"Developments in Calculated Load-Bearing Brick-Work"

Dr. S. M. K. CHETTY*

AND

S. S. BEDI†

Synopsis—

Although major part of the cost of any building goes in brick masonry works, the engineers and builders in this country are not well aware about its structural potentiality. Therefore, the thickness of walls are either based on some building bye-laws or designed by certain thumb rules resulting in uneconomical structure in multi-storeyed construction. Indian Standard Institution is revising the Code on masonry I. S. 1905–61 "Code of Practice for Structural Safety of Buildings ; Masonry Walls" which suggests to design the walls based on rational approach. This paper briefly reviews the factors affecting the strength of masonry and discusses the permissible stresses in it as given in the code.

★ ★ ★

1. *Introduction*

The use of brick work dates back to prehistoric times, but the engineers and builders are not well aware of its structural potentiality. Prior to the publication of I. S. 1905–61[1] the design was based on rules of thumb rather than on rational basis. This produced massive structures which due to their bulk were uneconomical in multi-storeyed construction. For the first time, in the above code permissible stresses in brick masonry built with bricks of different strength, mortars of different composition and for various slenderness ratio were given. It also specified the minimum thickness of walls in different storeys irrespective of the strength of brick and mortar. This code had very little impact on users and has been referred mainly for the design of walls of longer lengths or greater heights as met within warehouses and industrial buildings, etc., where the rules of thumb of determining the thicknesses were not available. The requirement of minimum thickness of walls for buildings of two

*Deputy Director, Central Building Research Institute, Roorkee.
†Scientist, Central Building Research Institute, Roorkee.

to three storeys was, however, followed in certain parts of the country where good bricks were available. The minimum thicknesses provided in the code appeared to be based on practical consideration rather than strength requirements. It has been seen for high rise buildings the minimum thicknesses indicated in the lower storeys are more than required from strength consideration even with commonly available good bricks. Such larger thicknesses, besides being costly, encroaches into valuable floor space and hence the use of brick masonry walls has not been popular for high rise buildings. It is not understandable why larger thicknesses are specified in the lower storeys of multi-storeyed buildings when such enhanced thicknesses in no way contribute to the stability of lesser thick wall above it. As is well-known, walls are never built for the full height of building at a stretch, but the same is interrupted at each floor level. The floor acts as horizontal diaphram and provide lateral support, thereby, subdividing the total height of the wall into storey heights. This fact has been recognised by the code for the calculation of slenderness ratio. In building the wall mason has a scope to align the wall and build to plumb at each successive storeys. The code has specified the use of single brick thick wall in the top storey of a multi-storeyed building. If the code could consider the building of a single brick thick wall at such a great height which is feasible from practical consideration, larger thicknesses should not have been specified in the lower storey on this account. In other words the thicknesses of the bearing walls shall not be more than one brick thick irrespective of the number of storeys from practical considerations. However, larger thickness than one brick shall be taken from strength considerations only. Hence the table for minimum thickness of wall is not required. This code is now under revision and the table for minimum thicknesses of walls has been deleted. It[2] recommends to design the walls like any other structural member, and the relevant data such as basic stress, reduction factors for slenderness and eccentricity, additional permissible stress under concentrated load, tensile and shear stresses and stiffening effect of pillasters and cross-walls, etc. which are required for the proper design of walls has been furnished in it.

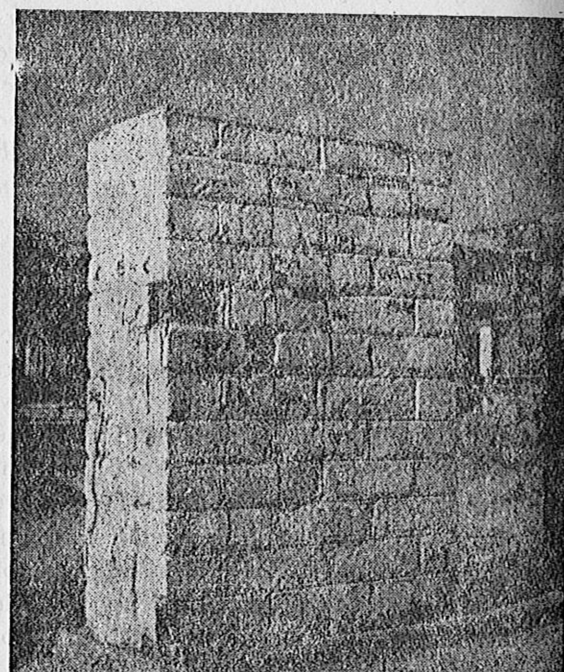
During this decade considerable research has been carried out in India and abroad which has proved that higher stress values than those stipulated in the code[1] can be permitted. This fact has been considered in this revision. The object of this paper is to familiarise the engineers and builders about the factors influencing the strength of masonry and the permissible stresses in it. An accurate prediction of the strength of masonry is difficult as factors affecting it are many. Important fatcors influencing the strength of masonry are discussed below.

2.1. *Physical Properties of Bricks*

The important properties influencing the performance are—

(i) Compressive and tensile strength.
(ii) Shape and texture.
(iii) Absorption and suction.

The performance of the masonry depends upon the interaction of brick and mortar.



Masonry strength increases with the increase in compressive strength of bricks. The relationship between the masonry strength and compressive strength of bricks is non-linear. Various tests on masonry have shown that the failure of brickwork subjected to axial compression is normally by vertical splitting due to horizontal tension in brick walls Photo[1]. The formation of these cracks and failure itself are attributed to tensile stresses in the bricks, generated by the mortar. The mortar between the bricks behaves like a pad of rubber which undergo a high lateral strain when compressed, forces the bricks apart and hence the tensile failure by vertical splitting. This is why the reinforcement embedded horizontally in the mortar bed joints not only increases the lateral strength of the wall, but also increases its vertical load carrying capacity. The tensile strength of the brick is, therefore, important. Tests[8] have shown

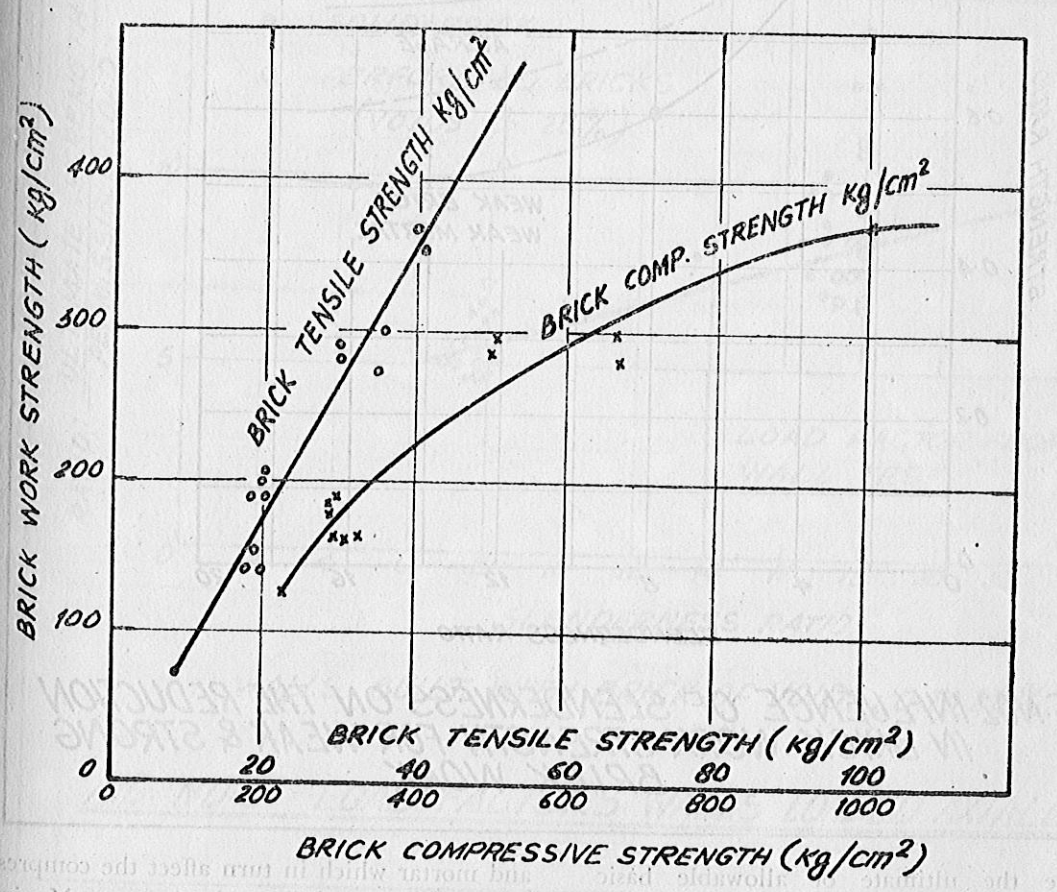


FIG. NO.1 RELATIONSHIP BETWEEN BRICK WORK STRENGTH AND BRICK TENSILE & COMPRESSIVE STRENGTHS that there is a linear correlation between the strength of brick masonry and the tensile strength of the brick. Fig. 1, shows the relationship between the strength of masonry and the tensile compressive strength of the brick. Various

masonry increases with increase in bond between brick and mortar.

Water absorption and suction rate of the bricks are other important properties affecting the water tightness and tensile bond between brick

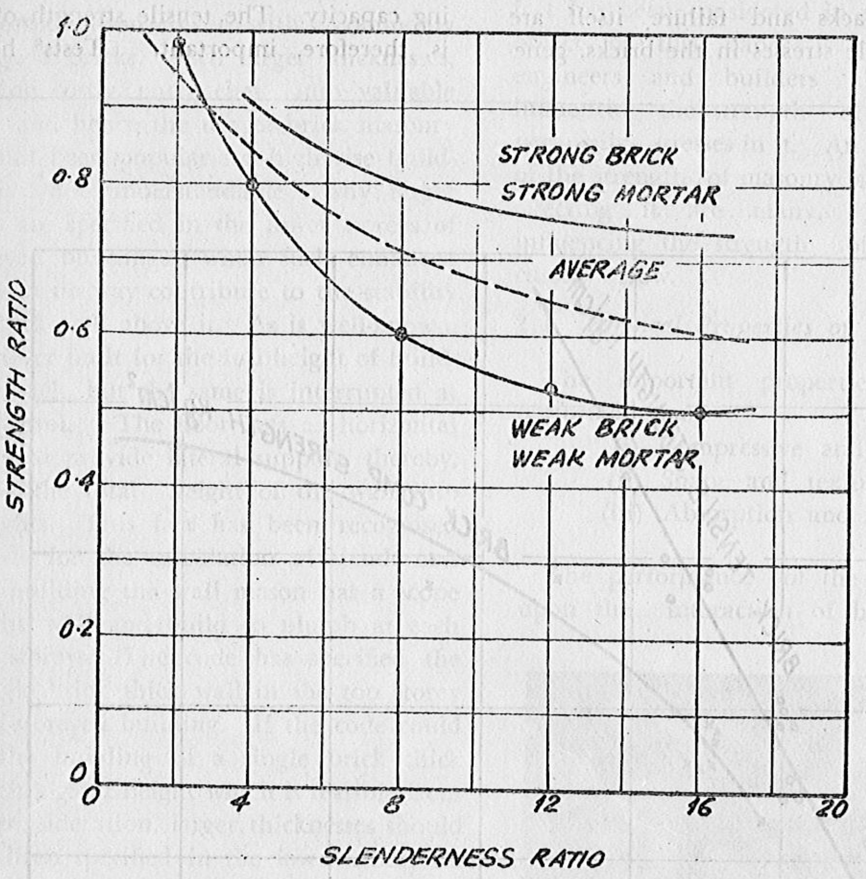


FIG. NO 2 INFLUENCE OF SLENDERNESS ON THE REDUCTION IN BRICK WORK STRENGTH FOR WEAK & STRONG BRICK WORK

codes give the ultimate or allowable basic stresses in masonry based on the compressive strength of bricks and composition of mortar as no standard method for finding the tensile strength of the brick has been evolved so far.

The bricks most regular in shape, size and with plane parallel faces give more masonry strength. Bricks with rough surface texture have more bond with mortar than bricks having smooth surface. Strength and durability of

and mortar which in turn affect the compressive and transverse strength of masonry. Maximum bond strength between mortar and brick is obtained with the bricks having suction of 10 to 20 gms./min./200 cm. sq. at the time of laying[4]. Therefore, bricks having greater suction rate should be soaked in water to the extent to bring the same to this value. On the other hand if the bricks are too wet, these should be left in the atmosphere to make the surface dry.

2.2. *Properties of Mortar*

From the working consideration, the desirable properties of the mortars are workability, water retentivity, good bond, sufficient early stiffening, compressive and tensile strength and durability. Modern mortars usually consist basically of cement, lime, sand and water. Workability, water retentivity and bond properties are imparted by lime, whereas cement and sand confer strength and durability. Cement lime mixes are generally superior to straight lime or cement mixes. In practice the above requirements cannot be fully attained in one mortar composition. Further, strong mortar is not required for all brick work, as there is little advantage in using a very strong mortar in most of the brick work.

The relationship between the compressive strength of mortar and masonry cannot be stated precisely. However, the strength of masonry increases with increase of mortar strength. In case of low strength bricks where failure is initiated by failure of bricks, increase in mortar strength beyond certain limit do not increase the masonry strength. For brick work with high strength bricks (beyond 350 kg./cm.²) the fall in strength of the masonry is much more pronounced as progressively weaker mortar is used. Therefore, only suitable mortar as given in table 1 matching with brick strength

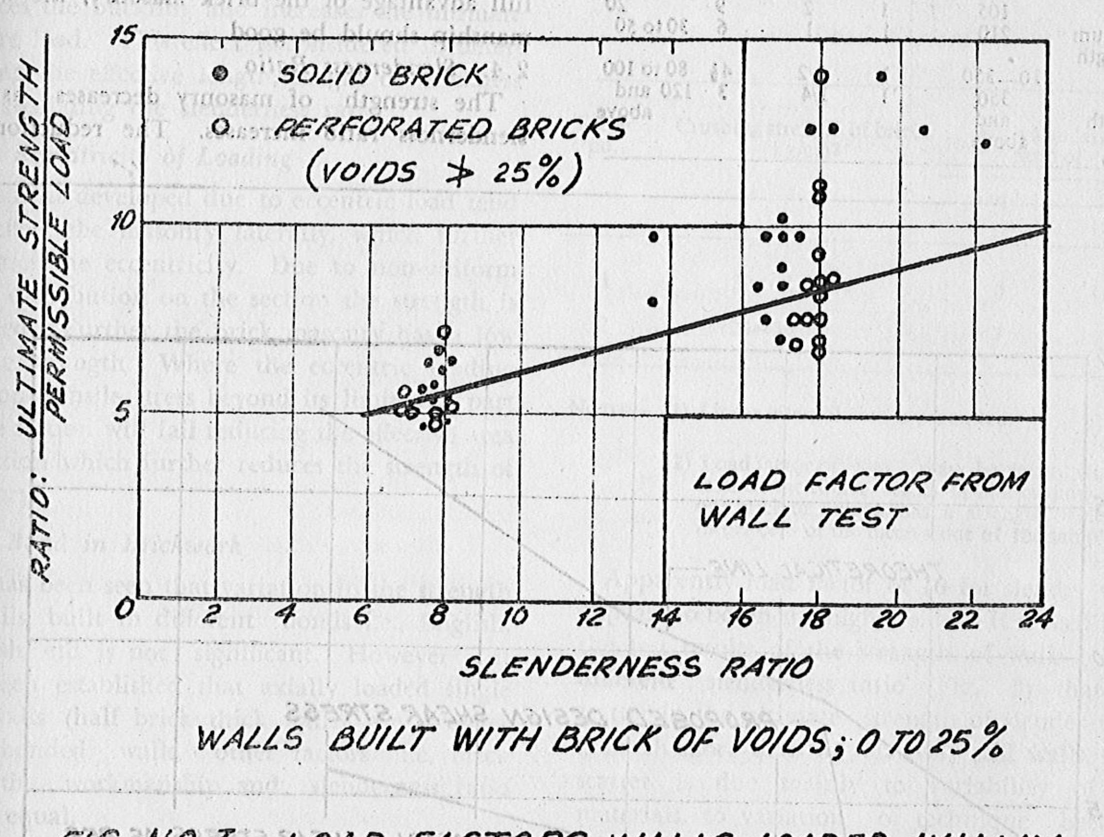


FIG. NO. 3 LOAD FACTORS WALLS LOADED AXIALLY should be used. In general the mortar should be weaker than brick strength as it gives more flexibility for the absorption of differential movements in the brick work :

TABLE No. 1

Suitable mortar mixes for various brick strength

Sl. no.	Brick strength: Designation	Brick strength: Kg/cm2	Mortar mix by vol.: Cement	Mortar mix by vol.: Lime	Mortar mix by vol.: Sand	App. compressive strength of mortar (28 days)
						Kg/cm2.
1	Low	.. 105	1	2	9	20
2	Medium strength	.. 210	1	1	6	30 to 50
		210—350	1	1/2	4½	80 to 100
3	High strength	.. 350 and above	1	1/4	3	120 and above

Some times rich mortar is used where early stiffening is required against lateral loadings as in the case of partition walls.

2.3. *Workmanship*

Workmanship has considerable influence on the strength of masonry. Poor workmanship may seriously impair the strength of brick work and may reduce it to as low as 60 per cent. Good workmanship may be stated as filling the vertical joints fully, unfurrowing horizontal beds, making joints thin, soaking bricks properly and building to true plumb. To obtain the full advantage of the brick masonry, the workmanship should be good.

2.4. *Slenderness Ratio*

The strength of masonry decreases as the slenderness ratio increases. The reduction in

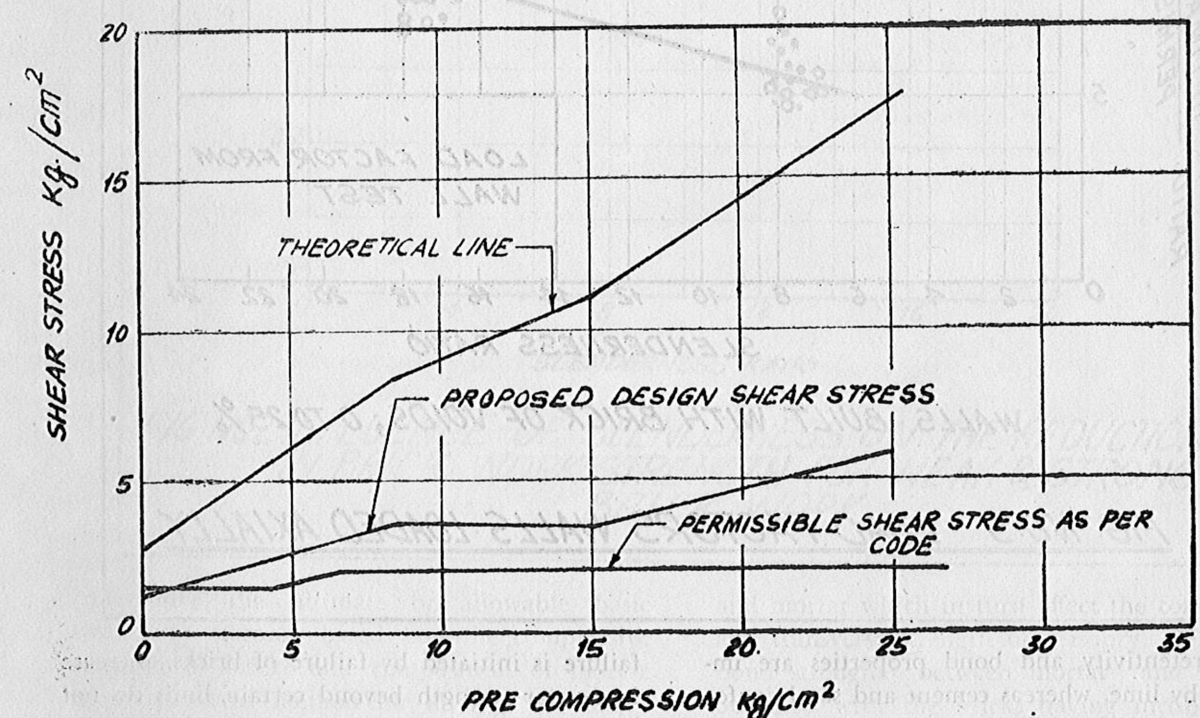


FIG. NO. 4 RELATIONSHIP BETWEEN SHEAR STRENGTH OF BRICK WORK AND NORMAL COMPRESSIVE STRESS AND PROPOSED DESIGN SHEAR STRESS (AFTER SINHA) strength for an increase in slenderness ratio is more severe when weak mortar and weak bricks are used (Fig. 2). The loss of strength is caused by elastic instability and limitations in workmanship. Members when subjected to axial compressive load, buckles, making the load eccentric which leads to an early failure. In case of eccentric loads, buckling effect is more pronounced. In slender piers, the buckling due to accidental eccentricity of loading, lack of straightness, etc. is more critical than in walls.

Restraint provided, both along the height or length by slabs, cross-walls or pillasters, etc. reduces the buckling and increases the ultimate failure load. This effect is considered in determining the effective length, height or thickness for calculating the slenderness ratio.

2.5. *Eccentricity of Loading*

Moment developed due to eccentric load tend to deflect the masonry laterally, which further increases the eccentricity. Due to non-uniform stress distribution on the section the strength is reduced. Further the brick masonry has a low tensile strength. Where the eccentric loading develops tensile stress beyond its limit, the part of the section will fail reducing the effective area of section which further reduces the strength of masonry.

2.6. *Bond in Brickwork*

It has been seen that variation in the strength of walls, built in different bonds i.e., English, Flemish, etc. is not significant. However[5], it has been established that axially loaded single leaf walls (half brick thick walls) are stronger than bonded walls, other factors i.e. brick strength, workmanship and slenderness ratio being equal.

3. *Permissible Stresses*

The influence of various parameters on the strength of masonry has been described in the preceding paras. But the object of the designer is to know the permissible stresses in walls in compression, tension and shear and is discussed below:

3.1. *Compressive Strength*

The appropriate ratio of strength of masonry to brick varies from slightly less than half to one fifth. The former is found for low strength bricks (105 kg./cm.^{2}) used with strong mortar and the latter is for high strength bricks (350 kg./cm^2. and above) used with weak mortar. However, when appropriate mortar is used this ratio varies from 0.4 to 0.3. The former being for low strength bricks and the latter for high strength bricks. The code allows the permissible stress in masonry with variable factor of safety which ranges from 5 to 10 for slenderness ratio of from 6 to 24, as given in Table no. 2:

TABLE No. 2

Load Factors

Serial no.	Crushing strength of bricks kg/cm^2	For a slenderness ratio of	
		6 or less	24
1	30 and above	5	10
2	20—30	7	12

NOTES— (1) Linear interpolation is permitted.

(2) Load factor of line 1 may be taken when the tests on the twelve bricks or blocks show that on one brick or block has a strength of less than 75 per cent of the mean value of the sample.

Apparently load factor of 10 for slender walls appears to be on the higher side. It is seen from the test results of the strength of walls having different slenderness ratio (Fig. 3) that the scatter in the ultimate strength of slender walls is much more than in relatively stiff walls. The scatter is due mainly to variability of the materials, to variation of technique between brick layers (workmanship) and to a lesser extent, to variation in test arrangement. The effect of these factors is more pronounced with the increase of slenderness ratio. In fact the code allows the permissible stresses with load factors ranging from 4 to 7 for stiff walls and for 7 to 14 for very slender wall with an average value of 5 and 10 respectively which beside other factors, covers the workmanship factor also. Therefore, if good workmanship is ensured higher stresses in masonry can be allowed even after maintaining a factor of safety of 5.

3.2. *Tensile Strength*

Resistance to tensile stress in masonry is due to tensile bond between bricks and mortar and increases with the increase in strength of mortar provided it is workable. Also the tensile resistance parallel to bed joint is twice to the tensile resistance normal to bed joints. Code of Practice allows in both directions, the same value of tensile stress and makes no distinction in mortar except that the mortar should not be weaker than 1 : 1 : 6 (Cement : Lime : Sand). The value of 1 kg./cm.^{2} provided in the code is very much on the conservative side, as the tensile resistance of brick masonry is much more. This is evident from the allowable tensile and shear stress values given in SCPI Code Table 3[6].

3.3. *Shear Strength*

Masonry walls are quite often subjected to racking (lateral), loads which produces shear stress. Shear resistance of brick work is due to shear bond between brick and mortar and increases with the increase of :

1. Shear bond between brick and mortar.

2. Pre Compressive stress in the masonry due to vertical dead load.

The shear bond increases with the roughness of the brick texture and with the increase of water contents in the mortar. The bond is also increased with the addition of certain proportion of lime in mortar and the optimum ratio of lime to cement between 1/4 and 1 develops maximum bond[4]. Shear resistance increases linearly with increase in vertical compression up to a limit where there is a breakdown of bond between the brick and mortar. This is indicated in Fig. No. 4, which also shows the permissible shear stress in brickwork as per code[2,7]. It is seen from this that the code allows a maximum shear stress of 2 kg./cm.^{2} only which is unnecessarily low when the masonry is under high compression. Proposed design shear stress value is also shown in the figure based on the work of Sri Sinha on 1/6 scale model brick work tests[8].

TABLE NO. 3

Allowable stresses in tension in flexure and shear in non-reinforced brick masonry as per SCPI Code.

Mortar Cement : Lime : Sand	Allowable stresses kg/cm2 — Tension in flexure: Normal to bed joints	Allowable stresses kg/cm2 — Tension in flexure: Parallel to bed joints	Shear
1 : 1/4 : 3 or 1 : 1/2 : 4½	2.5	5	3.5
1 : 1 : 6	2	4	2.8

3.4. *Slenderness Ratio*

The increase in slenderness ratio leads to an early failure due to buckling. The code of practice considers this effect and provides a table of stress reduction factors for various slenderness ratios. From economic considerations, it limits the slenderness ratio values as 24 for walls in dwellings of not more than two storeys and 18 for all other structures. But it has been seen that the walls restrained by concrete slabs rarely fails by buckling. The present limit of 18 for load bearing walls is, therefore, conservative. In such cases a value of at least 24 is more realistic. Canadian code[9] and the code recommended by SCPI[6] specifies the limit of 30.

Design :

Because of limitation of space, the actual design of brick masonry walls based on Code of Practice[2] is not included in this paper. The same with a few worked out examples and design aids shall be presented in a separate paper.

Acknowledgement

The authors thank Prof. Dinesh Mohan, Director, Central Building Research Institute, Roorkee for permission to publish.

References

1. IS : 1905—61—"Indian Standard Code of Practice for Structural safety of buildings : Masonry walls".

2. Draft Revision of IS—1905—61 Indian Standard Code of Practice for Structural Safety of Buildings — Masonry Walls.

3. Prof. A. W. Hendry — Structural Ceramics Research. The Consulting Engineer Vol. 32, No. 7, July 1968, page 54.

4. Plummer, H. C. — and Blume, J. A. 'Reinforced Brick masonry and Lateral force Design' Structural Clay Products Institute, Washington, D. C. November, 1953.

5. R. E. Bradshaw and A. W. Hendry "Crushing Tests on Storey height walls 4½" in thick" proceedings of the British Ceramic Society load bearing brick-work 1 and 2 No. 4, July, 1965 and No. 11, July, 1968, respectively.

6. SCPI May, 1966 "Recommended building code requirements for engineered brick masonry" — Structural Clay Products Institute Washington, D. C.

7. British Standard Code of Practice CP 111 : 1964 "Structural Recommendations for load bearing walls".

8. R. E. Bradshaw and K. Thomas, 'Modern Developments in Structural Brickwork,' Clay Products Technical Bureau's Technical Note Vols. 2 and 3. January, 1968, page 7.

9. 'National Building Code Canada 1965.'