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(21)

Strength of Brick Masonry*

Introduction

THE strength of brick masonry is influenced by several variable factors such as:—

1. Strength of the brick
2. strength of the binding mortar
3. eccentricity of loading
4. Slenderness ratio
5. type of construction
6. workmanship
7. adhesion of mortar to brick, and
8. the size, shape and regulartiy of the bricks.

Of these, the strength of the brick and that of the binding mortar are the most singnificant. Variables such as workmanship cannot be easily taken into account in the laboratory.

The strength of brick masonry has been the subject of several extensive investigations in the U.K.[1-7] and in the U.S.A.[8-13]. The British standard code of practice CP 111 (1948)[14] "Structural Recommendations for load Bearing Walls"—is based on the investigations carried out over a period of several years in the Buildings Research Station, Watford, England. The Nation Buildings Organisations considered that such investigations should be initiated in India to facilitate the formulation of an Indian code of Practice for the strength of Brick Masonry, on the same lines as the British Standard Code of Practice CP 111.

Scope

The proposed investigations which were to be carried out in several building research institutes situated in various parts of the country, consisted of :

(i) the study of the strength of the different mortars normally used in brick masonry, and

(ii) the study of the strength of brick masonry made out of these mortars using bricks of varying strength.

Originally nine mortars were suggested by the National Buildings Organisation for the investigations. These are listed in *Table* 1. However, later on it was thought that it would be adequate if the scope of the investigations was restricted to those mortars, used in India, for which data was not available in C.P. 111. The eight mortars finally included in the investigations are listed in *Table* 2.

The compressive strength of bricks proposed to be covered varied from 500 p.s.i. to 4000 p.s.i. Investigations with bricks of strength in the range of 500 to 1500 p.s.i. were to be carried out in the laboratories situated at Madras and Hyderabad. Bricks of strength in the range 1500 to 2000 p.s.i. were to be covered in the Central Building Research Institute, Roorkee. The P.W.D. Research Institute, Lucknow, was to carry out the investigation with bricks of strength in the range 2000 to 4000 p.s.i.

Procedure of Investigation

The specifications for the materials to be used in the preparation of the mortars included in the investigations and the detailed procedures to be followed in the preparation of the mortars

* Report on the investigation prepared by Sarvashri P.M. Abdul Rahman, S.S. Rehsi and S.K. Chopra of C.B.R.I. is being published here with some additions and modifications. —Editor

and in the casting, curing and testing of the mortar specimens, as drawn out by the C.B.R.I., are given in *Appendix 1*. The procedure for testing the bricks and for fabricating and testing the brick masonry cubes were also drawn out by the C.B.R.I. and are given in *Appendix II*, These sepecifications and procedures were circulated to all the other institutes where the investigation were proposed to be carried out.

Results of Investigation

Among, the research institutes which took up the investigations, the Central Building Research Institute, Roorkee, has completed the investigationas and the resultres obtained reported in the following paragraphs :

Strength of Bricks

The bricks obtained from a local kiln were tested for compressive and flexural strengths and water absorption according to standard procedures given in *Appendix II*. The test results are presented in *Table* 3 and in *Figures* 1 and 2. Six bond specimens were tested for each of the mortars under investigaton. In the absence of any accepted test procedure for determining bond, a method as described in *Appendix II* was followed. As the test results obtained were highly erratic and undependable, they have not been reported.

Strength of Mortars

Since the method of curing greatly influences the strength of a particular mortar, curing of lime-pozzolana or lime-pozzolana/sand mortars was done in moist air (at a relative humidity of 55$\pm$5 percent) as against the normal practice of curing the specimens under water[15]. Thus the conditions of curing in the field were closely simulated.

In the absence of any conclusive information[16] on the effect of particle size distribution of a pozzolana on the strength of lime pozzolana mortars, determined under a given set of experimental conditions, the pozzolanas (i.e. surkhi and cinder), having a fineness[17] equivalent to that specified for ordinary Portland cement (i.e., 2250 sq. cm. per gm) were used in the present series of experiments. Either the pozzolanas could be ground together with the binder to a fine mortar paste, or separately in a dry state to be mixed with the binder subsequently with or without water. The former procedure was adopted because it is easier to follow and results in more efficient grinding and intimate mixing. Moreover, combined grinding is more often employed in the field. Accordingly, grinding of the mortars was done in a power driven Winget-Edge runner capable of giving 20 revolutions per minute.

The effect of grinding on the fineness of the pozzolanas was studied with a view to find out the optimum period of grinding. The fineness was determined both by sieve analysis and by Blaines air permeameter.[18] It was found that grinding of the surkhi and cinder samples for 60 minutes and 120 minutes respectively, gave the desired fineness.

The compressive strengths of the eight different mortars included in the investigations are given in *Table* 4. It will be observed that lime-pozzolana and lime-pozzolana-sand mortars show much lower strengths than those reported in the available literature dealing with such mixes, cured under water.[16] Since curing in the field is done by sprinkling water on masonry walls from time to time, the present strength data gives a more realistic estimate of the strength development under field conditions. For example, the gain in strength from 14 to 28 days is not as much as is usually obtained on curing the specimens under water.

A comparison between the strengths of 1:2 and 1:3 lime pozzolana mortars shows that the latter possess higher strengths. This seemingly contradictory result is in fact in agreement with published data.[19]

Strength of Brick Masonry Cubes.

The results of tests on brick masonry cubes of 1'-6" size fabricated out of locally available bricks using the mortars under investigation are given in *Table* 4. In addition to testing the masonry cubes at the ages specified in *Table* 2, a few cubes were also tested at 28 days, to obtain additional information. The loads at which failure of the masonry cubes took place and the corresponding strengths of the mortars are reported in *Table* 4.

Relation between the strength of mortar and the strength of brick masonry.

From the limited test results available an attempt was made to relate the strength of mortar with the strength of brick masonry made with it, the strength of the brick remaining constant. A relation of the form $Y\text{-}178x^{0.214}$ fits the experimental results satisfactorily, x being the strength of mortar used and 'Y' the resulting ultimate unit strength of masonry. The relation is represented graphically in *Fig*.3.

Discussion of the result of the investigations carried out at the C.B.R.I.

The test results show that masonry cubes made with mortars 1 and 2 which contain cement have a markedly higher strength than the others containing lime alone as binder. It was observed that on loading the masonry cubes, the first crack appeared in the bricks when mortars 1 and 2 were used, while for other mortars the failure of the mortar preceded the failure of the bricks. Of the various mortars employed, pozzolanic mortars showed the highest gain in strength of masonry cubes at a later age.

In assuming factors of safety and arriving at safe working stresses, both the early strength at seven or fourteen days and the strength at 28 days will have to be given due weight. It is also rational to fix different factors of safety for masonry made with different types of mortars. For example, a lower factor of safety may be adopted in the case of masonry made out of mortars in which cement is the binding medium, the latter being a standardized product turned out by factories under conditions of strict quality control. On the other hand, lime being a non-standard material and of variable quality, it is but reasonable to apply higher factors of safety.

Based on these considerations, the working strength of brick masonry using mortars 1 and 2 may be safely taken as 120 p.s.i. at ages 7 and 14 days respectively. Brick masonry made with mortars 3,4,7 and 8 shows more or less the same order of magnitude of strength. The differences observed in strength amongst these mortars and the masonry made with them are probably not significant. It would therefore be reasonable to lay down the same working stresses for masonry made with these four mortars. A working strength of 50 p.s.i. is suggested as a safe value. Masonry made with mortars 5 and 6 were tested only at the age of 28 days. The strength of brick masonry made with these two mortars is likely to be of the same order of magnitude. A working strength of 80 p.s.i. appears to be reasonable.

As regards the relation derived between the strength of mortar and the strength of brick masonry, until the results of the tests from other laboratories are available, it will not be possible to say whether the same relation holds good for bricks having other ranges of compressive strength.

Summary of Results Obtained in the C.B.R.I.

The recommended working stresses and the implied factors of safety against ultimate failure and the first crack are summarised in *Table* 5. The relatively high factors of safety recommended are justified on the following grounds:

(i) The work reported here was carried out under laboratory conditions which involve strict supervision. Such conditions will not be obtained in the field.

(ii) The tests have been carried out with standard materials. The quality of a materials, especially of lime, varies widely.

The factors of safety against failure that have been assumed in arriving at the working stresses vary from 6 to 11. This is in good agreement with the range of 4 to 10. recommended by Rankine[20].

Recommended working stresses for brick masonry constructed with bricks of various strengths and mortars other than those included in the present investigations.

It was mentioned earlier that motars already covered in the investigations carried out in the Building Research Station, Watford, England, which formed the basis for the formulation of the B.S. Code of practice C.P. 111, have not been included in the present investigations. However, the working stresses, as recommended by the above B.S. Code of Practice for brick masonry constructed with bricks of varying strengths and mortars not included in the present investigations, have been given in *Table* 6, for the guidance of the readers, in the absence of any recommendations based on investigations carried out in India. The British and Indian specifications for the materials used in the preparation of the mortars being nearly the same, the stresses recommended in *Table* 6 are applicable in India also.

Factors for converting cube strength to wall strength for various slenderness ratios.

All the working stresses recommended in this report are for a slenderness ratio of unity as they are based on cube tests. The factors for converting cube strength to wall strength for brick masonry in cement, cement-lime and lime mortars for various slenderness ratios are given in *Table* 7. which is reproduced from B.S. Code of practice C.P. 111. The working stresses in cases where the slenderness ratios exceed unity should be obtained by multiplying the stresses permitted for a slenderness ratio of unity by the corresponding reduction factors given in *Table* 7.

Conclusion.

Investigations similar to those already completed in the C.B.R.I. are in progress in the Concrete Researeh Laboratory, Madras, and the P.W.D. Research Institute, Lucknow, with bricks of average strengths 1000 p.s.i. and 2500 p.s.i. respectively. The results of the investigations will be published in the Journal of N.B.O. in due course.

Acknowledgement.

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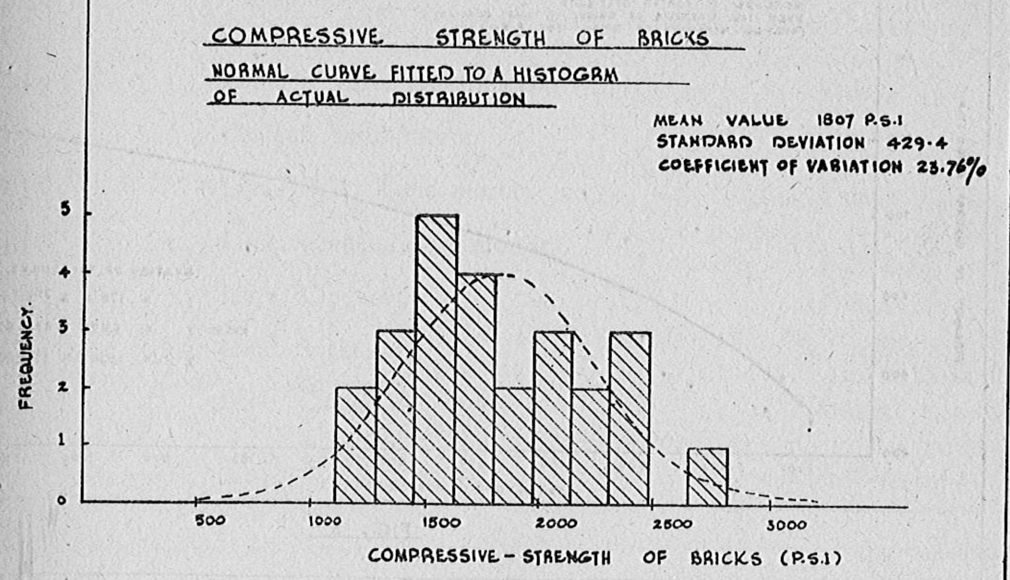
COMPRESSIVE STRENGTH OF BRICKS
NORMAL CURVE FITTED TO A HISTOGRM OF ACTUAL DISTRIBUTION
MEAN VALUE 1807 P.S.I
STANDARD DEVIATION 429·4
COEFFICIENT OF VARIATION 23.76%
FREQUENCY.
0
1
2
3
4
5
500
1000
1500
2000
2500
3000
COMPRESSIVE - STRENGTH OF BRICKS (P.S.I)

FIG. 1.

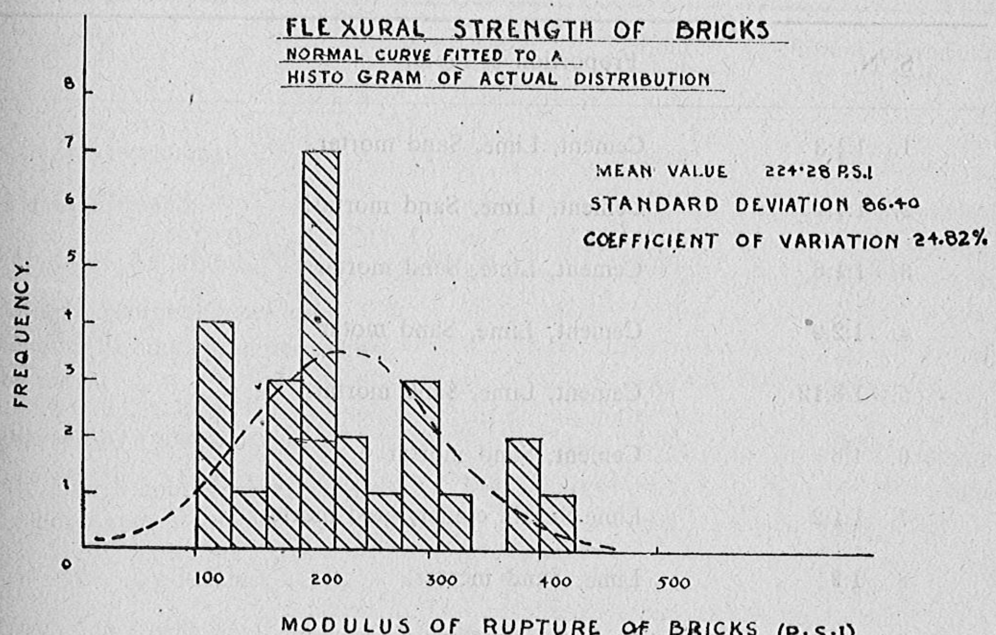
FLEXURAL STRENGTH OF BRICKS
NORMAL CURVE FITTED TO A HISTO GRAM OF ACTUAL DISTRIBUTION
MEAN VALUE 224·28 P.S.I
STANDARD DEVIATION 86·40
COEFFICIENT OF VARIATION 24.82%
FREQUENCY.
0
1
2
3
4
5
6
7
8
100
200
300
400
500
MODULUS OF RUPTURE OF BRICKS (P·S·I)

FIG. 2.

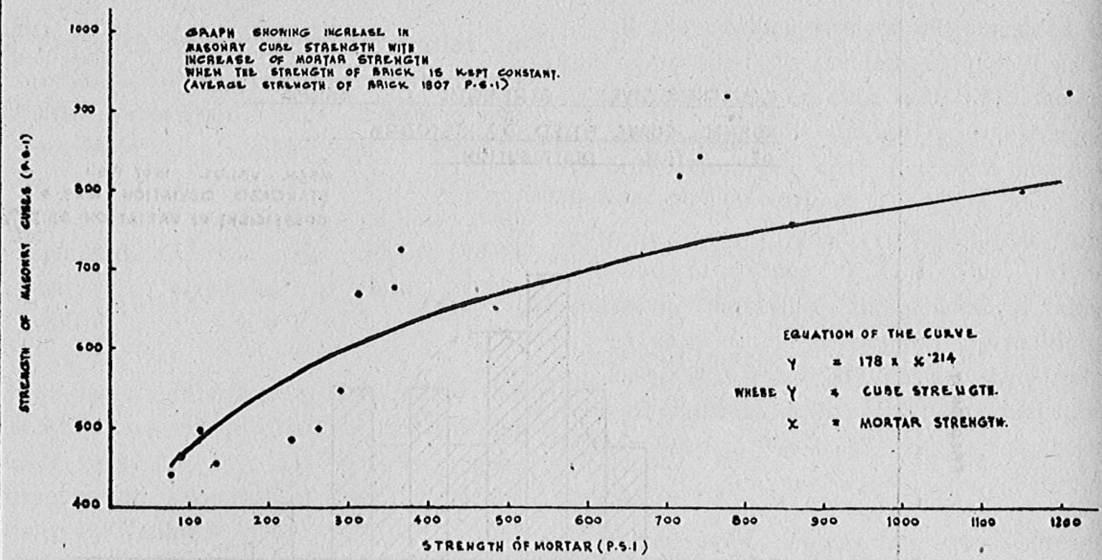

FIG. 3

TABLE 1.

S. N.		Proportion of motar
1.	1:$\frac{1}{4}$:3	Cement, Lime, Sand mortar.
2.	1:$\frac{1}{4}$:4	Cement, Lime, Sand mortar.
3.	1:1:6	Cement, Lime, Sand mortar.
4.	1:2:9	Cement, Lime, Sand motar.
5.	1:3:12	Cement, Lime, Sand mortar.
6.	1:6	Cement, Sand mortar
7.	1:1:2	Lime Surkhi cinder, sand mortar
8.	1:2	Lime, Sand mortar.
9.	1:3	Lime, Sand mortar.

TABLE 2.

S. No.		Proportions of mortar	Hardening period at which tests are to be conducted.
1.	1:½:4	Cement, Lime Sand mortar	7 days
2.	1:6	Cement, Sand mortar	14 days
3.	1:1:2	Lime, Surki, Sand mortar	14 days
4.	1:1:2	Lime, Cinder, Sand mortar	14 days
5.	1:2	Lime, Cinder	14 days
6.	1:2	Lime, Surki	14 days
7.	1:3	Lime, Cinder	28 days
8.	1:3	Lime, Surki	28 days

TABLE 3.

Properties of the Burnt Clay Bricks

S.No.	Property	Mean value	Standard Deviation	Coefficient of variation in per cent
1.	Compressive strength P.S.I.	1807	429.40	23.76
2.	Flexural strength (Modulus of rupture), P.S.I.	224.28	86.40	38.26
3.	Water absorption, per cent.			
	(i) after 24 hours total immersion, by weight	14.91	3.02	20.25
	(ii) - do- by volume	24.75	2.00	9.35
	(iii) after 5 hours immersion in boiling water, by weight	21.38	2.3	10.75
	(iv) -- do -- by volume	35.44	2.14	6.03
4.	Saturation Coefficient	0.695	—	—

TABLE 4.

Compressive Strength of various Mortars and the Masonry Cubes

S.No.	Mortar	Age. of Test Days.	Average Compressive Strength in p.s.i. Mortar	Masonry Cube
1.	1:¼:4 Cement : Lime : Sand	7	860	756
		28	1208	925
2.	1:6 Cement : Sand	14	717	821
		28	742	843
3.	1:2 Lime : Surkhi	14	229	484
		28	266	498
4.	1:2 Lime : Cinder	14	135	456
		28	292	547
5.	1:3 Lime : Surkhi	28	365	723
6.	1:3 Lime : Cinder	28	360	677
7.	1:1:2 Lime : Surkhi : Sand	14	78	441
		28	89	464
8.	1:1:2 Lime : Cinder : Sand	14	79	401
		28	114	495

TABLE 5.

Recommended working stresses*

S.No.	Proportion of mortar	Recommended Working Stress: age	Recommended Working Stress: lbs/sq.in.	Factor of Safety against observed first crack load	Factor of Safety against ultimate load.
1.	1:¼:4 Cement : Lime : Sand	7 days	120	2.0	6.3
2.	1:6 Cement : Sand	14 days	120	1.67	6.85
3.	1:2 Lime : Surkhi	28 days	50	3.38	11.00
4.	1:2 Lime : Cinder	28 days	50	4.65	10.95
5.	1:3 Lime : Surkhi	28 days	80	3.8	9.05
6.	1:3 Lime : Cinder	28 days	80	3.24	8.47
7.	1:1:2 Lime : Surkhi : Sand	28 days	50	2.92	9.30
8.	1:1:2 Lime : Cinder : Sand	28 days	50	1.94	9.90

*The mean strength of brick used in the investigation, for which working stresses have been recommended, is 1807 p.s.i.

TABLE 6

Maximum permissible uniformly distributed compressive stresses (at and after the stated times) on masonry members with slenderness ratio of unity.

S. No.	Description of mortar	Mix (parts by volume) not weaker than			Hardening time after completion of work (days)	Maximum uniformly distributed stress in lb/sq. ins. corresponding to units whose crushing strength (in lb/sq. ins) is‡				Remarks.
		Cement	Lime	Sand		400	1000	1500	3000	
1.	Cement	1	¼*	3	7	40	100	150	210	I.S.'C' Grade lime
2.	Cement—lime	1	1	6	14	40	100	140	190	I.S.'C' Grade lime
3.	Cement—lime	1	2	9	14	40	80	120	170	I.S.'C' Grade lime
4.	Cement—lime	1	3	12	14	30	70	100	130	I.S.'C' Grade lime
5.	Hydraulic—lime	—	1	2	14	30	70	100	130	I.S.'A' Grade lime
6.	Non-hydraulic	—	1	3	28	30	60	80	100	I.S.'B' or 'C' Grade lime

*The inclusion of lime in cement mortars is optional.

‡Linear interpolation is permissible for units whose crushing strengths are intermediate between those given in the table.

£A longer period should ensure where hardening conditions are not very favourable.

TABLE 7

Slenderness ratio	Factor	Slenderness ratio	Factor
1	1.0	12	0.50
2	0.96	14	0.40
4	0.88	16	0.35
6	0.80	18	0.30
8	0.70	21	0.25
10	0.60	24	0.20

APPENDIX I

PREPARATION AND TESTING OF MASONRY MORTARS

1. *Specifications for Materials.*

A Cementing Materials—

(i) Ordinary portland cement conforming to I.S. Specification 269-1958.

(ii) Type C Lime according to I.S. Specification 712—1956.

B. Aggregates

(i) A mix of 3 parts Badarpur sand and 1 part Ranipur sand by weight was used as it was found to conform to the grading recommended in clause 4 on page 14 of the B.S. Specification 1198, 1199 and 1200 (1955).

(ii) Well burnt cinder comparing B.S. Specification 1165 : 1944 was used.

(iii) Surkhi conforming to the Draft Indian Specification BDC 16.2/T-1 for surkhi for use in mortar and concrete was used.

2. *Design*

For the purpose of design the word 'Lime' in Appendix shall mean 'dry hydrated lime' which is defined as a dry powder obtained by treating quicklime with water enough to satisfy its chemical affinity for water under the conditions of its hydration. (It consists essentially of calcium hydroxide and some magnesium hydroxide). However, lime putty was used in the present investigation.

Motars in the laboratory were prepared on weight basis. For this purpose the volume proportion of constituents of the various mortars given in the Appendix A were converted into weight proportions by multiplying with he bulk densities of the individual constituents. The bulk density of the Portland Cement was assumed as 90 lb./cu.ft, of dry hydrated lime as 45 lb./cu.ft. and that of aggregates was determined according to IS: 383-1952. (Only dry aggregates shall be used for preparing the mortar mixes).

The actual weight of lime putty—equivalent to the weight of the hydrated lime used in any particular mix was calculated by using the following formula:

$$W_H = \frac{G}{G-1}\ (W_P - 62.4)$$

Where W_H=Weight of dry hydrate in 1 cu. ft. of putty.

G=Specific gravity of hydrate

(This need not be determined and be taken as 2.25).

W_P=Weight of putty per cu.ft.

For preparing lime putty, quicklime was slaked in a container and was sieved after 24 hours of slaking through a B.S. Sieve No. 7 into another container where it was allowed to settle for another 24 hours before use.

3. *Mixing.*

In case of composite mortar mixes, the weighed quantities of Cement and sand were mixed first in dry condition and then for one minute with water sufficient to wet the mix. Lime putty equivalent to the weight of hydrated lime was added next and mixed thoroughly for another one minute. Water was added in such a quantity that the workability of the mortar mix was between a flow of 100-115 per cent when determined as per ASTM Designation C 110-49).

For the preparation of lime/pozzolana and lime/pozzolana/sand mortars, lime putty was mixed with the coarse surkhi or cinder and ground in the Winget Edge Runner. Sufficient quantity of water was added so that the mortar paste did not stick to the rollers of the machine. When the mix had attained the desired fineness, additional amount of water was added to bring the mix to the standard workability. For lime/pozzolana/sand mortars, the aggregate was mixed before the addition of second lot of water.

4. *Casting.*

All the test specimens required for any single test were cast from the same mortar batch. Specimens for compressive strength, test were cast per clause 8 b of the ASTM Designation C270-54T for Mortar for Unit Masonry with modification that at least six specimens were cast for test at each age. The compressive strength of the mortars was determined at the age shown against each of the mortars in *Table* 2.

5. *Curing*:

Motar Mix	Curing Conditions.
1. 1:¼:4 Cement: Lime : Sand 2. 1:6 Cement : Sand	First 24 hours in the mould at 27±2° C and in humidity not less than 90 per cent. Demoulded the specimens and continued the curing under these conditions.
For mortars No.(3) to (8) both inclusive	Stored the moulded specimens (with top surface exposed at 27°±2°C and in humidity not less than 90 per cent till the demoulding was possible. The maximum time taken was 4 days. Subsequent curing was done at 27+2°C and humidity 50±5 per cent till tested.

6. Testing was carried out as per clause 8b of the ASTM Designation C270—54T for Mortar for Unit Masonry.

APPENDIX II

PROCEDURE FOLLOWED FOR TESTING BRICKS AND MASONRY CUBES FOR THE PROJECT ON THE STRENGTH OF BRICK MASONRY

1. The bricks were tested for the following properties :

1. Compressive strength
2. Flexural strength
3. Water absorption
4. Tensile Bond Strength

1.1 *Sampling of bricks*

Sampling of the bricks for the various tests was done during unloading of bricks from the delivery trucks. The loading labour was asked to pick out every 10th brick, which was worked out on the basis of the total number delivered and the number of bricks required for the tests, the latter being three times the actual number of bricks required for each of the tests. These bricks were kept separately and further sampling for each individual test was done in a similar way.

1.2 *Compressive strength*

Twenty-five bricks were tested. The procedure followed for this test was as per IS: 1077-1957. The test was carried out in a 200 Ton Amsler Compressive Testing machine.

1.3 *Flexural strength*

This test was carried out on 25 nos. of bricks. The bricks were tested on a hand operated standard transverse testing machine. Each specimen was supported flat on a span of 7 in. keeping the frog on the top side. Load was applied at the mid span. The ultimate load at failure was noted and the modulus of rupture of each specimen was worked out. The testing procedure followed was in accordance with the procedure laid down in ASTM Standard 1952, Part 3, page 414.

1.4 *Water absorption*

Twenty-four brick samples were tested. The entire test was carried out as laid down in B.S. 1257—1945.

1.5. *Tests on Bond*

Twelve bricks were used to yield six bond test specimens for each type of mortar. Bricks were kept immersed in water for 24 hours and then taken out, wiped with a damp cloth and kept out not more than 10-15 minutes before applying mortar. The specimen was in the form of a crossed brick couplet. The work is carried out in accordance with the method given in the paper 'Characteristics of Mortars' by Mehra S.R. and Chadda, H.R., Irrigation and Power Journal, Vol. 12, Jan. 1955.

2. *Fabrication of masonry cubes*

Bricks needed for fabricating the masonry cubes were taken out at random from the stack so as to form a fair representation of the entire lot and were kept immersed in water for twenty four hours.

The masonry cubes were fabricated on levelled steel plates made for the purpose. Iron studs of one inch size were welded to the bottom of plates, on which the plate was resting on the floor. Provision for hooking and lifting was made at the four corners of the 2′—0″ square plate on which the specimens were built and cured.

The steel plate resting on the studs was levelled in the two directions. A coat of mould oil was applied before fabricating to prevent mortar adhereing to the plate. A layer of ½ in. thick cement mortar of 1:1½ proportion was then spread on the plate. The cube was then fabricated on the bedding mortar using the morter under test. The bricks were bedded keeping frogs up. The same mason was employed throughout the job for keeping up the uniformity in workmanship. The fabrication was well inspected and therefore the quality of workmanship was of a high standard. On the top of the cube, again ½″ thick cement mortar of 1:1½ proportion was applied and carefully levelled by a spirit level in two directions at right angles. The masonry cubes were then pointed flush with the mortar. While fabricating, two deformeter plugs were kept vertically in the mortar joints (at 10″ c/c) on each of the two opposite faces of each specimen. The deformations under load were observed at different loads on the specimen. All cubes were fabricated inside the laboratory. Cubes made out of cement mortars and cement lime mortars were cured by wrapping them round with wet gunny bags. Cubes made out of the remaining mortars were cured by enclosing them inside a wooden frame work which was fully wrapped round with wet gunny bags. All the gunny bags were kept continuously wet up till the period of testing.

Method of testing the masonry cubes:

The masonry cubes were tested in a 500 ton capacity Losenhausenwork building materials testing machine. The cubes resting on the base plates were lifted from the place of fabrication to the testing laboratory. The cubes were then slowly shifted to the bottom *platen* of the testing machine by carefully sliding from the base plate. Three ply-plywood sheets were kept in between the specimen and the platens to cover up any irregularities on the surface. Specimens were carefully centered and load was then applied at the rate of 250 lbs/sq.in./min. The strain readings were taken with the help of Huggenburger deformeter at every increment of 10 tons load. For each specimen load at first crack and ultimate load was recorded and the type of failure noted. The average load was calculated after rejecting test values showing a variation greater than ± 15 per cent.

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