Experimental determination of statistical parameters associated with uniaxial compression behaviour of brick masonry

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In view of practical significance of the compression behaviour of brick masonry, this article discusses the evolvement of an experimental programme based on a survey of the literature. Also, it is known that large scatter is expected in the mechanical properties of masonry and studies characterizing these statistical variations are scant in India. Using the evolved experimental programme and results of tests conducted, the statistical parameters, namely mean and coefficient of variation (COV) associated with the uniaxial compression behaviour of typical brick masonry used in South India have been determined in this article. For the masonry considered in this study, the mean values of peak compressive stress, strain corresponding to peak stress and elastic modulus are 2.82 MPa, 0.009 and 0.4 GPa respectively. The corresponding values of COV are 0.15, 0.2 and 0.12 respectively. In addition, a trilinear curve has been suggested as an idealized stress–strain relation for the brick masonry used in South India.

Keywords: Clay brick masonry, compressive strength, elastic modulus, uniaxial compression, statistical parameters.

BRICK masonry structures are one of the oldest forms of construction. Even today, they are widely used especially for low rise and residential buildings in developing countries like India. Despite the long history, brick masonry is least understood with respect to its behaviour. The design of steel or reinforced concrete structures is based on mechanics-based principles, whereas the design of masonry structures is empirical in general[1]. Hence, there is ample scope for understanding brick masonry and establish mechanics-based inter-relationship between brick, mortar, nature of interface and masonry used in India.

The Bureau of Indian Standards (BIS) provides a table (table 8 in the respective code of practice) in which basic compressive stress of masonry is prescribed for a limited set of brick and mortar combinations based on their compressive strengths[1]. Whereas in the international scenario, a number of expressions have been proposed[2] among which the following expression is being widely used

$$f_{\mathrm{m}} = k f_{\mathrm{b}}^{\alpha} f_{\mathrm{j}}^{\beta}, \tag{1}$$

where f_{m} is the compressive strength of masonry, f_{b}, the normalized compressive strength of brick, f_{j} is the compressive strength of mortar and k, α and β are constants. Equation (1) is not considered to be rational as it does not take into account the factors that directly affect the compressive strength of masonry and an expression based on two-stage homogenization has been proposed in the literature[3]. However eq. (1) is known to give satisfactory results for practical purposes[3]. Hence for characterizing the compressive strength of masonry based on the compressive strengths of brick and mortar, this type of expression may be useful.

In most of the western countries where this type of expression (i.e. eq. (1)) is being used, the bricks are relatively stronger and stiffer than the mortar. In such conditions, in accordance with the elastic sandwich model[4], when a stack bonded prism is subjected to uniaxial compression, due to Poisson effect the mortar in the bed joints tends to laterally expand more than the bricks, but the mortar will be confined by the bricks because of the bond between them. Thus, the bricks will be subjected to relative tension and in turn the mortar will be subjected to relative compression. Whereas, in India, often the mortar used is relatively stronger and stiffer than the bricks. This would result in relative compression of bricks and relative tension of the mortar in contrast to the scenario in western countries. This issue has been pointed out in the literature[5,6]. Hence, adopting an expression such as

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eq. (1) needs thorough investigation; also the values of the constants k, α and β need to be evaluated in the Indian scenario by carrying out tests on a wide variety of brick and mortar combinations.

In order to characterize the compression behaviour of brick masonry, other parameters, viz. elastic modulus, and deformability are also important. Hence, the experimental results on compression stress–strain relation of brick masonry are of practical significance. Attempts towards testing of brick masonry under compression have been made in the recent past[5–10].

Testing of brick masonry under uniaxial and biaxial cyclic loading has been carried out by Naraine and Sinha[7], and AlShebani and Sinha[8]. The scope of the present article is the characterization of stress–strain relation of brick masonry subjected to monotonic, uniaxial compression loading. Hence the studies on cyclic loading are not included in further discussions.

Stress–strain relation for masonry has been obtained by Sarangapani *et al.*[5] through compression test on stack bonded prisms and the initial tangent modulus, secant modulus at 25% of ultimate stress and the strain corresponding to ultimate stress also have been obtained. Gumaste *et al.*[6] have tested four types of specimen (viz. stack bonded prism, English bonded prism, stretcher bonded wallettes and English bonded wallettes). In addition to the values of initial tangent modulus, secant modulus at 25% of ultimate stress and strain corresponding to ultimate stress, the constants k, α and β as given in eq. (1) have been evaluated by them. Kaushik *et al.*[9] have tested stack bonded prisms and have presented the chord modulus between 5% and 33% of ultimate stress and strains corresponding to eight different levels of normalized stress. Also, the expressions for compressive strength of masonry, strain corresponding to peak stress and simplified models for stress–strain relation of masonry have been presented. Though there are commonalities in the aspects considered in these studies, there are differences in the procedures adopted. It is also noted that there is no standard test procedure in the BIS for obtaining the stress–strain relation of masonry. Keeping these in view, a survey of the literature and standards has been carried out and based on this a detailed experimental programme has been evolved for carrying out test on compression behaviour of brick masonry. Actual test on a typical brick masonry fabricated using soft and weak bricks from South India has been performed and the results have been compared with those obtained from the expressions proposed in the literature. Results of these comparisons have been presented.

It is known that the variation in the mechanical properties of bricks, mortars and hence the masonry is large. Therefore, reliable estimates of mean and coefficient of variation (COV) of important parameters associated with uniaxial compression behaviour are necessary and are of practical significance.

Survey of Standards and the literature on the test procedure

Salient steps involved in the test and the corresponding recommendations as given in the Standards[1,11,12] and adopted in the literature[5,6,9] concerned with brick masonry used in India, are shown in Box 1.

Experimental programme on compressive stress–strain behaviour of brick masonry

In this section, we provide details of the experimental programme, evolved based on a survey of the literature. A critical discussion on the literature is also included at relevant places. More details of experimental studies carried out are given below. Some of the highlights of the present experimental programme are:

(1) It includes a procedure to control the moisture content in the bricks and mortar during fabrication of prism.
(2) It includes the usage of compressometer that is customized for measuring strain in the brick masonry prisms.
(3) It proposes a rate of displacement to be adopted in order to obtain the post-peak behaviour properly.

In the present experimental programme, stack bonded prisms used have been fabricated out of five bricks as shown in Figure 1. It is to be noted that the prisms measuring 420–440 mm height, 219–226 mm width and 100–105 mm thickness satisfy the requirement pertaining to the aspect ratio as given in IS[1] and ASTM[11]. Since the main concern of this article is to obtain statistical parameters associated with the stress–strain relation, it is considered the sample size of 6[6] and of 7[9] may not be sufficient. If a sample size of 7 is considered, the length of confidence interval for mean value at a 5% level of significance for a typical brick masonry with mean value of 4 MPa and standard deviation 0.5 MPa is 0.71, whereas the length of confidence interval comes down to 0.45 (a reduction of about 57%) if a sample size of 15 is considered. Hence, in the present programme, a sample size of 15 specimens has been considered.

We decided to use a poor quality brick and cement mortar (1 : 5) by weight that is commonly used in the construction of small residential buildings. The bricks have been subjected to monotonically increasing compression of 14 N/mm^2/min; Table 1 presents the mean and COV of compressive strength computed based on test results. In this programme, it has been decided to pre-wet the bricks to a level of approximately 75% of saturation. This is to achieve a good brick–mortar interface by avoiding the floating of bricks and limiting the loss of water from the mortar as recommended by Groot and Larbi[13]. In Table 1, the water absorption corresponding to

Box 1. Summary of survey of standards and literature

Description	Recommendation in standards / Adopted in the literature in India
Specimen type	ASTM[11]: Stack bonded prisms of aspect ratio (height to thickness ratio) between 1.3 and 5. BS[12]: Wallettes of 1.2–1.8 m length having a minimum cross-sectional area of 0.125 m^2 and 2.4–2.7 m in height. IS[1]: Stack bonded prisms of aspect ratio (height to thickness ratio) at least 2 but not more than 5. Sarangapani *et al*.[5]: Stack bonded prism, 435 mm × 225 mm × 105 mm. Gumaste *et al*.[6]: Stack bonded prism: 460 mm × 230 mm × 105 mm; English bonded prism: 460 mm × 230 mm × 230 mm; stretcher bonded wallettes: 600 mm × 520 mm × 105 mm; English bonded wallettes: 665 mm × 520 mm × 230 mm. Kaushik *et al*.[9]: Stack bonded prisms, 400–410 mm height, 110 mm thickness.
No. of specimens	ASTM[11]: To be decided in accordance with ASTM E122-09 (ref. 23). BS[12]: Minimum of 2 nos. IS[1]: Minimum of 5 nos. Sarangapani *et al*.[5]: Not mentioned. Gumaste *et al*.[6]: Six specimens for each sample. Twenty-one samples out of four types of specimen, two types of bricks and six types of mortar have been considered. Kaushik *et al*.[9]: Seven specimens for each sample. Twelve samples out of four types of bricks and three types of mortar have been considered.
Conditioning of units	ASTM[11]: Surface of the units shall be free of moisture at the time of laying. BS[12]: Bricks with IRA more than 1.5 kg/m^2/min may be docked or be water content in the mortar may be adjusted. IS[1]: Moisture content of the units at the time of laying shall be same as that used in the structure. Sarangapani *et al*.[5]: Not mentioned. Gumaste *et al*.[6]: Table moulded bricks are soaked under water for 15 min and wire cut bricks for a duration of 45 min. This is to achieve 75% of saturation. Kaushik *et al*.[9]: Not mentioned.
Preparation of mortar	ASTM[11]: No specific recommendation. BS[12] (BS[24]): 35–140 litre/50 kg of cement depending on the proportion of the mix. IS[1]: Consistency of the mortar and thickness of joint shall be same as that used in the structure. IS[25]: The working consistency of a mortar or plastering mix as judged by the worker from its behaviour during application. Generally, only as much quantity of cement mortar as would be sufficient for 30 min of work shall be mixed at a time. Sarangapani *et al*.[5]: Not mentioned. Gumaste *et al*.[6]: Not mentioned. Kaushik *et al*.[9]: Not mentioned.
Fabrication of the specimen	ASTM[11]: Orient the units in the prism as in the corresponding conduction. In the case of hollow blocks with multiple cells, only one cell shall be trimmed flush and used. In the case of grouted masonry, the grouting shall be carried out between 4 and 48 h after fabrication of the specimen. BS[12]: Construction and bond of the wallettes should correspond to those to be used in practice. IS[1]: Workmanship and quality of construction shall be same as that used in the structure. Sarangapani *et al*.[5]: Not mentioned. Gumaste *et al*.[6]: Not mentioned. Kaushik *et al*.[9]: Not mentioned.

(*Contd*)

Box 1. (*Contd*)

Description	Recommendation in standards Adopted in the literature in India
Curing	ASTM[11]: Up to 48 h covered with moisture-tight bag and left undisturbed/do not transport. After 48 h cure at 24 ± 8°C and humidity less than 80%. BS[12]: Up to 3 days: covered with polyethylene sheets and then left uncovered until tested. Recommended age of testing: 28 days; when required, this may be extended to 35 days. IS[1]: No specific recommendation. Sarangapani *et al*.[5]: Method of curing has not been mentioned. But the duration of curing is 28 days and the specimen is soaked under water for 48 h before testing. Gumaste *et al*.[6]: Method of curing has not been mentioned, but the duration of curing is 28 days and the tests have been carried out under saturated condition. Kaushik *et al*.[9]: Not mentioned.
Capping	ASTM[11] (ASTM[26]): Either gypsum cement materials or sulphur capping materials. Age of the caps shall at least be 2 h and possess a compressive strength of at least 24.1 MPa at an age of 2 h. BS[12]: No specific recommendation. IS[1]: No specific recommendation. Sarangapani *et al*.[5]: Not mentioned. Gumaste *et al*.[6]: Specimens were capped with rich cement sand mortar (1 : 1) before curing and allowed to gain strength during curing itself. Kaushik *et al*.[9]: Not mentioned.
Requirements for testing machine	ASTM[11]: Accuracy of ±1% of the anticipated load range. The upper platen shall be spherically seated and attached to the centre of the head of the machine. The centre of the sphere shall be free to move in any direction. The diameter of the upper platen shall be at least 150 mm. BS[12]: No specific recommendation. IS[1]: The upper platen shall be spherically seated. Sarangapani *et al*.[5]: Not mentioned. Gumaste *et al*.[6]: Not mentioned. Kaushik *et al*.[9]: Not mentioned.
Requirements for strain gauge	ASTM[11] (ASTM[27]): Class B1 or better quality. BS[12]: No specific recommendation. IS[1]: No specific recommendation. Sarangapani *et al*.[5]: Demec gauge of 200 mm gauge length. Gumaste *et al*.[6]: Demec gauge of 200 mm gauge length. Kaushik *et al*.[9]: Epsilon extensometers are positioned such that they covers three mortar joints.
Rate of loading	ASTM[11] (ASTM[27]): The speed of testing shall be low enough that thermal effects of adiabatic expansion or contraction are negligible and that accurate determination of load and extension is possible yet the speed shall be high enough that creep will be negligible. In loading with dead weights, avoid temporary overloading due to inertia of the weights. The strain rate should be reported. BS[12]: No specific recommendation for obtaining compression behaviour, but for obtaining compressive strength alone, a rate of 1 $N/mm^2/min$ is prescribed. IS[1]: No specific recommendation for obtaining compression behaviour, but for obtaining compressive strength alone, a rate of 350–700 kN/min is prescribed. Sarangapani *et al.*[5]: Constant displacement rate of 1.25 mm/min. Gumaste *et al*.[6]: Not mentioned. Kaushik *et al*.[9]: Not mentioned.

Table 1. Summary of results of tests on brick, mortar and masonry prism

Parameter*	Mean	COV
	Material	
Brick		
Dimension		
Length [6 measurements × 50 bricks#=300#]	219.45 mm	0.007
Breadth [6 measurements × 50 bricks#=300#]	102.41 mm	0.012
Height [6 measurements × 50 bricks#=300#]	75.5 mm	0.026
Water absorption		
@24 h immersion [15#]	12.21%	0.037
@15 min immersion [5#]	9.59%	–
Compressive strength [15#]	5.31 N/mm^2	0.19
Mortar		
Consistency: Slump test (in accordance with RILEM[14])		
@ w/c ratio 1.0: slump = 203 mm		
@ w/c ratio 0.9: slump = 79 mm		
@ w/c ratio 0.85: slump = 68 mm (chosen in this experimental programme)		
@ w/c ratio 0.70: slump = 0		
Peak compressive stress [10#]	19.14 N/mm^2	0.09
Strain corresponding to peak stress [10#]	2.664×10^{-3}	0.12
Modulus of elasticity [10#] (chord modulus between 5% and 33% of peak compressive stress)	16695.29 N/mm^2	0.07
Masonry		
Peak compressive stress [15#]	2.82 N/mm^2	0.15
Strain corresponding to 5% of the peak stress ε_i [15#]	0.2213×10^{-3}	0.263
Strain corresponding to 33% of the peak stress ε_e [15#]	2.222×10^{-3}	0.216
Strain corresponding to 50% of the peak stress [15#]	3.568×10^{-3}	0.190
Strain corresponding to 70% of the peak stress [15#]	5.173×10^{-3}	0.171
Strain corresponding to 90% of the peak stress [15#]	7.081×10^{-3}	0.153
Strain corresponding to peak stress ε_p [15#]	9.063×10^{-3}	0.115
Strain corresponding to 90% of the peak stress in recession limb [11#]	10.499×10^{-3}	0.179
Strain corresponding to 60% of the peak stress in recession limb ε_u [8#]	13.599×10^{-3}	0.264
Modulus of elasticity [15#] (chord modulus between 5% and 33% of peak compressive stress, in accordance with the recommendations[9,11,22])	401.72 N/mm^2	0.127
Ratio $\varepsilon_u/\varepsilon_p$ [15#] (a parameter similar to ductility)	1.526	0.187

*Values presented in the square brackets indicate sample size.

Figure 1. Fabrication of bricks masonry stack bonded prism.

24 h immersion represents the saturated condition. The percentage of moisture corresponding to 15 min immersion is 9.59%, it is around 78% of the value (12.21%) corresponding to 24 h immersion. Hence, the bricks have been pre-wetted by soaking under water for 15 min before fabrication.

RILEM[14] recommends a slump of 170 mm which is too fluidic and generally not used in India. Hence, the slump requirement for the mortar used in India has been assessed, based on the slump test on mortar (results of the slump test have been presented in Table 1). Mortar with w/c ratio of 0.85 which gives rise to a slump of 68 mm, and which has been adjudged by three different expert masons as 'the convenient workable mix and normally used in the field', has been used. Importantly, the water content has been controlled by mixing water with small batches of dry mix and the resulting mix has been used for fabrication within 30 min. In order to determine the parameters required to describe the compression behaviour of the mortar cylinders of 150 mm diameter and 300 mm length have been subjected to monotonically increasing displacement at the rate of 0.15 mm/min. Table 1 presents the results, mean and COV of peak compressive stress.

Figure 2. ***a***, Curing of fabricated specimen under water up to 7 days. ***b***, Curing of specimen under wet burlap during 8–28 days.

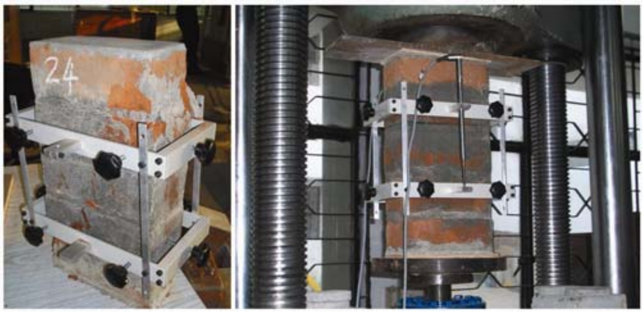

Figure 3. Set-up for carrying out test on compression behaviour of brick masonry specimen.

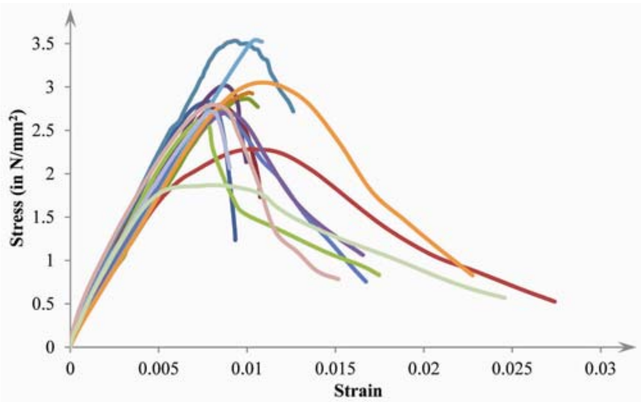

Figure 4. Compressive stress–strain curves of masonry obtained from tests on 15 different specimens.

In order to apply a uniform compression force on any cross-section of the masonry prisms, a thin cap has been provided at the top and bottom of the specimen using a rich mortar (1 : 2). The capping has been done during fabrication itself, so that the cap also attains sufficient strength during the curing of the specimen. As far as curing of brick masonry prisms is concerned, it is common to cure the specimens under moist gunny bags; however, in this programme it has been decided that for the first 7 days the specimens shall be soaked under water (Figure 2 *a*) and from 8 to 28 days, the specimens shall be cured under moist gunny bags (Figure 2 *b*). This will help minimize the variation of moisture content and its effect on the structural behaviour of brick masonry. Just before transporting the specimen from the curing yard for testing, it is thoroughly watered so that the tests are carried out on wet specimens.

For measuring strain in the masonry prism, a customized compressometer has been designed and fabricated. The compressometer is designed in such a way that the gauge length can be adjusted, two LVDTs can be fitted and 12 foot screws are used to fix the compressometer with the prism specimen. In this test programme, 170 mm gauge length has been used in such a way that two mortar joints and approximately two bricks are covered (Figure 3). LVDTs having least count of 0.001 mm have been used. For measuring compressive force, an external load cell with a least count of 0.01 kN has been used.

The specimens have been placed between the platens of the servo-controlled compression testing machine with a 3 mm plywood at top and bottom. A rate of displacement of 1.25 mm/min has been adopted by Sarangapani *et al*.[5]. However, trial tests indicated that 1.25 mm/min was too high to capture the post-peak behaviour properly, while a value of 0.25 mm/min was found to be reasonable. Hence, the compression load has been applied at a constant displacement rate of 0.25 mm/min throughout the strain ranges reported here using the servo-controlled compression testing machine. Table 1 and Figure 4 present the results.

Discussion of results

The compressive strength of the bricks used in this programme is quite low and hence, as expected, the peak

Table 2. Deviation of the mean value of peak stress obtained from tests with estimations according to the literature

Reference	Estimated compressive strength (N/mm^2)	Deviation of the result of tests* (%)
Dayaratnam[18]: $f_m = 275\ f_b^{0.5} f_j^{0.5}$	2.772	+1.73
Eurocode[19]: $f_{mk} = 0.6(1 \times 0.89 \times f_b)^{0.65} (f_j)^{0.25}$ (characteristic compressive strength)	3.444	–18.11
Bennett *et al.*[16]: $f_m = (3/10)f_b$	1.593	+77.02
MSJC[22]: $f_m = 1.0(400 + 0.25f_b)$ (in psi)	4.085	–30.97
Gumaste *et al.*[6]: $f_m = 0.317\ f_b^{0.866} f_j^{0.134}$	1.998	+41.14
Kaushik *et al.*[9]: $f_m = 0.63\ f_b^{0.49} f_j^{0.32}$	3.671	–23.18
Freeda Christy *et al.*[10]: $f_m = 0.35\ f_b^{0.65} f_j^{0.25}$	2.167	+30.13

*Mean value of peak compressive stress as obtained from the tests: 2.82 N/mm^2.

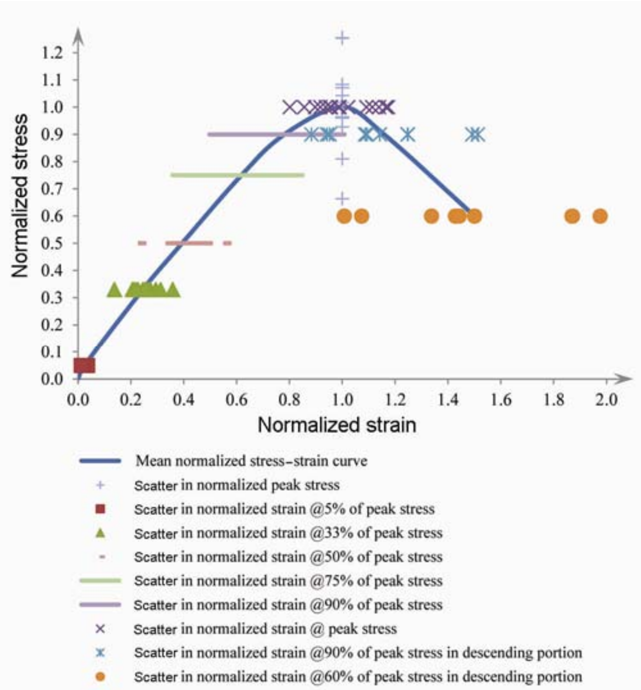

Figure 5. Mean normalized stress–strain curve of brick masonry obtained from the tests.

compressive stress of the masonry is also quite low. It is noted from the literature[6,9,15] that the peak compressive stress of the masonry is lower than that of the bricks used. Also it is worth noting that though strain was not recorded when the bricks were subjected to compression, visual observations indicated that the bricks undergo large deformations. The relative movement of the heads of the compression testing machine around the peak stress was approximately 9–14 mm. These observations indicate that the bricks used are 'soft' and also 'weak'. The brick masonry prisms used have undergone high levels of strain at peak stress (mean value of 0.0093) compared to those presented by Kaushik *et al.*[9] (0.0036 for brick masonry prisms fabricated using cement mortar 1 : 6 and 0.0029 for brick masonry prisms fabricated using cement mortar 1 : 3). On the other hand, the mean value of strain corresponding to peak stress as obtained is comparable with that presented by Gumaste *et al.*[6] (prisms fabricated using table-moulded bricks). The mean value of modulus of elasticity is approximately 150 times that of the mean peak stress of brick masonry, which is much less than the range presented by Kaushik *et al.*[9] (i.e. 250–1100 times the compressive strength of masonry). These observations indicate that the masonry fabricated using soft and weak brick possesses larger deformability than those fabricated using stiff and strong bricks.

The measured mean peak stress of brick masonry showed a COV of 0.15. Measured mean peak stress of brick masonry is compared with that estimated using the expressions given in the literature (Table 2). Bennet *et al.*[16] do not take into account the compressive strength of the mortar. Similarly MSJC[17] is also less sensitive to the compressive strength of the mortar. Hence these may not be advisable for countries like India, where wide varieties of mortar are used. From the results presented in Table 2, it is noted that the predictions made by Dayaratnam[18] are close to the experimental value. He gives equal weightage for compressive strengths of mortar and brick[18]. Eurocode[19], Gumaste *et al.*[6] and Kaushik *et al.*[9] give higher weightage to compressive strength of brick. While for the expression of Gumaste *et al.*[6], the summation of the constants α and β is equal to '1' (see eq. 1)), which makes it dimensionally balanced, the same is not true for the expressions of Eurocode[19] and Kaushik *et al.*[9]. Hence, it is proposed that the constants α and β may have to be arrived based on the thickness ratios of brick and mortar joint. It will not only fulfil the dimensional balancing, but also to some extent the mechanics of the behaviour. Nevertheless, this needs further experimental studies on different brick and mortar combinations, including relative strength and stiffness between brick and mortar.

The stress–strain curves for brick masonry shown in Figure 4 were normalized with respect to peak stress and strain corresponding to peak stress. The curve corresponding to mean and the variation of peak stress and strain are presented in Figure 5. There is variation of COV in the normalized strain at different levels of the normalized stress; however, for engineering purpose, an

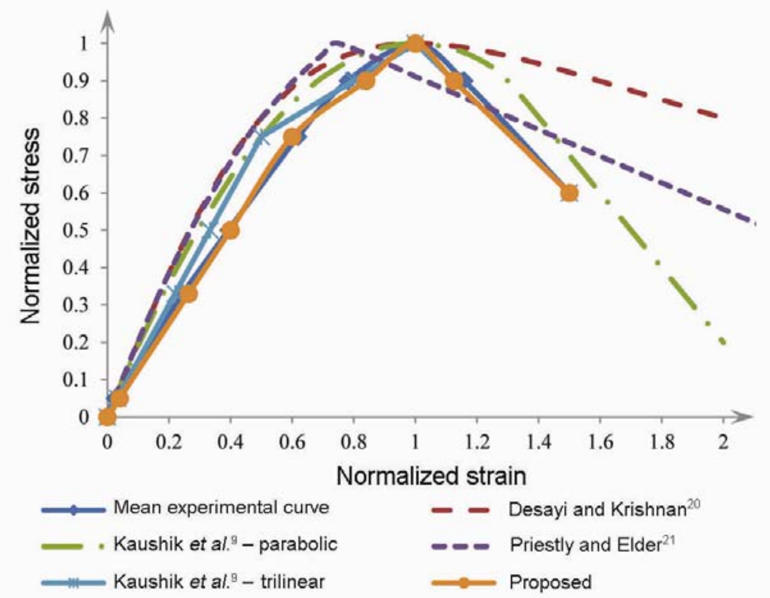

Figure 6. Comparison of normalized stress–strain curves. Desayi and Krishnan[20]: RMSD = 0.6240; Priestly and Elder[22]: RMSD = 0.1932; Kaushik *et al.*[9] – parabolic: RMSD = 0.0918; Kaushik *et al.*[9] – trilinear: RMSD = 0.0499; Proposed: RMSD = 0.02632.

average value of 0.2 may be used throughout. The proposed value of 0.2 for the COV of normalized strain at different levels of the normalized stress could be suitable while soft and weak bricks are used. While using strong and stiff bricks, the COV of normalized strain at different levels of the normalized stress needs to be assessed from similar experimental studies.

By comparing the root-mean-square deviation (RMSD) values of the mean normalized stress–strain curve as obtained from the tests with those estimated using equations available in the literature[9,20,21], it is found that the curve obtained from the test is comparatively closer to that proposed by Kaushik *et al.*[9] (Figure 6). It is to be noted that the normalized form of the stress–strain relation for concrete given by Desayi and Krishnan[20], is also considered because of its simplicity. Between the two equations proposed by Kaushik *et al.*[9], the trilinear equation fits the experimental curve better than the parabolic curve. However, it is observed that for the weak and soft bricks the initial linear part has to be more slanting and hence, a normalized strain level of 0.6 corresponding to 75% of peak stress as shown in Figure 6 has been proposed for better agreement with the obtained experimental data. Also, this needs concurrence from similar experimental studies.

Conclusion

This article presents procedure for obtaining the compressive stress–strain relationship of masonry. A trilinear stress–strain relation has been proposed for typical brick masonry used in South India. It is important to establish mechanics-based inter-relationship between compressive strengths of brick, mortar, nature of interface and masonry. In order to achieve this, there is a need to carry out similar experimental programmes using different brick and mortar combinations. While considering different combinations of brick and mortar, their relative strength and stiffness need to be taken into account. Towards these aspects, studies are being continued at CSIR-SERC.

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