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Numerical Simulation of Masonry Prism Test using ANSYS and ABAQUS

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***Abstract*— The compressive strength of masonry, whether it is brick or concrete block (solid or hollow), is of paramount importance in the design of masonry structures which are now being increasingly used. The compressive strength of masonry depends on the strength and elastic properties of masonry unit, mortar etc. Experimental determination of masonry compressive strength requires a lot of time in addition to effort. This drawback can be overcome by effective and reliable computer simulation of masonry prism test. The present work aims at simulating the masonry prism test using ANSYS and ABAQUS software. Some of the masonry prism tests available in literature as well as the prism test conducted in the present work have been successfully simulated using the aforesaid software. There is a reasonable agreement between the experimental and numerical values for compressive strength of solid concrete block masonry as obtained from the prism test of present work. The value predicted by ANSYS is closer to the experimental result compared to that predicted by ABAQUS. The crack patterns observed during the experiment (masonry prism test) and predicted by ANSYS resemble each other to a good extent.**

Keywords*— *Masonry prism; concrete block; compressive strength; finite element analysis; ANSYS; ABAQUS

1. INTRODUCTION

Masonry construction can be considered to mark the commencement of the civil engineering. It has a pleasing appearance. The international building code defines masonry as "a built-up construction or combination of building units or materials of shale, clay, stone, glass, concrete, gypsum or other units bonded together with mortar or without mortar or grout". ASTM (American Society for Testing and Materials) defines masonry as "construction usually in mortar of natural stones or manufactured masonry units like brick, concrete block, adobe, brick tile, manufactured stone and gypsum block". The compressive strength of masonry is usually determined by testing the masonry specimens in compression. In general, 3 types of masonry specimens are considered, namely, masonry prism, masonry wallette and masonry wall. Masonry prisms consist of several courses of masonry units laid on mortar. The prism could be stack bonded or in other bonds like English and Flemish. The masonry prism is usually of one brick or masonry unit of one width. Masonry prisms are tested for compressive strength in accordance with American Standard Testing of Materials (ASTM) [1]. Testing of masonry prism is the simplest and least expensive. Masonry wallette is a short wall of several courses. The width of the wallette consists of 3 or more units of masonry. The wallette usually contains more number of masonry units than a prism. It has a number of perpend joints beside the bed joints. Wallettes are more realistic than a prism since they contain a number of perpend joints. However, testing of a wallette is more expensive in terms of financial outlay and effects involved. A masonry wall has a height comparable to the actual wall. Such a specimen helps in evaluating the effect of slenderness more accurately [2]. A vast literature exists on masonry testing and a few of them are mentioned here. **Boult** [3] studied the relationship between the compressive strength and height of masonry prism made up of different masonry units. Stack bonded prisms with a height to least lateral dimension (h/d) of 2 to 5 were constructed using different masonry units. Test results showed that as the prism height increased the compressive strength of the masonry prism decreased. The rate of decrease was dependent on masonry units used. The results also showed that the decrease in masonry prism strength as height of the prism increased appeared to be insignificant between the 5 course high prism and the 12 course high column. Boult suggested that the material properties of the masonry units, mortar and grout should be considered while assembling the masonry prism. **Brown and Whitlock [4]** studied the compressive strength of grouted hollow brick prisms. High tensile strength of brick, high strength of grout and mortar etc. were factors that increased the compressive strength of the masonry prism. **Drysdale and Hamid [5]** carried out a study on the behavior of hollow concrete block masonry under axial compression. 146 axial compression tests on concrete block prisms were performed and it was established that a 3 course block prism is preferable to 2 course block to represent the behavior of the actual wall. Large increase in strength of the grout is observed to result in small increase in the strength of the prism. **Hegemier et al. [6]** carried out a study on compressive strength of concrete masonry prisms normal to the bed joint. It was found that the prism strength was primarily a function of the number of bed joints and not the height by least lateral dimension ratio. It was recommended that prism must be constructed from 4 to 5 courses with 3 to 4 mortar joints. **Appukutty and Murugesan [7]** carried out experiments on masonry prisms by substituting quarry dust for sand in cement mortar of brick masonry. **Christy et al. [8]** carried out compressive load tests on masonry short prisms using two types of masonry units. Flyash bricks and clay bricks using cement mortar were used to build the prisms. The masonry prism was reinforced with wire mesh at the alternate bed joints. And it was tested for compressive strength and elastic modulus. Cement mortar of 1:6 ratio with 20% replacement of sand with fly ash exhibited high strength. **Viswanathan et al. [9]** carried out a study on numerical simulation of unreinforced brick masonry under compression and shear loading. The masonry prisms were modeled using finite element software ANSYS. The material properties of the brick and mortar required for numerical analysis were obtained experimentally. **Shivaraj Kumar and Renuka Devi [10]** carried out a study on the strength of hollow concrete block masonry prism which was dependent on the various factors like strength of unit, mortar and grout strength. Three- dimensional micro modeling in ANSYS 14.5 was used for nonlinear investigation to predict the compressive strength, failure and crack pattern of the hollow concrete block masonry prism. The material properties of the brick and mortar were obtained experimentally. And nonlinear material properties like stress and strain were also obtained by experiments on hollow concrete block, mortar and grout. William Warnke's five parameter failure theory was adopted to model the failure of the masonry material. **Sandeep et al. [11]** studied the behavior of unreinforced and reinforced hollow concrete block masonry prisms under compression. Strength of hollow concrete block masonry prism was dependent on the various factors like strength of unit, mortar and bond strength. In the numerical program, 3-dimensional micro modeling using ANSYS 14.5 was used for non-linear investigation to predict the compressive strength, failure and crack pattern of the hollow concrete block masonry prism. Micro modeling approach was developed for reinforced and unreinforced masonry prism. Non-linear material properties like stress and strain were also obtained by experiments on hollow concrete block, mortar and grout. The FE model successfully predicted ultimate failure compressive stress of unreinforced and reinforced masonry prisms close to 85% of experimental values. **Sandeep et al. [12]** studied the behavior of reinforced masonry prisms in compression and the effect of slenderness. **Ravi et al. [13]** carried out an experimental study and numerical investigation on material properties of brick masonry prism as they are inelastic and have non-homogeneous properties. Experimental study was performed to determine the compressive strength, modulus of elasticity and stress strain characteristics. FE modeling was carried out using ANSYS. Stress distribution, interface properties and failure of brick masonry were analyzed using ANSYS. Micro modeling and macro modeling of the brick prism triplets for different mortar joints ratio were developed and compared with the experimental results. The results indicated that higher the mortar ratio higher will be the strength and the mortar ratio 1: 2 has the maximum strength. **Sabid [14]** carried out tests on masonry prisms with different proportions for mortar. Type of bond used was English bond. Dimensions of the prism were 230 mm x 230 mm x 300 mm. The specimens prepared were tested after 7 and 28 days of curing. The results were verified using model created using ANSYS.

2. PRESENT WORK

The present work is limited to studies on prism tests used for determining the compressive strength of masonry.

2.1 Experimental Work

Before casting the masonry prism, the following preliminary tests were carried out:

- Tests on solid concrete block such as dimensionality, compressive strength and modulus of elasticity.
- Tests on 1: 8 cement sand mortar such as compressive strength and modulus of elasticity.

2.1.1 Tests on Solid Concrete Blocks

(a) ***Dimensionality test***

This test was carried out according to IS 2185 Part 1-1979 [15]. Ten solid concrete blocks were selected and placed in line on the level surface. The overall dimensions of all the blocks were measured using tape. The average dimension of the solid concrete block was found to be 401.5 mm x 202.6 mm x 98.5 mm.

(b) ***Compressive strength***

The compressive strength of masonry unit was obtained by testing masonry blocks of size 400 mm x 200 mm x 100 mm. The blocks were capped by providing 5 mm thick mortar of ratio 1:0.25:2 (cement: gypsum: sand) on both surfaces of the block. The block was placed in UTM and the load was gradually increased on the unit until the failure took place. The average of three determinations was adopted. The average value adopted was 5.6 MPa.

(c) Modulus of elasticity

Modulus of elasticity of unit was obtained by testing masonry blocks of size 400 mm x 200 mm x 100 mm under compression. In the present study, the blocks were capped by providing 5mm thick mortar of ratio 1:1/4:2 (cement: gypsum: sand) on both surfaces of the block. The block was placed in UTM and load was applied on the unit until the failure took place. For every 10 kN load, stress and strain values were noted and graph of stress versus strain was plotted as shown in Fig.2.1. The initial tangent modulus was determined from the graph. The average of 3 initial tangent modulus determinations was adopted as the Young's modulus which was found to be 15750 N/mm^2.

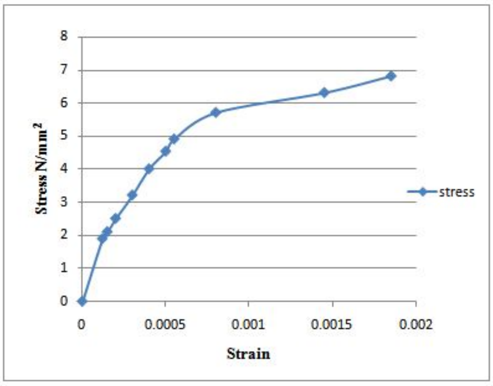

Fig.2.1: Average Stress-Strain Curve for Solid Concrete Blocks

2.1.2 Tests on 1:8 Cement Sand Mortar

(a) Compressive strength

The compressive strength of mortar was obtained by testing mortar cubes of size 70 mm x 70 mm x 70 mm in compression. Cement: sand proportion was 1:8 and water cement ratio of 1.26 was used. Here weak mortar and strong block combination is used for masonry prism. After 28 days curing, the cubes were tested in UTM. The cube was placed in UTM and load was gradually increased until failure occurs. The average of three determinations was adopted and the same is found to be 4.21 MPa.

(b) Modulus of elasticity

The modulus of elasticity of mortar was obtained by testing mortar cube of size 70 mm x 70 mm x70 mm. The specimen was placed in UTM and load was gradually applied on the specimen until the specimen failed. For every 10 kN load, stress and strain values were recorded and the graph of stress versus strain was plotted as shown in Fig.2.2. From the graph, the initial tangent modulus of mortar was determined. The average of 3 determinations was adopted. The initial tangent modulus was thus found to be 5500 N/mm^2.

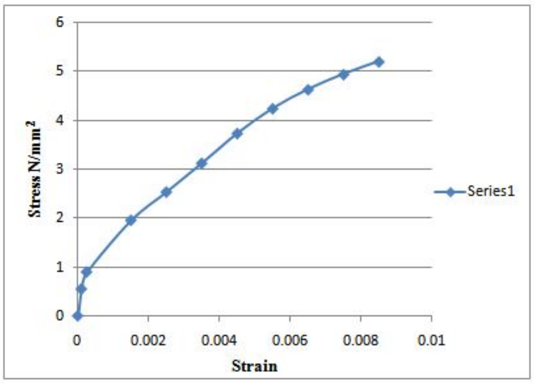

Fig.2.2: Average Stress-Strain Curve for Mortar

2.1.3 Tests on Concrete Block Masonry Prism

The size of the masonry unit used was 400 mm x 200 mm x 100 mm. The thickness of the joint adopted was 15mm. The total height of masonry prisms was 560 mm. Ordinary Portland cement of 53 grade was used. The cement-sand mortar (1:8) with water-cement ratio 1:26 was used. Three solid concrete block masonry prisms were cast. The masonry unit was placed on a level surface and the first layer of mortar joint was applied and then the second solid concrete block was placed on it. This process was continued until the fifth solid concrete block was placed. Curing was done for 28 days with wet gunny bags. Standard compression test was conducted on prisms made of solid concrete blocks and mortar after 28 days of curing in universal testing machine of capacity of 400 kN capacity to determine the compressive strength of masonry and load-deformation behavior including crack pattern as per ASTM C 1314. Fig.2.3 shows the compression test in progress and Fig.2.4 shows the crack pattern observed in the test. The compressive test results are given in Table 2.1.

Fig.2.3: Testing of Masonry Prism

Fig.2.4: Crack Pattern of Masonry Prism

Table 2.1: Compressive Strength of Masonry Prism

Specimen No.	Load at failure kN	Compressive strength MPa	IS:1905-1987 C.F.=1.17 Corrected Compressive strength MPa
1	360	4.50	5.27
2	380	4.75	5.56
3	320	4.00	4.68
Mean Compressive Strength MPa		**4.41**	**5.17**

2.2 Numerical Simulation using ANSYS

2.2.1 Prism tests of present work

The masonry prism was modeled using the software ANSYS14. The masonry prism was of size 400 mm x 200 mm x 560 mm with mortar joints of thickness 15mm. The experimentally determined values of modulus of elasticity and Poisson's ratio of masonry unit and mortar were given as input. The concrete block and mortar were modeled as isotropic and homogeneous materials. Tensile strength of the concrete was taken as low. Plane sections were assumed to remain plane during the entire duration of loading. The solid 65 element was used to model solid concrete block as well as mortar joint. The element has eight nodes with 3 DOF at each node viz., translations in x, y and z directions. This element is capable of plastic deformation, cracking in three orthogonal directions and crushing. The element is shown in Fig.2.5.

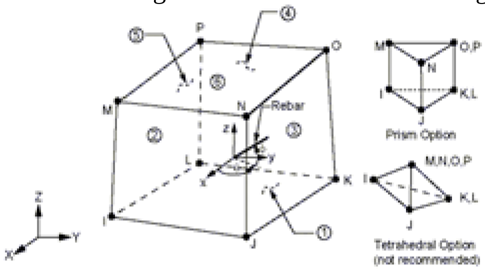

Fig.2.5: Solid 65 Element (SAS,2009)

A value of zero was entered for all the real constants for rebar. The solid 65 element requires linear isotropic and multi linear isotropic material properties to model the solid concrete block and mortar. The multi linear isotropic material properties use the Von Mises failure theory along with the William Warnke's model to define the solid concrete block and mortar. For multi linear isotropic material properties, stress strain relationship was used. The curve starts at zero stress and strain. These stresses and strains were obtained from the experimental study conducted. Implementation of the William Warnke's material model in ANSYS 14 requires nine constants viz., shear transfer co-efficient for open crack, shear transfer co-efficient for close crack, uniaxial cracking stress, uniaxial crushing stress, biaxial crushing stress, hydrostatic pressure, hydrostatic biaxial crushing stress, hydrostatic uniaxial crushing stress and tensile crack factor to be defined. Shear transfer co-efficient ranges from 0 to 1.0. A value of '0' represents smooth crack and '1' represents rough crack. In smooth crack complete loss of shear transfer occurs whereas in rough crack no loss of shear transfer takes place. The uniaxial cracking stress is based on the modulus of rupture. This value is determined using $F_r = 0.7\sqrt{f_{ck}}$. The uniaxial crushing stress is based on the uniaxial compressive strength (f_{ck}) and is denoted by f_t. The properties used are given in Tables 2.2 through 2.4.

Table 2.2: Liner Isotropic Material Properties

	Linear isotropic		
Solid 65		Solid concrete block	Mortar
	EX	15750	5500
	PRXY	0.18	0.16

Table 2.3: Multi-Linear Isotropic Material Properties

	Multi linear isotropic				
		Solid concrete block		Mortar	
		Strain	Stress	Strain	Stress
Solid 65	1	0.00012	1.89	0.00010	0.55
	2	0.00015	2.1	0.00025	0.90
	3	0.00020	2.5	0.00150	1.96
	4	0.00030	3.21	0.00250	2.54
	5	0.00040	4	0.00350	3.13
	6	0.00050	4.53	0.00450	3.74
	7	0.00060	4.90	0.00550	4.25
	8	0.00080	5.70	0.00650	4.64
	9	0.00140	6.30	0.00750	4.95
	10	0.00180	6.80	0.00850	5.21

Table 2.4: Concrete Material Properties

	Concrete		
Solid 65		Solid concrete block	Mortar
	ShrCf-Op	0.3	0.3
	ShrCf- CL	0.6	0.6
	UnTenSt	1.2	0.6
	UncompSt	12	6
	HydroPrs	Default	Default
	BiCompSt	Default	Default
	UnTenSt	Default	Default
	TenCrFac	Default	Default

Masonry prism was finely meshed to get the accurate result. Micro-modeling was used. The compressive load was applied at the top in the form of pressure loading. Loading was applied in steps. Constraint was applied at the bottom surface of the prism. The loading and boundary conditions used are shown in Fig.2.6.

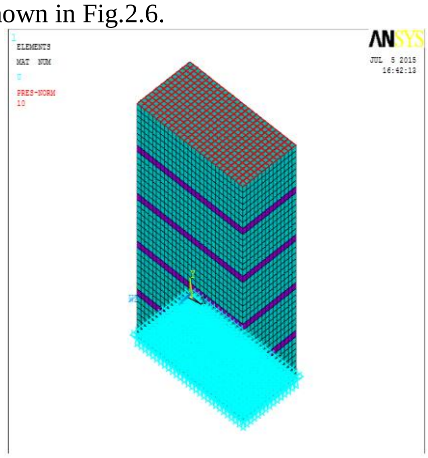

Fig.2.6: Loading and Boundary Conditions for Masdonry Prism

Nonlinear analysis was carried out until convergence of the solution was achieved. The displacement contour and stress contour are shown in Figs.2.7 and 2.8.

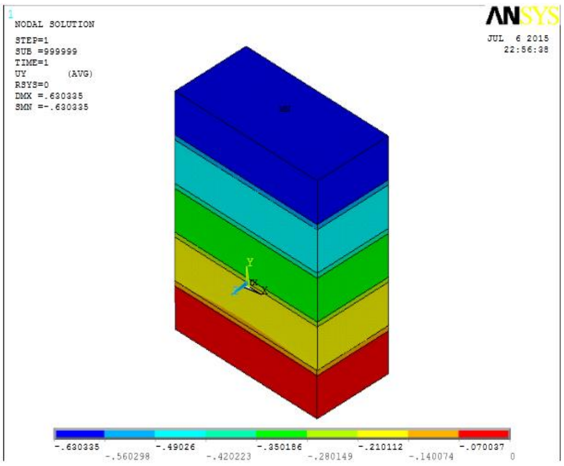

Fig.2.7: Displacement Plot of Masonry Prism

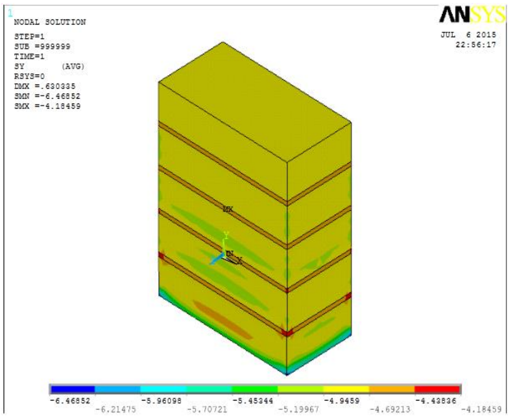

Fig.2.8: Stress Plot of Masonry Prism

The crack pattern at 100 % of the ultimate failure compressive stress of masonry prism FE model is shown in Fig.2.9; crushing is indicated with an octahedron line and cracking is indicated with a circle outline in the plane of the crack**.** The first, second and third cracks at centroid of element are shown with a red, green and blue circle outlines respectively.

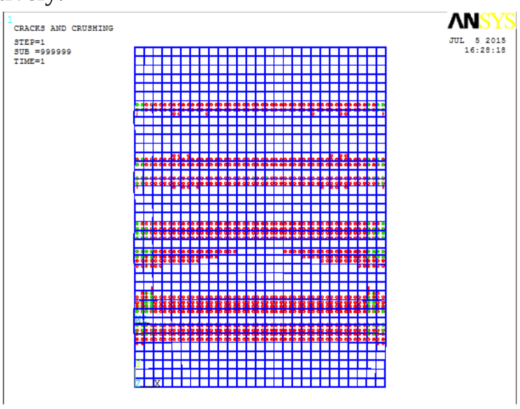

Fig.2.9: Crack Pattern of Masonry Prism

Dividing the failure load given by ANSYS by the area of load application gives the compressive strength of masonry prism as 4.84 MPa. The percentage of discrepancy between ANSYS value and the experimental value is found to be 9.75. There is good agreement between the experimental and ANSYS values.

2.2.2 Other Prism Tests of Literature

(i) Shivaraj Kumar and Renuka Devi [10] carried out studies on the strength of hollow concrete block masonry prism with and without reinforcement. The compressive strengths of hollow concrete block masonry prisms with and without reinforcement were obtained as 8.02 MPa and 4.21 MPa respectively. The experimentally determined values for modulus of elasticity and Poisson's ratio of masonry unit, mortar joint and grout were given as input to the software in the present work. The experimentally determined values for stress and strain values of masonry unit, mortar joint and grout were also input to the software in the present work. These are given in Tables 2.5, 2.6 and 2.7. Dividing the failure load given by ANSYS by the area of load application gives the compressive strength of hollow concrete block masonry prisms with and without reinforcement as 7.63 MPa and 4.03 MPa respectively. The percentages of discrepancy between ANSYS values and literature values for hollow concrete block masonry prisms with and without reinforcement are 4.83 and 4.03 respectively.

Table 2.5: Linear Isotropic Material Properties

Solid 65	Linear isotropic			
		Hollow concrete block	Mortar	Grout
	EX	14393.5	10428.63	26367.47
	PRXY	0.18	0.16	0.18

Table 2.6: Multi-Linear Isotropic Material Properties

	Multi linear isotropic						
		Hollow concrete block		Mortar		Grout	
		Strain	Stress	Strain	Stress	Strain	Stress
Solid 65	1	0.0002	2.87	0.00012	1.251435	0.00001	0.264
	2	0.0004	4.97	0.00024	2.291335	0.00002	0.526
	3	0.0006	6.70	0.00036	2.910289	0.00003	0.786
	4	0.0008	8.05	0.00048	3.323839	0.00004	1.044
	5	0.0010	9.22	0.00060	3.79269	0.00005	1.301
	6	0.0012	9.55	0.00072	4.153252	0.00006	1.557
	7	0.0014	10.41	0.00084	4.41542	0.00007	1.811
	8	0.0016	10.92	0.00096	4.899172	0.00008	2.063
	9	0.0018	11.20	0.00108	4.961844	0.00009	2.314
	10	0.0020	11.48	0.00120	5.024515	0.00010	2.563
	11	0.0022	12.44	0.00132	5.087186	0.00020	4.962
	12	0.0024	12.69	0.00144	5.149858	0.00030	7.198

Table 2.7: Concrete Material Properties

	Concrete			
Solid 65		Hollow concrete block	Mortar	Grout
	ShrCf-Op	0.3	0.3	0.3
	ShrCf- CL	0.6	0.6	0.6
	UnTenSt	1.2	0.6	2.3
	UncompSt	12	6	23

(ii) Sandeep et al. [11] carried out studies on the strength of hollow concrete block masonry prism with and without reinforcement. The compressive strengths of hollow concrete block masonry prism with and without reinforcement were obtained as 8.3 MPa and 5.43 MPa respectively. The experimentally determined values for modulus of elasticity and Poisson's ratio of masonry unit, mortar joint and grout were given as input to the software in the present work. The experimentally determined values for stress and strain values of masonry unit, mortar joint and grout were also input to the software in the present work. These are tabulated in Tables 2.8, 2.9 and 2.10. Dividing the failure load given by ANSYS by the area of load application gives the compressive strength of hollow concrete block masonry prism with and without reinforcement as 7.57 MPa and 3.81 MPa respectively. The percentages of discrepancy between ANSYS and literature values for hollow concrete block masonry prisms with and without reinforcement are 8.82 and 29.79 respectively.

Table 2.8: Linear Isotropic Material Properties

	Linear isotropic			
Solid 65		Hollow concrete block	Mortar	Grout
	EX	14383.5	12500	27700
	PRXY	0.18	0.16	0.18

Table 2.9: Multi-Linear Isotropic Material Properties

	Multi linear isotropic						
		Hollow concrete block		Mortar		Grout	
		Strain	Stress	Strain	Stress	Strain	Stress
Solid 65	1	0.0002	2.8787	0.00005	0.625	0.00008	2.216
	2	0.0004	4.9750	0.00010	1.236	0.00016	4.3064
	3	0.0006	6.7097	0.00015	1.858	0.00024	5.9410
	4	0.0008	8.0582	0.00020	2.301	0.00032	7.393
	5	0.0010	9.2236	0.00025	2.819	0.0004	8.5500
	6	0.0012	9.5528	0.00030	3.243	0.00048	9.9582
	7	0.0014	10.4191	0.00035	3.627	0.00056	11.454
	8	0.0016	10.9227	0.00040	4.026	0.00064	12.573
	9	0.0018	11.2015	0.00045	4.380	0.00072	13.626
	10	0.0020	11.4805	0.00050	4.411	0.00080	14.478
	11	0.0022	12.444	0.00055	4.666	0.00088	15.234
	12	0.0024	12.696	0.00060	4.869	0.00096	14.343

Table 2.10: Concrete Material Properties

	Concrete			
Solid 65		Hollow concrete block	Mortar	Grout
	ShrCf-Op	0.3	0.3	0.3
	ShrCf- CL	0.6	0.6	0.6
	UnTenSt	1.2	0.6	2.3
	UncompSt	12	6	23

(iii) V. Uday Vyas and B. V. Venkatarama Reddy [16] carried out studies on the strength of solid concrete block masonry prism.The compressive strength of solid concrete block masonry prism was experimentally obtained as 6.15MPa. The experimentally determined values for modulus of elasticity and Poisson's ratio of masonry unit, mortar joint and grout were given as input to the software in the present work. The experimentally determined values for stress and strain values of masonry unit, mortar joint and grout were also used as input to the software in the present work. These are tabulated in Tables 2.11, 2.12 and 2.13. Dividing the failure load given by ANSYS by the area of load application gives the compressive strength of solid concrete block masonry prism as 5.036 MPa. The percentage of discrepancy between ANSYS and the literature value for solid concrete block masonry prism is 18.11.

Table 2.11: Linear Isotropic Material Properties

	Linear isotropic		
Solid 65		Solid concrete block	Mortar
	EX	14500	6500
	PRXY	0.18	0.16

Table 2.12: Multi-Linear Isotropic Material Properties

	Multi linear isotropic				
		Solid concrete block		Mortar	
		Strain	Stress	Strain	Stress
Solid 65	1	0.00013	1.89	0.0000965	0.63
	2	0.000154	2.1	0.000279	0.75
	3	0.000185	2.5	0.00104	1.68
	4	0.000271	3.21	0.00264	2.79
	5	0.00038	4.2	0.003475	3.13
	6	0.000491	4.53	0.005568	3.91
	7	0.000578	4.9	0.00628	4.18
	8	0.000811	5.7	0.00721	4.64
	9	0.00143	6.3	0.00798	5.2

Table 2.13: Concrete Material Properties

		Concrete	
		Solid concrete block	Mortar
Solid 65	ShrCf-Op	0.2	0.2
	ShrCf- CL	0.5	0.5
	UnTenSt	0.71	0.35
	UncompSt	7.88	3.5

2.3 Numerical Simulation using ABAQUS

2.3.1 Prism tests of present work

The masonry prism test was simulated using ABAQUS software. The experimentally determined values of modulus of elasticity and Poisson's ratio of concrete block and mortar were input to the software. The stress-strain characteristics of block and mortar were also input to the software. C3D8R elements were used to model the masonry unit and mortar joint in ABAQUS 6.10. It is an 8-node element having three degrees of freedom (DOF) at each node. The 8 node continuum element (C3D8R) is formulated based on Lagrangian description of behavior where the element deforms with the material deformation. The boundary condition for masonry prism is applied on bottom area, that is, the masonry prism is constrained at the bottom surface as shown in Fig.2.10. Uniformly distributed load was applied on top area of the masonry prism as shown in Fig.2.10. Fig.2.11 shows the meshing applied.

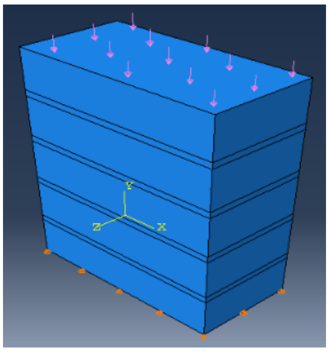

Fig.2.10: Boundary and Loading Conditions

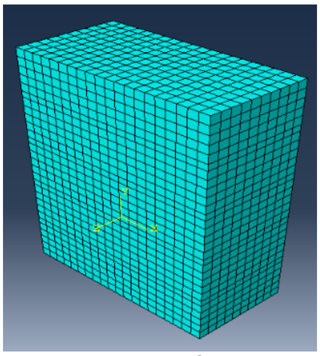

Fig.2.11 Meshing

Figs.2.12 and 2.13 represent the deformation contours and stress contours respectively. Dividing the failure load given by ABAQUS by the area of load application gives the compressive strength of masonry prism as 5 MPa. The percentage of discrepancy between ABAQUS value and the experimental value is 13.37. There is reasonable agreement between the experimental and ABAQUS values.

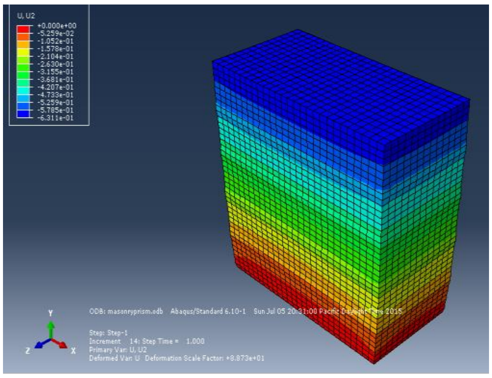

Fig.2.12: Displacement Contours for Masonry Prism

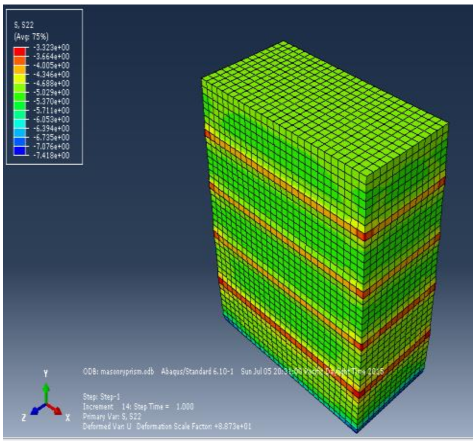

Fig.2.13: Stress Contours for Masonry Prism

2.3.2 Prism tests of available literature

(i) Shivaraj Kumar and Renuka Devi [10] carried out studies on the strength of hollow concrete block masonry prism with and without reinforcement. The compressive strengths of hollow concrete block masonry prism with and without reinforcement were found to be 8.02 MPa and 4.21 MPa respectively. The experimentally determined values of Shivaraj Kumar and Renuka Devi [10] for modulus of elasticity and Poisson's ratio of masonry unit, mortar joint and grout were given as input to the software in the present work. The experimentally determined values of Shivaraj Kumar and Renuka Devi [10] for stress and strain values of masonry unit, mortar joint and grout were also input to the software in the present work. Dividing the failure load given by ABAQUS by the area of load application gives the compressive strength of hollow concrete block masonry prism with and without reinforcement as 8.29 MPa and 4.07 MPa respectively. The percentages of discrepancy between ABAQUS and the literature values for hollow concrete block masonry prism with and without reinforcement are 3.38 and 3.37 respectively.

(ii) Sandeep et al. [14] carried out study on the strength of hollow concrete block masonry prism with and without reinforcement. The compressive strengths of hollow concrete block masonry prism with and without reinforcement were obtained as 8.3 MPa and 5.43 MPa respectively. The experimentally determined values of Sandeep et al., [14] for modulus of elasticity and Poisson's ratio of masonry unit, mortar joint and grout were given as input to the software in the present work. The experimentally determined values of Sandeep et al. [14] for stress and strain of masonry unit, mortar joint and grout were also given as input to the software in the present work. Dividing the failure load given by ABAQUS by the area of load application gives the compressive strength of hollow concrete block masonry prism with and without reinforcement as 8.03 MPa and 3.85 MPa respectively. The percentages of discrepancy between ABAQUS and the literature values for hollow concrete block masonry prism with and without reinforcement are 3.27 and 29.14 respectively.

(iii) V. Uday Vyas and B. V. Venkatarama Reddy [15] carried out studies on the strength of solid concrete block masonry prism. The compressive strength of solid concrete block masonry prism was 6.15 MPa. The experimentally determined values of V. Uday Vyas and B. V. Venkatarama Reddy [15] for modulus of elasticity and Poisson's ratio of masonry unit, mortar joint and grout were given as input to the software in the present work. The experimentally determined values of V. Uday Vyas and B. V. Venkatarama Reddy [15] for stress and strain of masonry unit, mortar joint and grout were also input to the software in the present work. Dividing the failure load given by ABAQUS by the area of load application gives the compressive strength of solid concrete block masonry prism as 4.82 MPa. The percentage of discrepancy between ABAQUS and literature values for solid concrete block masonry prism is 21.64.

2.4 Discussion of Results

2.4.1Compressive Strength of Masonry Prism

The compressive strength values predicted by the various methods in the present work are given in Table 2.14.

Table 2.14: Masonry Compressive Strength

SL. No	Masonry type	Mean compressive strength (N/mm^2)		
		Experimental	ANSYS (FE model)	ABAQUS (FE model)
1	Solid masonry prism	4.41	4.84 (9.75%)	5.00 (13.37%)

The number within parentheses represents the percentage of discrepancy relative to the experimental value. There is reasonable agreement between the experimental and numerical values. The value predicted by ANSYS is closer to the experimental result compared to that predicted by ABAQUS.

2.4.2 Crack Pattern

Fig.2.14 and Fig.2.15 show experimentally obtained crack pattern and crack pattern obtained in numerically simulated masonry prism block in ANSYS. The crack patterns observed during the experiment and predicted by ANSYS resemble each other to a good extent.

Fig.2.14: Experimental Crack Pattern

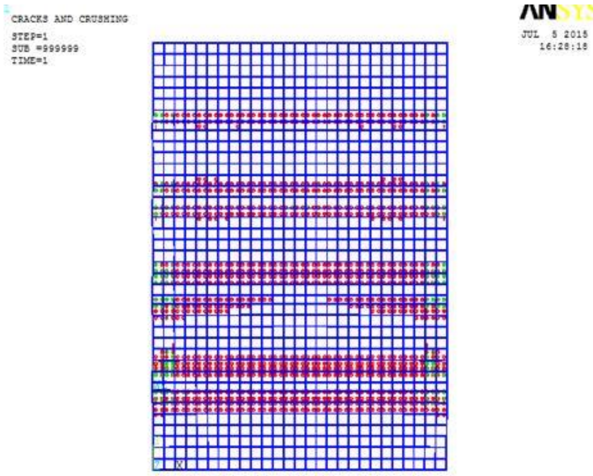

Fig.2.15: Crack Pattern in ANSYS

3. CONCLUSIONS

On the basis of present study, the following major conclusions have been drawn:

- Computer simulation of some of the prism tests conducted in the available literature (previous researchers) using ANSYS/ABAQUS in the present work reveals that there is reasonable agreement between the experimental and the simulation values of the compressive strength of masonry.
- Computer simulation of the prism tests (experiment) conducted in the present work using ANSYS/ABAQUS also reveals that there is reasonable agreement between the experimental and the simulation values of the compressive strength of masonry. The value predicted by ANSYS is closer to the experimental result compared to that predicted by ABAQUS.
- The crack patterns observed during the masonry prism test (experiment) and predicted by ANSYS resemble each other to a good extent.

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