Investigations on the Compressive Strength of Walls built using Local Chamber burnt Bricks

by
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SUMMARY

This paper presents the details of experimental investigations on the compressive strength of prisms and storey height walls using two types of locally made bricks at Madras, India. Majority of the bricks produced in India are hand moulded and burnt in local kilns. Therefore, they have a low ratio of tensile to compressive strength and the variation in their strength is also large. This paper critically discusses the applicability of the permissible stresses given in the Indian Code (IS:1905-1980) for the design of masonry walls built using local bricks. Experimental investigations indicate that the observed permissible compressive stresses derived from wall as well as prism tests are considerably lower than the codal values derived from unit strength of bricks. In the absence of research data on the compressive strength of walls using local bricks and workmanship, Indian Code has prescribed the same values of permissible stresses adopted in the earlier version of the British Code (CP: 111- 1964). Tests on masonry prisms or in special cases storey-height walls built using the same type of masonry unit, mortar and workmanship are suggested to determine the permissible design stresses and for quality control.

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INTRODUCTION

Load bearing masonry construction in India is traditional and designs are generally based on rule-of-thumb techniques. Such constructions were hence found to be uneconomical for the construction of multistoreyed buildings when compared to the reinforced concrete frame and masonry infill constructions. However, design of structural walls following the calculated masonry design methods prescribed in the Indian Code has been found to result in reduced thickness of walls for residential buildings in the range of four to five storeys [1] . Single brick thick walls (200 to 230 mm) for residential buildings of four to five storeys result in considerable savings in cement and steel when compared to reinforced concrete frame and masonry infill construction and therefore such constructions are recommended at present in India [2] . Though it is possible to design single brick thick load bearing masonry walls for normal residential buildings upto five storeys using bricks of strengths 7 to 10 N/mm^2, quality control tests to verify the design permissible stresses are found necessary especially in the case of bricks produced with the normal methods of moulding and burning [3] . Detailed experimental investigations on the compressive strengths of brick masonry walls are being carried out at the Structural Engineering Research Centre, Madras, with the aim of developing rational design procedures. This paper describes the experimental investigations on the compressive strength and behaviour of walls built using two types of chamber burnt bricks that are available at Madras, India.

INDIAN CODE PROVISIONS FOR THE DESIGN OF LOAD BEARING MASONRY WALLS

The design of load bearing masonry walls is based on the permissible compressive stresses prescribed in the Indian Code. The permissible compressive stresses depend upon the type and strength of individual masonry units, mix of mortar, slenderness ratio of walls, eccentricity of loading, shape and size of masonry units and cross-sectional area of walls. IS:1905-1969 had prescribed permissible compressive stresses based on CP:111-1964 [4] . There has been no change in the value of the permissible stress in the recent revised code IS:1905:1980 [5] . The recent code, however, alternatively permits the permissible compressive stresses based on the test results of prisms made of masonry units and mortars to be actually used in a particular job. Permissible compressive stresses are to be modified by stress reduction factors due to slenderness and eccentricity. While there is no change in the values of the stress reduction factors, the IS:1905:1980 Code has increased the maximum allowable slenderness from 18 to 27. Values of permissible stresses are applicable only to common bricks having size of 230mm x 115mm x 75mm. Metric bricks of size 200mm x 100mm x 100mm are yet to become popular in India. Code has recommended shape factors to enhance the permissible stresses of bricks having a ratio of height to width greater than 0.75 and crushing strengths not greater than 15 N/mm^2. According to IS:1905-1969 where the cross-sectional area of a wall or column does not exceed 3000 cm^2, the basic stress shall be multiplied by a reduction factor equal to $(0.75+A/12000)$ where A is the area in sq cm of the horizontal cross-section of the wall or column. IS 1905:1980 has liberalised this provision and reduction factors are to be applied only when the cross-sectional area of a wall or column does not exceed 0.2 m^2 and the reduction factor is equal to $(0.70 + 1.5A)$ where A is the area in m^2.

EXPERIMENTAL PROGRAMME

Bricks

Two types of local bricks have been tested in this investigation. Local bricks were table moulded and burnt in Hoffman kilns. Samples of bricks were collected using standard sampling procedure [6] . Bricks were tested for their physical properties and the results are given in Table 1. Compressive strengths of the samples of bricks were corrected if the coefficient of variation 'V' exceeded 12% by a factor 1-1.5 (V-0.12) [7] . Individual bricks were tested for flexure on their beds under two point loading with loads applied at quarter span points. The tensile strengths of bricks were determined by the 'Brazilian' tension test in which the brick is subjected to a compressive force through point loading at centre along its length. The suction rate of brick was determined from tests as prescribed in ASTM-C67 [8].

Mortar

Mortar of cement:sand proportion 1:6 has been used since there is no special advantage in using rich mortar with low strength bricks. A water-cement ratio of 1.65 was obtained for the required workability [9] . Average compressive strength of mortar was found to be 3.51 N/mm^2 with a coefficient of variation of 0.46.

Masonry prisms

Modern masonry codes suggest prism tests for identification and control of masonry strength as they are rapid and less expensive than wall tests. Four course prisms (2300mm x 2300mm in cross section and 3300mm high) were cast along with walls to correlate their strengths with that of walls [10] . Prisms were tested in a 300t compression testing machine. Plywood sheet of 3mm thickness over a layer of plaster of paris was used as capping while testing the specimens. Three prisms for each wall were tested to determine the stress-strain relationship and modulus of elasticity of masonry.

Masonry walls

Walls of 230mm (one brick) thickness and 900mm wide were constructed to a height of 2.70m in the casting yard. Special frames were made for facilitating the safe handling and transportation of walls to the laboratory (Fig.1). The frame consists of a rolled steel channel beam at top and at bottom and two numbers of 25mm diameter tie bolts on both sides.

Two identical walls were cast for each type of brick and both the walls were cast simultaneously to a height of about 1.35m on the first day. They were completed to their full heights on the next day and cured for 28 days by spraying water. The top surfaces of the walls were levelled using cement mortar of proportion 1:3. The tie bolts at both ends of the walls were tightened and thus a slight precompression was applied to the wall. The frame with the wall tightly held was lifted by a mobile crane and placed on the arms of a fork-lift truck. The wall was then carefully transported and erected inside the loading frame in the laboratory.

Test set-up and instrumentation

A loading frame of 4000 kN capacity was used for testing the walls (Fig.2). The wall specimens were kept directly on the heavy testing floor

Fig. 1(a)

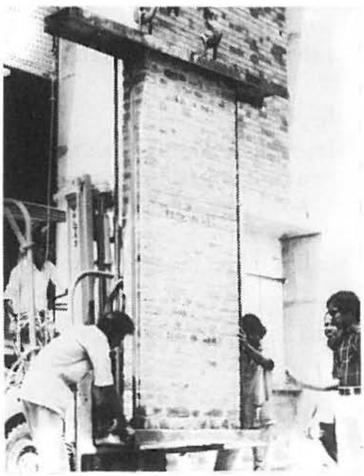
FRAME FOR HANDLING WALL SPECIMENS

of the laboratory along with the bottom channel on which it was constructed. The top channel and the tie rods of the handling frame were removed. A stiff rolled steel I-section of 450mm depth was placed above the wall and load was applied by means of two 1000 kN 'Enerpac' hydraulic jacks fixed to the testing frame. The vertical axes of the jacks and the wall were aligned properly to avoid eccentricity of loading. The test set-up was designed to prevent rotation at the base of the wall while permitting rotation at top, a condition considered ideal for testing load bearing walls [11] .

Loads were applied in increments of 40 kN till failure and were measured by means of 1000 kN proceq load cells kept directly below the jacks. Under axial loading, the wall specimens having a slenderness ratio of about 12 were not expected to buckle. However, lateral deformations were measured upto some loading stages to verify the lateral sway of the wall. The tops of the walls were found to sway but they were negligible in the range of 5mm. Horizontal and vertical strains were measured at various locations as shown in Fig.3 in the central portion of walls using Pfender type mechanical strain gages.

Fig.1(b)

TRANSPORTING WALL SPECIMENS



DISCUSSION OF TEST RESULTS

General observations on the test

Failures in all the wall specimens were initiated by vertical cracking at around 0.75 times the ultimate load. Final failures occurred by crushing at top or bottom ends of the walls. Extensive vertical cracking was observed in all the tested specimens before failure. Failure pattern for each type of tested wall is shown in Fig. 4(a) and 4(b). Lateral tension was also found to develop across the thickness of wall specimens. A typical vertical splitting across the thickness of the wall specimen is shown in Fig.4(c).

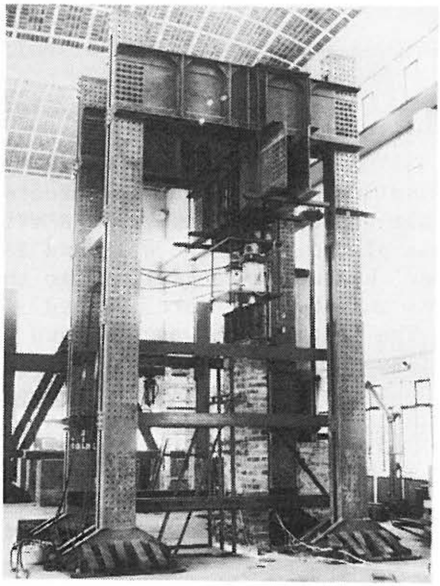


Fig. 2 TEST SET-UP AND INSTRUMENTATION

Final failure was not sudden in all the cases excepting in one wall which crushed to pieces. The tested specimens having a slenderness ratio of 12 did not exhibit any appreciable deflection before failure. Thus, buckling failures are not expected for single brick thick walls of normal storey heights. Observed failure loads of type 1 and type 2 walls are close to each other though there is appreciable difference in their individual unit strengths.

Stress-strain behaviour

Vertical strain measurements made along the five vertical lines and lateral strain measurements made along the seven horizontal lines have been averaged in the central portion of the wall and their values at different stages of load are shown in Fig.5 and 6 respectively. Both vertical and lateral strains are found to be approximately uniform at working load levels (100 kN).

Type 2 brick walls showed greater amount of vertical and lateral strains than type-1 wall for the same stress. This may possibly be the reason for the lower strength of type 2 walls than expected based on the unit compressive strength of type 2 bricks. The ratio of lateral strain to vertical strain in the case of type 1 brick walls is observed as 0.07 and for type 2 brick wall is observed as 0.10 at working loads. Development of vertical and

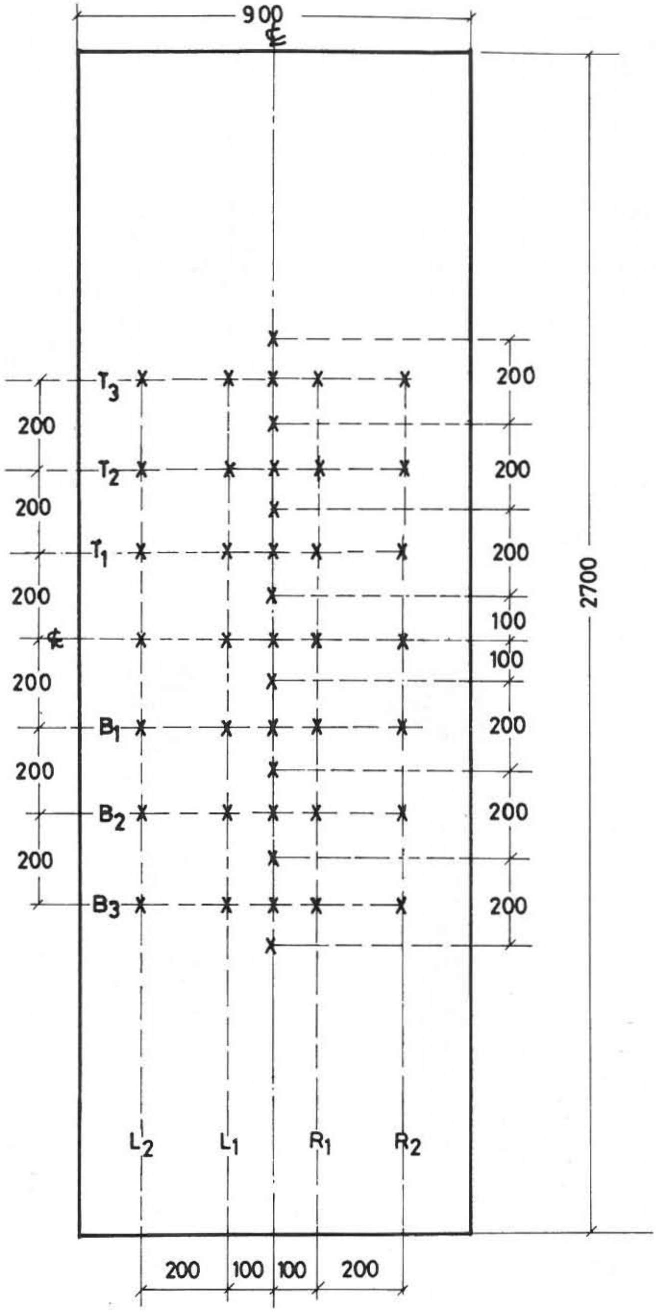


FIG. 3. POSITIONS OF STRAIN GAUGES

lateral strains at different stress levels for the tested wall specimens are shown in Fig.7. A linear stress-strain relationship is found to approximate the behaviour upto 0.75 times the failure load. Stress-strain behaviours of brick masonry and mortar are shown in Fig.8. Individual bricks were tested to obtain stress-strain behaviour. Masonry stress-strain behaviour has been obtained from wall tests. Stress-strain relationship of mortar has been derived from that of brick and masonry assuming that total compressive strain of masonry is equal to that due to brick and mortar courses over a particular height.

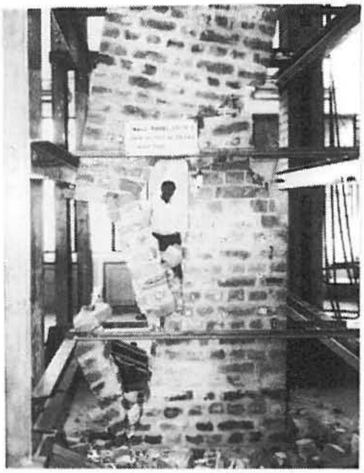


Fig.4(a)

FAILURE PATTERN OF TYPE-1 SPECIMEN

<u>Comparison of allowable compressive stresses from experiments with codal values</u>

Type 1 bricks tested had mean compressive strengths of 6.80 N/mm^2 with a coefficient of variation of 0.28 while type 2 bricks had a mean compressive strength of 7.72 N/mm^2 with a coefficient of variation of 0.15.

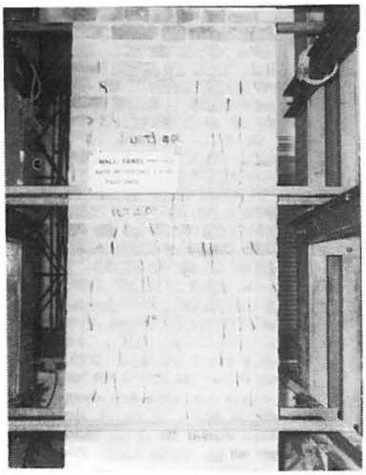


Fig.4(b)

FAILURE PATTERN OF TYPE-2 SPECIMEN

Because of the large variations in the strength of type 1 bricks, the difference in the corrected strengths between type 1 and type 2 bricks had increased further. Table 1 shows the details of unit compressive strengths, rates of suction and tensile strengths of the two types of bricks. Test results of brick strength, prism strength and wall strength have been compared in Table 2. It is significant to note that the prism and wall strengths of both the types of bricks are more closer to each other than their individual unit compressive strengths. Use of bricks with high suction rates along with straight cement and sand mortars having high coefficient of variation in their strengths may possibly be the reasons for the same

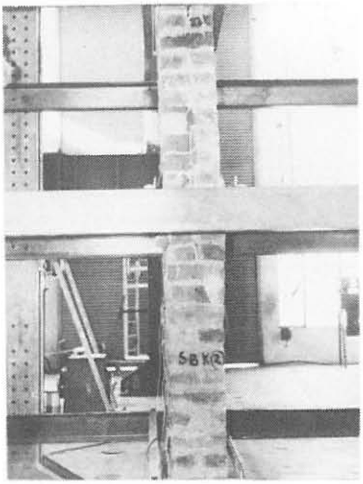


Fig. 4(c) TYPICAL VERTICAL SPLITTING OF WALL ACROSS THE THICKNESS

masonry strength irrespective of the compressive strength of bricks within the tested range. The ratio of wall strength to brick strength in the case of type 1 brick is 0.37 and that of type 2 is 0.27. Observed prism strengths have been corrected for statistical variation and for height to thickness ratio [7] . Permissible stresses have been obtained from the corrected prism strengths using a safety factor of 4. Mean observed compressive strengths of two walls using same type of bricks have been reduced by a factor of safety of 6.6 to obtain permissible stresses [4] . Indian code is found to over-estimate the strength of masonry using type 1 bricks by about 15% and type 2 bricks by about 32% when compared to the permissible stresses derived from wall tests. Indian code is found to over-estimate the strength of masonry using type 1 bricks by about 36% and type 2 bricks by about 34% when compared to the permissible stresses derived from prism tests. Both compansion prism tests and storey-height wall tests thus indicate that Indian Code over-estimates the permissible stresses of masonry using chamber bricks that are tested in this investigation. Indian Code, however, was found to prescribe the permissible stresses close to the values obtained from prism and wall tests of masonry using wire-cut solid bricks [12].

Chamber bricks tested have a suction rate of about 45 N/m^2/minute against the normal suction rate of 10.33 N/m^2/minute beyond which wetting is required [7] . Design permissible stresses recommended in the Indian Code seem to have been adopted from the British code of Practice CP:111-1964 [13] . Bricks in the developed countries such as Britain are mainly produced by mechanised processes and hence it appears unreasonable to adopt these values to the design of load bearing masonry structures using bricks having high suction rate and low ratio of tensile to compressive strength. However, extensive experimental investigations on the compressive strength of masonry using different types of bricks are necessary before modifying the values of permissible stresses corresponding to brick unit strengths. Tests have indicated a close correlation between permissible compressive strengths derived from prism and wall tests. Permissible values of compressive strength from wall tests are observed to vary from 0.8 to 1.0 times the permissible values from prism tests. These results lead to the conclusion that the axial load capacity of the wall is not significantly affected by slenderness upto a value of 12. Since storey-height wall testing is difficult and expensive, prism tests are suggested for the design and quality control of brick masonry walls.

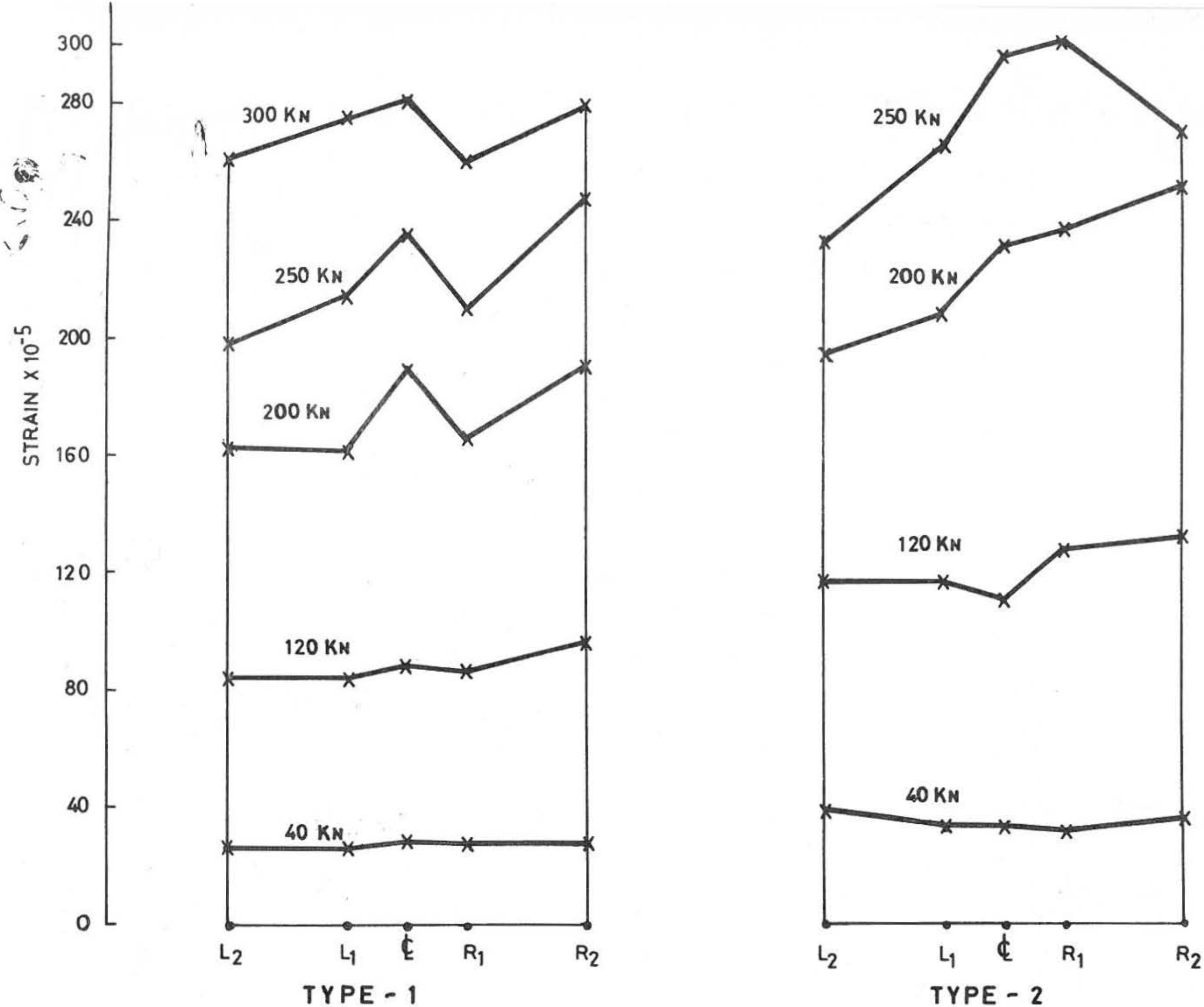


FIG. 5. TYPICAL VERTICAL STRAIN DISTRIBUTION ALONG THE WIDTH

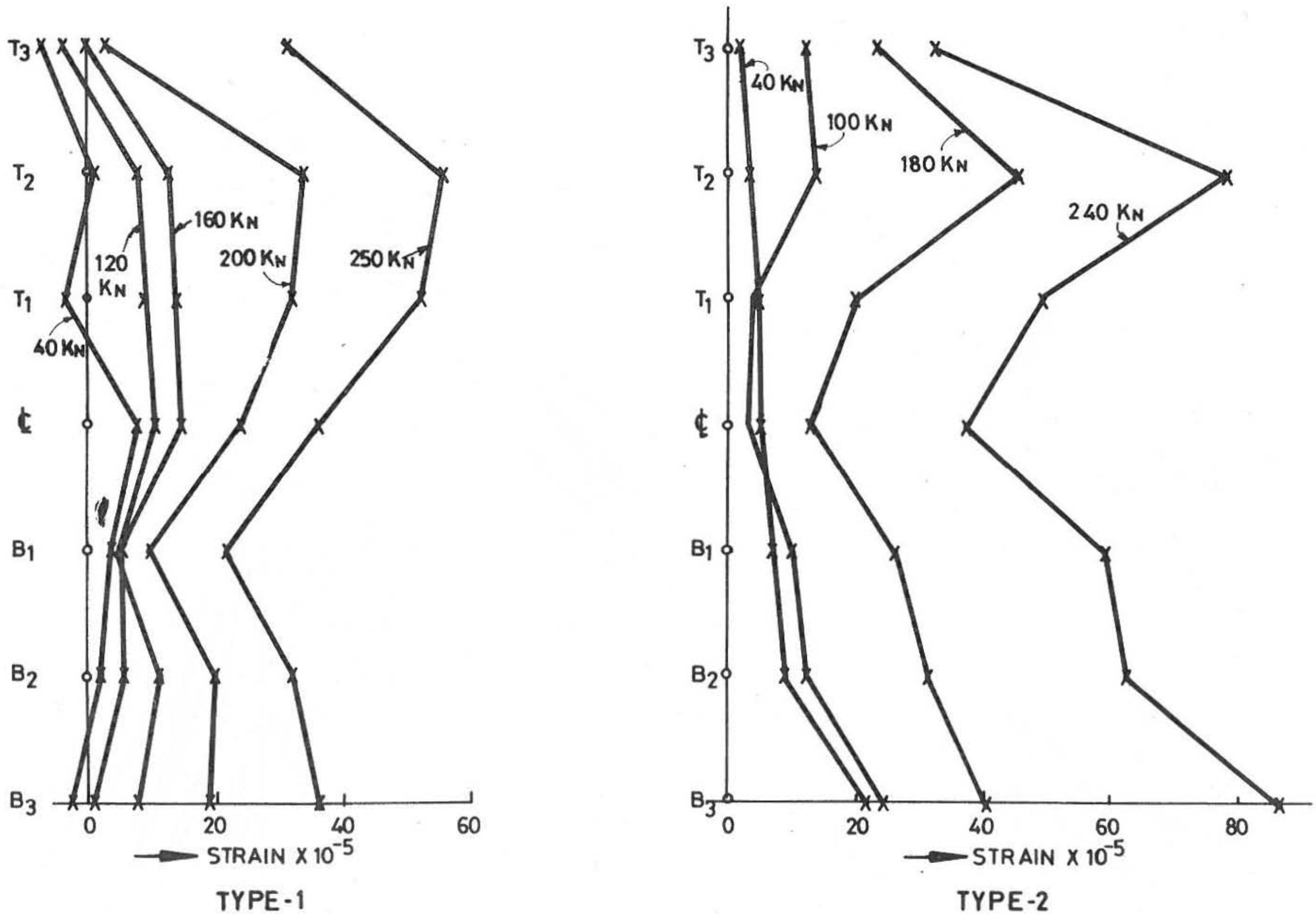


FIG. 6. TYPICAL LATERAL STRAIN DISTRIBUTION ALONG THE HEIGHT

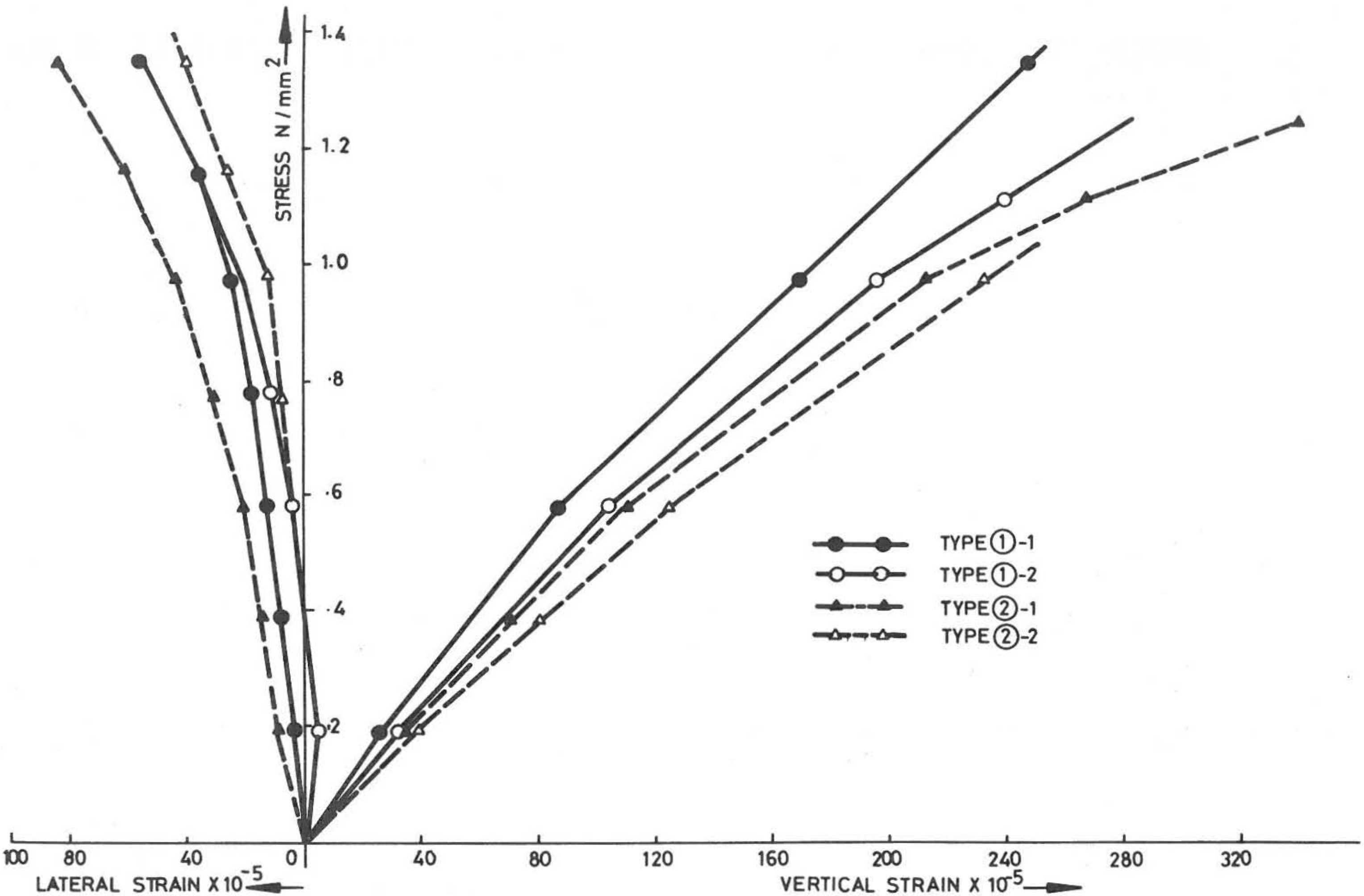


FIG. 7. STRESS STRAIN BEHAVIOUR OF WALL SPECIMENS

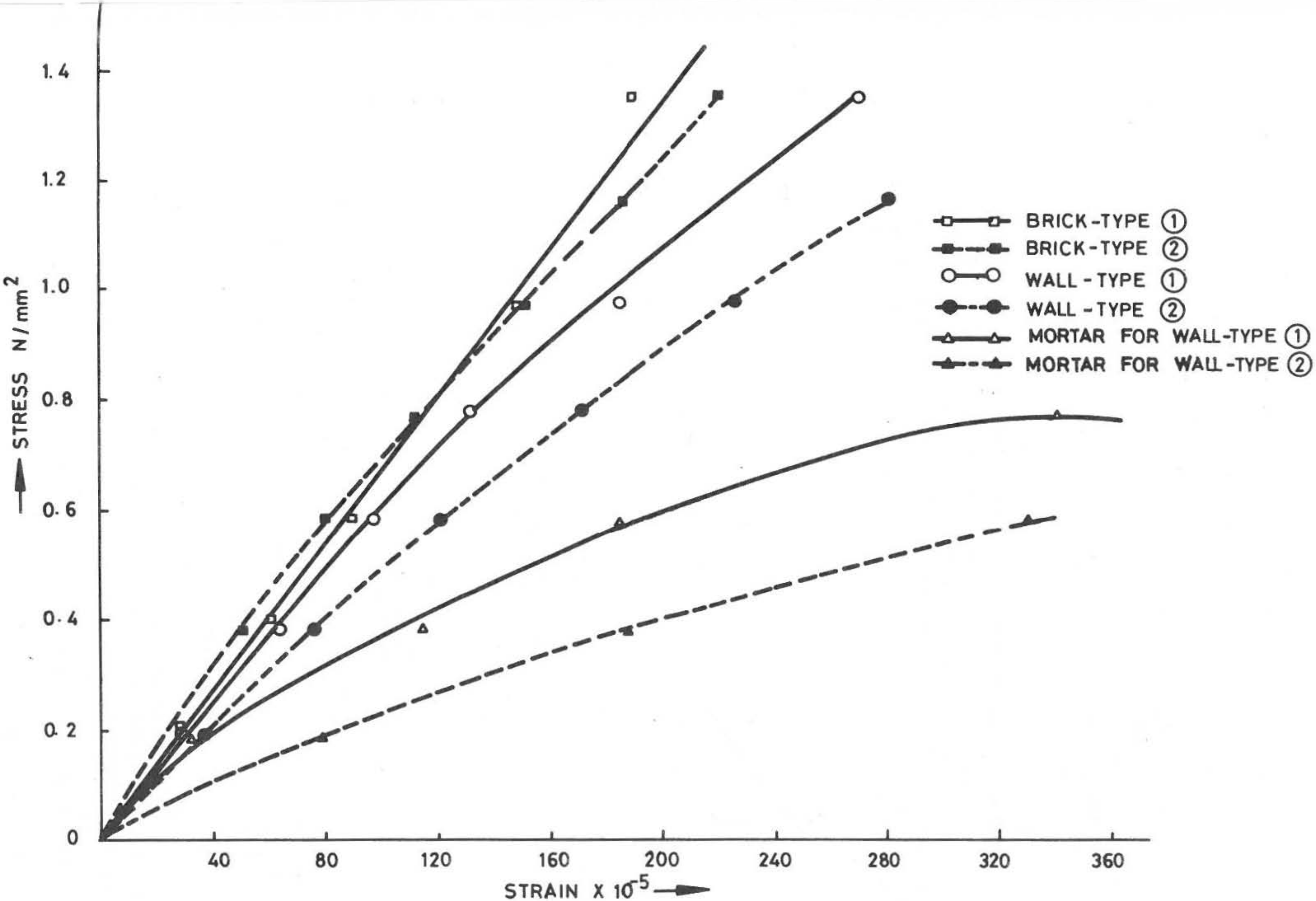


FIG. 8. STRESS-STRAIN BEHAVIOUR OF BRICK UNIT MASONRY AND MORTAR

Comparison of wall strength with failure theories of masonry walls

It has been generally recognised that the vertical splitting of the masonry unit is related to the lateral strain of the mortar joint. The modulus of elasticity of mortar is found to be considerably less than that of brick (Fig.8) and hence mortar under lateral restraint has induced lateral tensile strain in the adjoining bricks leading to vertical cracks in the tested specimens. It is thus found appropriate to compare the failure strengths with theories based on the Poisson's ratio effect between brick and mortar.

Hilsdorf presented an analytical procedure to predict the compressive strength of masonry based on stress analysis consideration [14] . Multi-axial states of stress in brick and mortar were analysed by him by assuming Mohr's theory of failure in which the failure criterion corresponded to a straight line. Francis, Horman and Jerrems [15] presented a method to quantitatively predict the compressive strength of masonry based on strain considerations. Like Hilsdorf, he also assumed the failure criterion corresponding to a straight line. An uniformity coefficient of 1.60 has been assumed in both these procedures while comparing the predicted values with the experimental ultimate compressive strengths [14] . Both the theories have been found to over-estimate the strength of prisms by about 18% and walls by 33%. Chamber bricks are found to have a very low ratio (0.02) of tensile to compressive strengths. Though both the theoretical predictions account for the tensile strength of brick, the compressive strength of brick significantly influences the masonry strength in their derived relations. Hence they seem to predict more strength for masonry built using type 2 bricks than that built using type 1 bricks.

CONCLUSIONS

All tested wall specimens showed extensive vertical cracking before final failure. The ratio of lateral strain to vertical strain is observed as 0.09 for chamber brick walls.

The ratio between wall strength to brick strength is 0.37 for type 1 bricks and 0.27 for type 2 bricks. Brick walls developed about 90% of the prism compressive strength indicating that the axial load capacity of the wall is not significantly affected by slenderness of wall upto a value of 12. From the investigations, it is found that the Indian Code (IS:1905-1980) considerably over-estimates the compressive strength of masonry built with chamber bricks and thus may lead to unsafe designs. The correlation between prism strength to brick strength is 0.29 for type 1 bricks and 0.27 for type 2 bricks. Since storey-height wall testing is difficult and expensive, prism tests are suggested for the design and quality control of brick masonry walls.

Existing failure theories are found to over-estimate the strength of walls built using chamber-bricks having low ratio of tensile to compressive strength. The influence of the tensile strength of bricks does not seem to have been adequately considered in both the stress and strain based failure theories.

ACKNOWLEDGEMENT

The authors wish to express thanks to Dr.M.Ramaiah, Director,

Structural Engineering Research Centre, and Shri N.V.Raman, Deputy Director, for their support in carrying out the investigations. The authors also thank the staff of heavy testing laboratory for their help in carrying out the various tests. This paper is published with the kind permission of the Director, Structural Engineering Research Centre, Madras.

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Table 1 : PROPERTIES OF BRICK

Type of bricks	Properties	No. of samples	Mean	Coefficient of variation	Mean corrected for coefficient of variation
Type 1	Rate of suction N/m^2/minute	20	47.5	0.29	-
	Compressive strength N/mm^2	6	6.80	0.28	5.17
	Flexural strength N/mm^2	12	0.64	0.21	-
	Tensile strength N/mm^2	9	0.13	0.53	-
Type 2	Rate of suction N/m^2/minute	22	42.00	0.18	-
	Compressive strength N/mm^2	6	7.72	0.15	7.37
	Flexural strength, N/mm^2	12	0.64	0.24	-
	Tensile strength N/mm^2	7	0.16	0.24	-

Table 2: COMPARISON OF BRICK STRENGTH, PRISM STRENGTH AND WALL STRENGTH

	Prism		Wall	
	Type 1	Type 2	Type 1	Type 2
Mortar type	1:6	1:6	1:6	1:6
Corrected unit strength, N/mm^2	5.17	7.37	5.17	7.37
No. of specimens	15	16	2	2
Observed mean com.strength N/mm^2	2.39	2.31	1.89	1.96
Coefficient of variation	0.35	0.19	0.04	0.0
Corrected for coefficient of variation, N/mm^2	1.51	2.01	1.89	1.96
Reduction factor for h/t ratio	0.76	0.76	-	-
Corrected prism strength, N/mm^2	1.15	1.53	-	-
Prism strength corrected for coefficient of variation/unit strength	0.29	0.27	-	-
Permissible stress from prism tests (Factor of safety of 4)	0.29	0.38	-	-
Permissible stress from IS code	0.45	0.58	-	-
Permissible from prism/ permissible from code	0.64	0.66	-	-
Permissible stress from wall (F.S. = 6.6)	-	-	0.29	0.30
Permissible stress from IS Code (Reduction for slenderness=0.76)	-	-	0.34	0.44
Theoretical compressive strength				
By stress approach	-	-	2.65	3.17
By strain approach	-	-	2.45	3.20
Permissible from wall/ permissible from code	-	-	0.85	0.68
Permissible from wall/ permissible from prism	-	-	1.00	0.79
Wall strength/unit strength	-	-	0.37	0.27