, June of the summer season. At the top there was a variation from about 26°C in the morning to 32°C at mid day. Outside the silo the maximum temperature recorded was 38°C at mid-day.

The variation of temperature during the months of monsoon and cold seasons followed an almost similar pattern.

b) Moisture content, growth of insects, rodents etc. and general condition of silo :—

(May-July) :—During the period silo-lid has been opened once a week for the purpose of observation. Moisture content (M.C.) of the grains at the time of loading was 14.1% (dry basis-heated for 1 hr. at 130°C, ½ hr. to constant weight). Two and a half months later, the average M.C. was found to be only marginally higher at 14. 68% and grain condition was dry and free from fungi or other rodents. It showed that the silo was able to withstand the attack of humidity and water percolation when there was a noteworthy rainfall, 52 inches in three months. Both internal and external faces of the silo were dry & normal; its general condition was alright. However, a slow growth of insects started since June and these were mostly 'Alphibius' type, less harmful to paddy. No fumigants or insecticides was applied at any stage of the storage.

(Aug-Oct.) :—Av. M.C. 14.2% (decreased slightly) samples drawn from the bottom gave higher values of M.C., 15.8% at the maximum. It was the time when growth of insects increased rapidly.

(Nov.-Mar. '78):—Near about 5 maunds of paddy lying in touch with side wall (upto a height of 1'-6" from base) was found moistened. Growth of bacteria and fungi appeared notable in the affected grains; grains were removed from the silo, dried in the sun. Possibility of water percolation was cheked by covering external face with rages and pauring water over it continually for 3 days, but water did not soak through. Grains were again stored.

Growth-rate of insects showed a slow decrease and ultimately came to dead stop, probably due to the fact that during this period observations were made once a fortnight for avoiding frequent disturbance of silo environment.

Silo condition has been normal except the formation of 3 or 4 microhaircracks on its external face.

8.0 Concluding Remarks

Construction of Ferrocement silo as studied above involves very low level of technology and as such it can easily be adopted in our clime and by our farmers. Cost of construction as shown here can be reduced to a good extent by a careful selection of the principle of designing and construction. Replacement of M.S. rod with bamboo strips may further reduce the cost

It should be noted here that some discouraging developments took place in course of the present study. But they should not at all disappoint a careful observer. The study has to be initiated in a race against time and as such all could not be done carefully.

Besides, due to severe paucity of manpower at our disposal, the study of the silo has to be restricted to some limit. However, further work on ferrocement Silo as well as corrugated sheet, sank, pan, roofing elements for lowcost housing etc. is about to be under taken. Relevent to this one may recall that under the sponsorship of the Institute, an IGLOO-TYPE dome-shaped ferrocement house of the dimension 16'-0" x 16'-0' was built experimentally in 1971 and the building still remains unscratched. Construction of the house cost Taka 1463.90, cost per sft. being Taka 7.75. The Instiute is going to initiate shortly research project so as to unfold the vast possibilities held out by ferrocement in a developing economy like our where only limited resources of building materials are at hand.

Acknowledgement

The authors want to express their thanks to Mr. A.K.M. Khorshed Alam, Senior Research Officer of Housing and Building Research Institute for his time to time help and assistance in undertaking this work and preparing the technical report.

Possibility of Introducing Precast Elements for Low-cost Housing

MIRZA MAHBUBUL HAQUE AND KAZI ATA-UL HAQUE

Housing & Building Research Institute, Dacca.

Introduction :

The roofing/flooring of a building is one of the most important element of a building. The function it has got to play is to protect the interior of the building from the effects of the weather, rain, temperature, wind, load etc. and to serve the above functions efficiently it must be durable to resist these natural forces. Making such durable roof in conventional way takes much time and consumes much scarcely and costly materials like cement, steel, timber etc.

Therefore, studies have been initiated in the Institute to experiment serveral designs and construction techniques for reducing the consumption of these scarcely and costly materials by utilising local materials and potentials to the best advantage. Attempts of experimentation with the following types of pre-cast schemes have been directed towards, (a) least volume of centering, shuttering works, (b) speeding up of construction, (c) improving the quality of construction, (d) overall economy and saving of costly materials.

Experimental Schemes :

Different pre-cast schemes as experimentated in the Institute are as follows :

1. Pre-cast R.C. Channel for floors/roofs.

Pre-cast R.C. channel is one form of pre-cast R.C. element-inverted 'U' or 'trough' in section which can be used for floors and roofs with ordinary wall and framed structure. It does not require any beam or joist and it does not also require support or prop during construction. Deck concrete is also not required. This type of roofing is suitable for 8'-0" to 12'-0" span.

The floor/roof system consists of pre-cast R.C. channels which are placed directly on wall or beam adjacent to one other. After assembling, the joints are filled with normal concrete and cured. The floor finish/roof finish is done afterwards.

Size and dimension of the units used in the Experimental house have been shown in the figure. Normal width of the unit is 12" and the depth is 5" and average thickness of section is $1\frac{1}{4}$". (Fig.1)

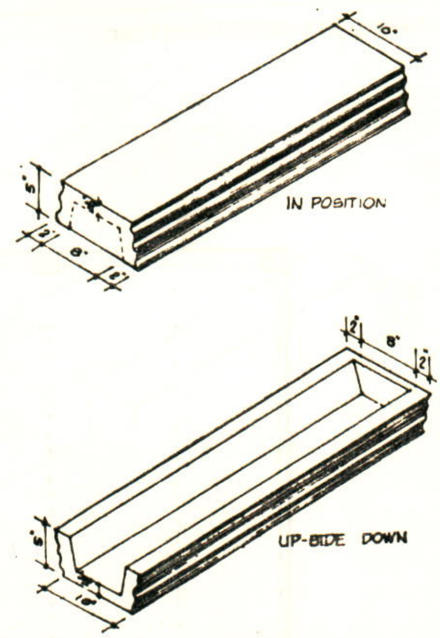


Fig. 1. R. C. Channel

The units are cast with the help of simple wooden frame "trough shaped" in section. Ordinary cement concrete (1:2:4) with 3/8" down graded aggregate is used for casting the units. The framework is placed on the ground and reinforcement cage based on design requirement is placed in framework over a layer of cement concrete of proper thickness and concreting is done with the help of a vibrator for proper compaction and finishing on the surface is done. The unit is left undisturbed for 24 hours after which it is removed for water curing for 2 weeks and air-during for two weeks. Then the units are lifted manually and placed one adjacent to the other. After assembling the elements, negative reinforcement is provided at the top close to the support. The joints are filled in with ordinary concrete (1:2:4) and cured. Floor finish/roof finish is done afterwards. This may be used in school /health centre/residential building in rural areas.

Economics (for 100 sft. area of roof):

Item	Conventional R.C. slab.	Channel unit	Saving
Cement	7.42	6.37	14%
Steel	201.96lbs	153.5 lbs	24%
Cost	Tk.1699.00	Tk.1250.00	26%

Besides, saving in construction time.

2. Basic Support structures scheme :

The scheme is of better quality than any other conventional house in rural areas and very much flexible. It can be constructed in stages; first durable supports with roof are constructed then walls, doors, windows, may be added later according to financial capacity of the owner.

In many parts of the country where good quality of bricks are not available and places which are prone to cyclone and flood, this support structures may be adopted profitably. This system require minimum quantity of concrete. Different pre-cast concrete components of the support structure are footing, hollow column, D.C. tiles pre-cast beam for shortspan and partial pre-cast beam for long span. Spacing of the column may be variable depending on the size of the D.C. tile adopted for the purpose. The partially pre-cast beam carries load from D.C. tiles and transfers the same to the column through the beam. The cladening wall may be made of any local materials, such as sundried bricks mud walls, burnt bricks or

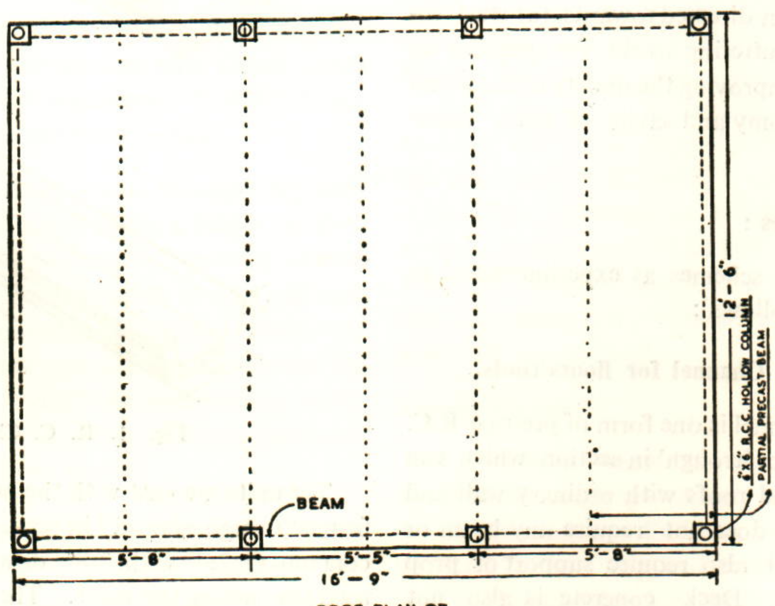


Fig. 2. Different Elements of Basic Support House

bamboo mats. A room (16'-9" x 12'-6") has been constructed with the above technique (Fig.2).

All together 8 hollow 6' x 6" square pre-cast R.C. column with hollow footing, 5'-8" long pre-cast beam, 12'-6" long partially pre-cast beam with 2'-6" D.C. tiles have been used in the above scheme. It is so flexible that it can be extended both longitudinally and transversely with addition of columns and beams.

Economics :

Itme	Conventional R.C. slab.	Basic Support Structure.	Saving
Cement	15.52	12.32	20%
Steel	507 lbs	389.55 lbs.	23%
Cost	Tk.3705.56	Tk.2853.88	30%

Besides saving in construction time.

3. Plank type flooring/roofing scheme :

Plank type flooring/roofing scheme consists of partially pre-cast R.C. beam and R.C. plank partly 2" and partly 1" thick.

The planks are 4'-0" long and 1'-4" wide. The central portion is 2'-0" long and 2" thick and the end portion is 1" thick. The shape and cross section of the planks are as shown in the figure. The scheme is profitably adopted for the span upto 12'-0".

Casting of the plank is done in a simple mould with ordinary (1:2:4) concrete, size of the aggregate restricted to 3/8" down graded brick aggregate.

The planks so cast are placed on partially pre-cast beam and haunches are filled in with concrete (1:2:4).

The beam with in-situ concrete act as T-beam and finishing including water proofing is done over plank after wards.

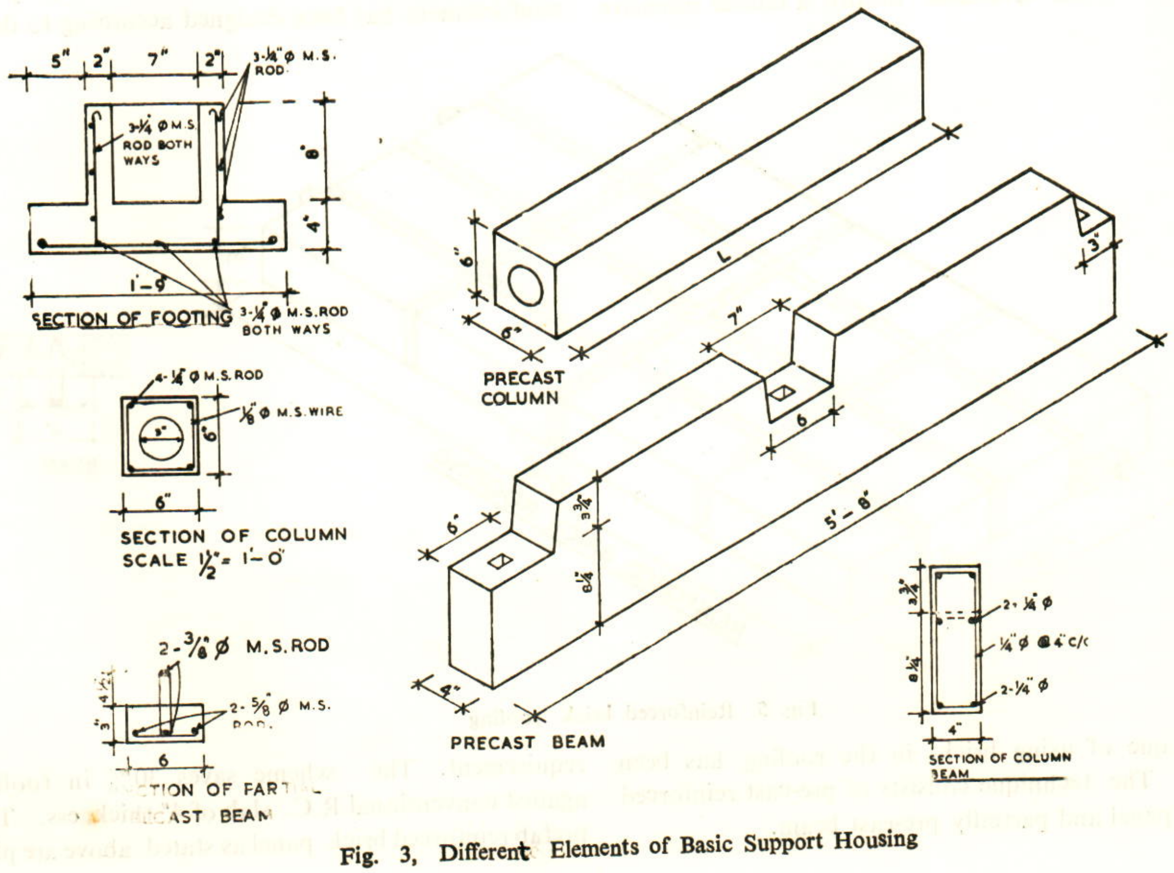


Fig. 3, Different Elements of Basic Support Housing

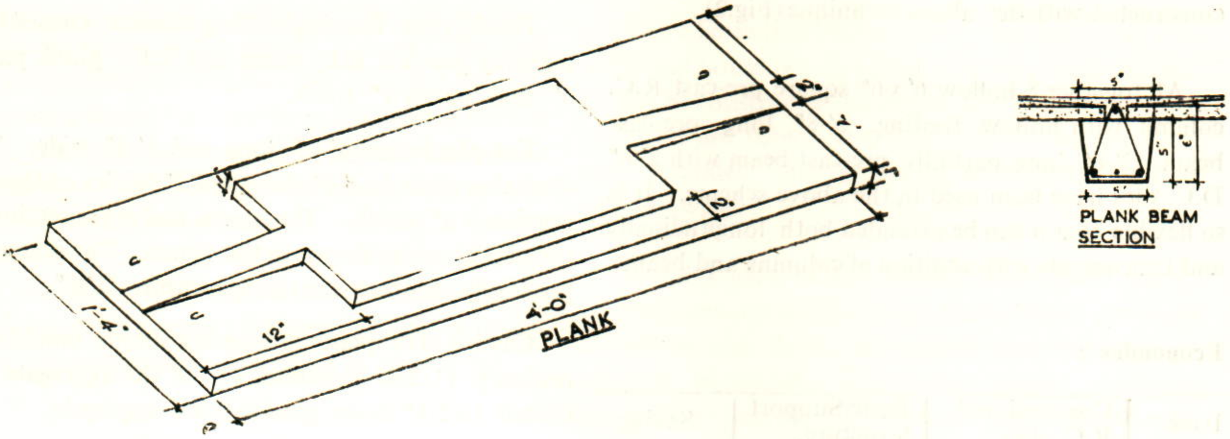


Fig. 4. R. C. Plank

The scheme is expected to consume 47% less in cement and 20% less in steel. The cost is 26% against conventional R.C. slab (Fig4).

4. Reinforced brick roofing scheme :

Bricks being common local building material and human labour available locally, a labour intensive

Reinforced brick panel is of 3'-6" x 1'-9" size, 16 Nos. 1st class bricks in (1:4) cement mortar reinforced with 2-⅜" dia m.s. rod have been used as shown in the figure (Fig. 5).

Pre-cast reinforced concrete beam with projecting reinforcement has been designed according to design

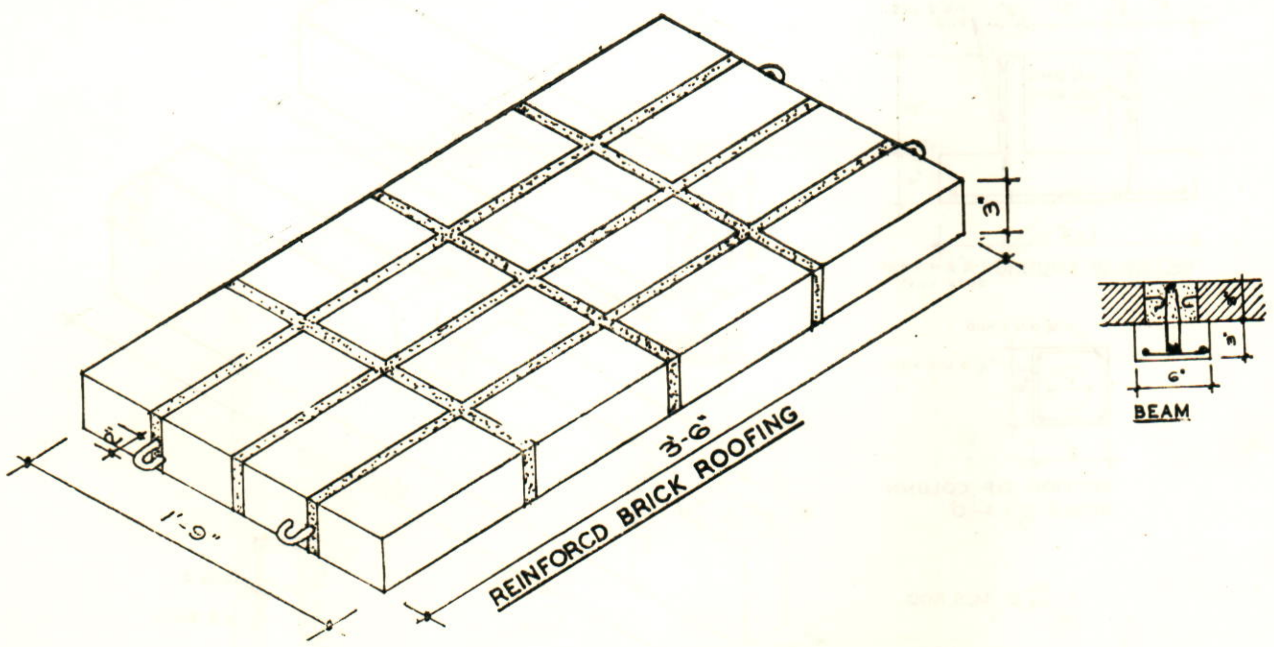


Fig. 5 Reinforced brick roofing

technique of using bricks in the roofing has been tried. The technique consists of pre-cast reinforced brick panel and partially pre-cast beam.

requirement. The scheme saves 30% in roofing against conventional R.C. slab of 4" thickness. The prefab reinforced brick panel as stated above are placed on the partally pre-cast beam which are suppoıted at middle third of the span and the joints are filled in with cement mortar. Deck concrete with temp. and negative reinforcement are provided all over the roof to form flange of the T-beam with the beam.

Discussion :

The Institute is evaluating further performance and serviceability of the elements and houses. The study will provide guide for further refinement of technique and better use of conventional materials. The new innovative constructional techniques and economical specification may be popularised for adoption on large scale in housing programme.

Investigation into the Problems of Brick Manufacturing in the Southern Part of Bangladesh

A.U. AHMED, MAJUMDER A.K.M.A. HANNAN
AND
M.A. SATTAR
Housing & Building Research Institute, Dacca.

There are mainly three varieties of soil in Bangladesh : alluvial soil, black soil and red soil. Out of these three, only alluvial type of soil are suitable for manufacture of good bricks. A good brick should have a fine, compact and uniform texture and should also have a sound hard and less water absorbing properties. Compressive strength of a good quality bricks varies from 2000 to 4000 psi for hand made burnt bricks and 4000 to 8000 psi for machine made bricks. Proper burning should be ensured to obtain a quality product. An invstigation into the problems of manufacturing good quality bricks at the coastal regions of Khulna, Barisal, Patuakhali and also Jessore and Faridpur districts have been carried out by this Institute.

Most of the brick fields which were considered during the investigation belonged to the Public Works Department and Roads & High Ways Department and running by the private firms on contract basis. The capacity of brick fields varies from 40 to 50 lakh per batch and coal was used as the main source of heat energy. The burning process was a batch system and there was no temperature control device. During these investigation the working persons of the brick fields were interrogated about the quality of bricks they are manufacturing and the problems they face from time to time for the production of good quality of bricks. It is reported that the gradation of the quality of bricks produced per batch are more or less as follows,

1st class	—	60%
2nd class	—	30%
3rd class	—	10%

Sample of bricks, soil and water from these sites were also collected and brought to the laboratories for experimentation. The test results are given in Table 1 and II.

Table - I

Physical properties of the bricks collected from the different brick-fields of southern part of the country

Location of the brick field	Average size of the bricks (lxbxh) in inch.	Percentage of water absorpsion	Compressive strength of the bricks in psi	Percentage of salt-content of burned bricks.
Kharnia, Khulna	9.5x5.1x3.1	13.45	1,876	0.40
Kanchanpur, Khulna	10.1x4.8x2.8	25.99	1,046	0.40
Chukhnagar, Khulna	10.0x4.8x2.8	16.82	1,597	0.53
Fakhirhat, Khulna.	9.7x4.8x2.9	19.20	2,562	0.30
Patchadighee, Bagerhat.	9.7x4.8x2.8	15.84	1,925	0.20
Shatighata, Jessore.	9.6x4.7x2.7	12.86	2,412	1.14
Manikgonj, Faridpur.	9.6x4.7x2.8	17.02	2,303	1.95
Barisal Sadar	9.5x4.6x2.8	14.09	2,299	0.38
Patuakhali Sadar	9.6x4.7x2.7	13.00	2,804	0.45

Table - II

Grain size analysis of soil

Location	Percentage of Sand	Percentage of Silt	Percentage of Clay
Kharnia, Khulna	9	75	16
Kanchanpur, Khulna.	8	75	15
Chukhnagar, Khulna.	12	70	18
Fakhirhat, Khulna.	14	62	24
Patchadighee, Bagerhat.	12	71	17
Shatighata, Jessore.	7	73	20
Manikgonj, Faridpur	12	73	15
Barisal Sadar	10	70	20
Patuakhali Sadar.	14	64	22

Discussions

From the results in the Table 1, it is found that bricks produced at Patchadighee of Bagherhat, Satighata of Jessore, Manikgonj of Faridpur, Barisal Sadar and Patuakhali Sadar brick fields are of better quality. It is also observed that water absorption of bricks of these fields are more or less within the limit of good quality bricks.

From the results in Table II it is observed, that the amount of sand in soil is less than that of requisite quantity[1] of 15 to 35 percent depending on plastic and sandy clay respectively. Moreover the mixture of clay and sand is heterogeneous. The process of pugging the soil is most unscientific, uneconmic and laborious. As a result both the employers and employees try to avoid rendering their services and funds for better processing of clay before making the bricks. Furthermore, for the lack of knowledge on the effect of using heterogeneous soil for the manufacture of bricks, the manufacturers never concentrate their due attention in this regard.

Percentage of water absorption of bricks after 24 hours immersion in water were determined and results are given in Table I. From this Table it is found that water absorption by the bricks of Kanchanpur, Chukhnagar and Fakhirhat of Khulna, Patchadighee of Bagerhat, Manikgonj of Faridpur district indicates inferior quality. This may be due to the underburning of the bricks. Furthermore, higher water absorption of the bricks is the cause of efflorescence and dampness of the building.

The salinity of the soil and bricks were also investigated and found that the percentage of salt in the bricks of Khulna. Barisal and Patuakhali regions are not upto the extent that may cause a harmful effect on the buildings. The lower salt content of these bricks as observed by the authors is due to the use of water from shallow tubewell.

Conclusion :

1. Bricks of Patuakhali and Barisal districts are of good quality. The credit is probably due to the manufacturing authority and local departmental officer who pay a careful attention to the control of composition and homogenity of soil in pre-firing stages.

2. Efflorescence in the buildings has been observed in Khulna and Barisal district. It is ascertained that the cause of attack is more likely to be due to the salinity of water used from river or canal in the preparation of mortar during construction works. Further the presence of soluble salts in sand and cement may enhance the efflorescence process.

3. As under-burnt bricks are liable to efflorescence and dampness of the building, the proper burning should be ensured for good bricks.

Acknowledgement :

The Authors wish to express their grateful thanks to Mr. Alhaj Abdul Hadi, Executive Engineer, P.W.D. Divn. 1, Barisal, Mr. Sheikh Md. Abdul Hai, S.D.E., Divn. 1, Sub. Divn. 2, P.W.D. Barisal, Mr. Harun-or-Rashid, S.D.E., P.W.D. Divn. 2, Sub. Divn. 1, Barisal, Mr. Jasimuddin, S.D.E., P.W.D., Patuakhali and Mr. Kamal Uddin Ahmed, Executive Engineer, Khulna Divn., Housing & Settlement Dte., Khulna, for their co-operation and valuable views expressed during this investigation, in manufacturing bricks in the country kiln.

Reference ;

1. G. J. Kulkarni, A. Text Book of Engineering Materials, Page 68, 8th Edition, 1968.

ADDENDA

Page No.	Position	Addendum
38.	After the last line	References : 1. Ferrocement Applications in Developing Countries, National Academy of Sciences, Washington. D. C , 1973. 2. Focus Ferrocement—Information Sheet, No. 77/2 April ,1977 and No. 77/4, June, 1977, AIT, Bangkok. 3. Construction Report on a Experimental Ferrocement Silo, Mirpur (H & S) Division—2, Dacca 1977.
43.	After the last line	References : 1. Building Notes No. 172, Overseas Divn. Building Research Establishment, U. K. 2. Proceedings CIB seminar on Building Research and its Application in Developing Countries held in New Delhi, India. Vol. 1, Feb. 28 to March 1st, 1977.

Housing And Building Research Journal

Vol. 1, No. 1, 1978

CONTENT

Printed in Bangladesh by M.A. Wahab at Associated Printers Ltd. Dacca. Cover design by M.A. Saddeque, H & B.R.I., Darus-Salam, Mirpur, Dacca.