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SPLIT TENSILE STRENGTH OF BRICK MASONRY

K. MADHAVI[1], M. V. RENUKA DEVI[2] & K. S. JAGADISH[3]
[1]Assistant Professor, Department of Civil Engineering, Rashtreeya
Vidyalaya College of Engineering, Bangalore, Karnataka, India
[2]Professor, Department of Civil Engineering, Rashtreeya
Vidyalaya College of Engineering, Bangalore, Karnataka, India
[3]Former Professor, Department of Civil Engineering,
Indian Institute of Science, Bangalore, Karnataka, India

ABSTRACT

Load bearing masonry walls of a building, when subjected to earthquake experience in plane and out of plane forces which may lead to sudden collapse. Since a state of pure shear leads to diagonal tension and compression, Split tension tests are conducted on masonry panels to obtain the tensile strength of masonry. The tensile strength of masonry is determined with masonry bed joints as horizontal and with bed joints inclined at 45° to the horizontal. Stress analysis has been carried out using finite element analysis. Both isotropic and orthotropic cases were considered. Split tensile strength of masonry is evaluated from the formula obtained by finite element analysis and the experimental failure loads.

KEYWORDS: Masonry, Split Tension, Square Specimen

INTRODUCTION

Brick masonry buildings generally suffer significant damage when subjected to earthquake ground motions. The damages are usually of two kinds, namely a. Due to shear failure of in plane loaded walls and b. Due to flexural failure of walls loaded out of the plane. Shear walls are the major load resisting elements in a building subjected to horizontal forces. Often, complete failure of the shear walls leads to a collapse of the building. The in plane loading of the shear walls results invariably in the development of diagonal tension cracks. It is hence necessary to understand the strength of masonry walls subjected to diagonal tension. Such diagonal tension strength of a material is frequently investigated through the split tension test. The split tension test on concrete cylinders is a well-known test. Neville (2011) also suggests cubes and prisms of concrete can be subjected to splitting tests with results similar to that of a cylinder test. In the case of masonry strength under diagonal tension, ASTM E 519 (2010) recommends a split tension test using a square masonry panel with the compression applied along the diagonal of the square panel. Sundara Raja Iyenger and Chandrashekara (1962) analysed the split tensile stresses in a rectangular plate subjected to concentrated loads using the theory of elasticity.

The shear strength of masonry is interpreted from diagonal split tension tests. A number of experimental and analytical studies on the diagonal tensile strength of masonry are hence available in the literature. RuiSousa (2012) conducted a limited number of experiments on the diagonal compressive strength of masonry to verify and calibrate a numerical model. The interface between the unit and joint was considered rigid. Despite the simplification made to the model, the adopted model fairly represents the behavior of masonry in shear. Valerio Alecci (2013) calculated masonry shear strength by diagonal compression test, applying the three formulas available in the literature. The results indicated that the shear strength calculated by the formula obtained by modelling the stress state at the Centre of the panel as isotropic and homogeneous is in line with triplet test results. Fiber reinforced polymer materials are emerging as an attractive option to strengthen masonry structures against earthquakes. Many investigators (Robert B. Petersen (2010), Ahmad A. Hamid (2005), have conducted diagonal compression tests to determine the shear strength of masonry strengthened with different FRP techniques.

The present study aims to arrive at the formula for split tensile strength of masonry considering masonry as isotropic and orthotropic. Various approaches to the split tension test of brick masonry are examined in this paper. Using a combination of finite element analysis and a split tension test, the diagonal tensile strength of masonry is arrived at. A diagonal split tension test of brick masonry was also attempted by Saikia (2012)

MASONRY MATERIALS AND THEIR CHARACTERISTICS

Bricks

Local bricks of Bengaluru were selected and their compressive strength and water absorption were determined as per the guidelines of IS 3495 (1992). Twenty bricks were selected for each characteristic. The initial rate of absorption was also determined by dipping the dry brick in a 3mm layer of water for one minute. The results of the tests on bricks are presented in Table 1.

Table 1: Properties of Bricks

Characteristic of Brick	Average Value	Standard Deviation	Coefficient of Variation (%)
Compressive strength (N/mm^2)	6.4	1.1	17.3
Water absorption(%)	11.66	0.914	7.84
IRA(Kg/m^2/min)	1.51	0.534	35.3

Mortar

Masonry assemblages for experiments were prepared using a 1:6 cement mortar. The mortar compressive strength was 7.14N/mm^2.The thickness of the joints were in the range of 10mm to 12mm.

Masonry

The modulus of elasticity of the brick masonry was obtained by compression testing of prisms. The moduli for loading perpendicular to bed joints and loading parallel to bed joints were obtained by testing two types of prisms. The initial tangent modulus for loading perpendicular to bed joints was found to be 522N/mm^2.In the case of loading parallel to bed joints, the initial tangent modulus was found to be 1112N/mm^2.

MASONRY PANELS FOR SPLIT TENSION TEST AND THEIR FINITE ELEMENT ANALYSIS

Three types of masonry specimens are considered for testing and stress analysis. They are

- A near square specimen with horizontal bed joints.
- A near square specimen with bed joints at 45° to the horizontal.
- A near square specimen for diagonal testing.

All the specimens are of half brick masonry with a thickness of 100mm.

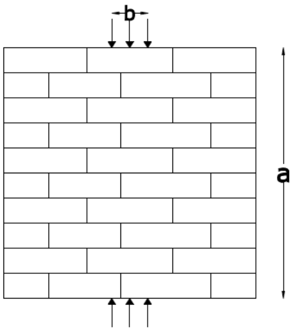

Figure 1: Masonry Panel: Horizontal Bed Joints

Near Square Specimen with Horizontal Bed Joints

A specimen size of 470x400x100mm is considered. It is subjected to concentrated loads as shown in Figure 1 over a width of ‘b’. The width ‘b’ is varied, keeping the total load constant at 15kN.Three values of ‘b’ namely 182mm,82mm and 20mm are considered for the finite element analysis using ANSYS. 2-D elasticity elements were used for analysis. The resulting split tension values along the middle vertical are shown in Figure 2. The analysis makes use of isotropic theory. The Figure clearly shows that the split tension reaches a constant value in most of the specimens when the load width is 20mm for a specimen width of 470mm.For larger width, the split tension is not uniform and hence the loading width should be 5% or less than 5% of the total width of the specimen.

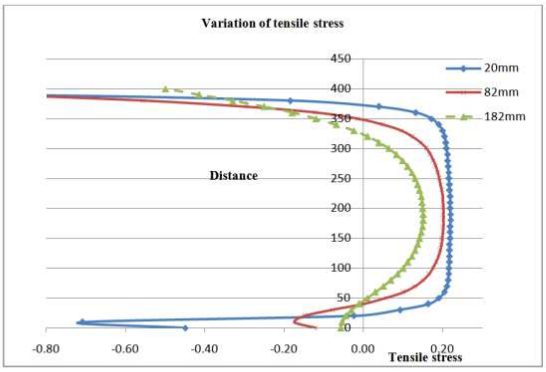

Figure 2: Variation of Tensile Stress Across the Height of the Specimen by Varying ’b’

The analysis of the specimen with horizontal bed joints is repeated considering both isotropic and orthotropic model. The size of the specimen for the analysis is 700x690x100mm.The results of isotropic and orthotropic analysis are now compared in Figure 3.It is seen that for a concentrated load of 15kN,the split tension is 0.13N/mm^2 for isotropic case and 0.16N/mm^{2}for orthotropic case.

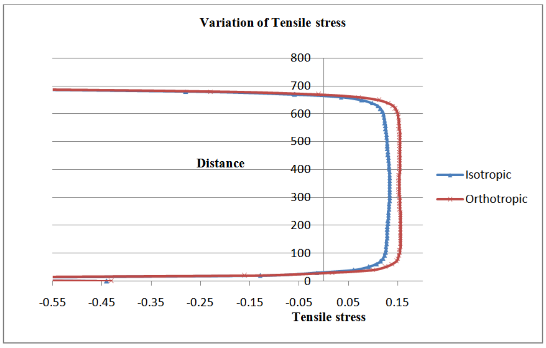

Figure 3: Variation of Tensile Stress for Specimen with Horizontal Bed Joints

Near Square Specimen with Bed Joints at 45° to the Horizontal

A specimen of size 700x700x100mm is now considered as shown in Figure 4 with a loading width of 20mm. The resulting split tension is shown in Figure 5 for a load of 15kN.It is seen that the resulting split tension is 0.13N/mm^2 for the isotropic case and 0.16N/mm^2 for the orthotropic case.

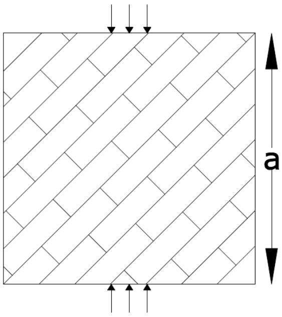

Figure 4: Masonry Panel: Bed Joints at 45° to the Horizontal

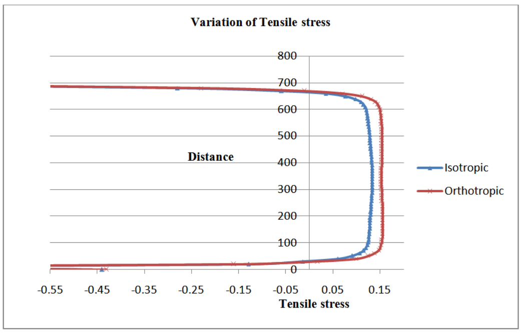

Figure 5: Variation of Tensile Stress for Specimen with Bed Joints at 45° to the Horizontal

The results of the two specimens may now be summarized in Table 2 as follows.

Table 2: Split Tension Values for Two Specimens Concentrated Load P=15kn

Type of Specimen	Model Type	Split Tension (N/mm^2)	Split Tensile Strength = $\frac{kP}{at}$
			k
Near square specimen with Horizontal Bed joints	Isotropic	0.13	0.61
	Orthotropic	0.16	0.75
Near square specimen with Bed joints at 45° to horizontal	Isotropic	0.13	0.61
	Orthotropic	0.16	0.75

It may be seen that the values for the two specimens are very close and the orthotropic case shows higher value of stress.

Near Square Specimen with Diagonal Loading

A specimen of 680x760x100mm is now considered as shown in Figure 6.The split tension along the vertical diagonal is shown in Figure 7.It is interesting to note that the split tension is now far from uniform. It has a peak value in the middle and the non-uniformity is greater in the orthotropic case. If one considers the maximum value of the split tension, its relation to the concentrated load is presented in Table 3.

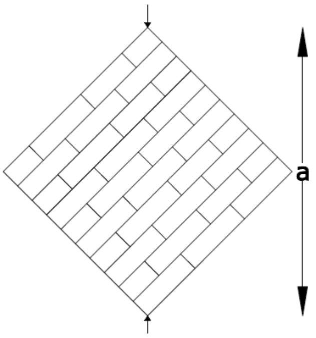

Figure 6: Diagonal Specimen with Inclined Bed Joints

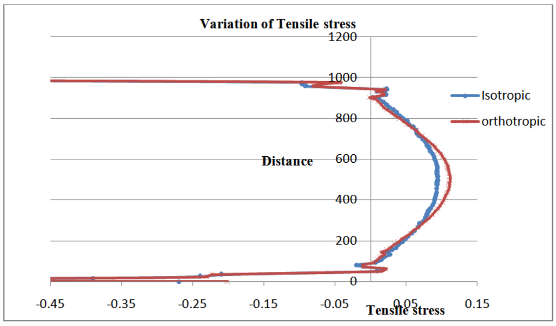

Figure 7: Variation of Tensile Stress for Diagonal Specimen

Table 3: Split Tension in Diagonal Specimen P=15kN, a=1020mm

Model	Peak Tension N/mm^2	Split Tensile Strength $= \frac{kP}{at}$
		k
Isotropic	0.095	0.65
Orthotropic	0.112	0.76

It is interesting to note that even in the diagonal specimen, the peak stress is not very different from the values of uniform tension in the square non diagonal specimens.

The split tension value proposed by ASTM test is

$$S = \frac{0.707P}{A}$$

Where $A = \frac{(w+h)t}{2}$

Using this formula for the diagonal specimen loaded with 15kN,

$$\text{Weget}\frac{0.707 X 15000 X 2}{(680+760) X 100} = 0.147 N/mm^2.$$

This is very much higher than values obtained by stress analysis. Again, in view of the fact that the split tension values are not uniform in the diagonal specimen it appears that such specimens are not ideal for split tension test.

EXPERIMENTAL STUDIES

The earlier finite element analysis established the relationship between the concentrated load and the split tension values for three types of specimens. However the analysis did not obtain the failure tension values. Experiments were now carried out to obtain the load at which the split tension failure takes place. Using the analytical results the actual split tension failure values were arrived at. Three sample specimens each were considered for each type of test. The results of such tests are now presented in Table 4 and Table 5. Figure 8, Figure.9 and Figure 10 show typical failed specimens.

The Table 4 shows that the specimen with horizontal bed joints and vertical loading shows the highest split tension value. However the diagonal cracks during earthquake indicates splitting approximately at 45° to the bed joints. Hence the result of the second specimen appears more appropriate to diagonal failure of masonry during earthquake. Earlier studies on racking load tests have shown shear strength of 0.1N/mm^2.Hence the second result appears to confirm the shear strength of masonry.

Table 4: Split Tension Strength of Near Square Specimens

Type of Specimen	Size of Specimen (mm)	Failure Load (kN)	k	Tensile Strength= $\frac{kp}{at}$ (Orthotropic) N/mm^2	Average Tensile Strength N/mm^2
Near square Specimen with horizontal ed joints	700x690x100mm	20.59	0.75	0.22	0.22
	710x690x100mm	22.22	0.75	0.23	
	700x690x100mm	19.51	0.75	0.20	
Near square Specimen with bed joints at 45°	700x700x104	12.9	0.75	0.13	0.127
	700x697x100	11.49	0.75	0.12	
	700x700x100	12.5	0.75	0.13	

Table 5: Split Tension Strength of Diagonal Specimens

Size of Specimen (mm)	Length of Diagonal mm	Load (kN)	k	Tensile Strength (Orthotropic) N/mm^2	Average Tensile Strength N/mm^2
685x750x107	1016	21.5	0.76	0.15	0.145
680x760x105	1020	16.73	0.76	0.12	
685x735x104	1005	22.7	0.76	0.17	

Figure 8: Failure of Specimen with Horizontal Joints

Figure 9: Failure of Specimen with Inclined Bed Joints

Figure 10: Failure of Diagonal Specimen

The split tension test of diagonal specimen, gives results which are comparable. However, since the split tension varies significantly over the height of the specimen, it appears the use of near square specimen with 45° bed joints and vertical loading is the best approach to split tension testing of masonry.

CONCLUSIONS

The finite element studies of various masonry specimens showed the following.

- Near square specimens with vertical loading do lead to uniform split tension over the height.
- When the near square specimen is tested with load along the diagonal, the split tension does not vary uniformly along the diagonal.

- Orthotropic theory leads to slightly higher split tension, when the modulus parallel to the bed joints is more.
- The Experiments showed that when the loading is perpendicular to the bed joints the split tension values are quite high at around 0.22N/mm^2.
- When the bed joints are at 45° to the horizontal and the loading is vertical the split tension value is 0.127N/mm^2.This appears to be the most satisfactory way of obtaining split tension strength of masonry.

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