A

DISSERTATION REPORT

ON

FINITE ELEMENT MODELLING OF HOLLOW CONCRETE BLOCKS

Submitted in partial fulfillment of the requirements for the award of degree of

MASTER OF TECHNOLOGY

IN

STRUCTURAL ENGINEERING

Submitted by

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JUNE 2016

CERTIFICATE

This is to certify that the dissertation work entitled **"FINITE ELEMENT MODELLING OF HOLLOW CONCRETE BLOCKS"** which is being submitted by **SONAM KUMARI SHARMA** (2014PCS5085) in partial fulfillment for the award of the degree of Master of Technology in Structural Engineering, MNIT, JAIPUR is a bonafide work done by her under our guidance and supervision.

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DECLARATION

I hereby certify that the work which is being presented in the Dissertation report **"FINITE ELEMENT MODELLING OF HOLLOW CONCRETE BLOCKS"**, in partial fulfillment of the requirements for the award of the Degree of Master of Technology and submitted in the Department of Civil Engineering of the Malaviya National Institute of Technology, Jaipur is an authentic record of my own work carried out during a period from July 2015 to June 2016 under the supervision of my guide **Dr. RAVINDRA NAGAR,** Professor and my co-guide **Dr. S. K. TIWARI,** Associate Professor, Department of Civil Engineering, Malaviya National Institute of Technology, Jaipur, India.

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This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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ABSTRACT

All the methods of analysis can be broadly categorized into three categories: Experimental, Analytical and Numerical methods. Experimental methods are the most reliable but they are very costly as they require special equipment, testing facilities etc. Analytical methods are also reliable but for high level of accuracy they become time consuming and cumbersome. To simplify the analysis various assumptions have to be made. Numerical methods; though give slight approximate results are simple and do not require any laboratory set up. Because of their adaptability they are becoming very popular these days. This report also deals with numerical methods based on Finite Element Method. A numerical model for the simulation of laboratory axial compressive test of hollow concrete blocks has been developed by using the Abaqus software. Different mesh sizes with two different element types have been tried to achieve accuracy in analysis with an optimum computational time. To calibrate this model experimental compressive strength test have been performed. For this hollow concrete blocks were casted and tested in the laboratory under uniaxial compression. Kota-stone waste has been used as an ingredient in manufacturing of hollow concrete blocks. Kota stone is found in Kota and Jhalawar districts of Rajasthan and its production is continuously increasing day by day. In this report an attempt has been made to raise the support for the development of value added products from stone waste. The compressive strength test results showed that the hollow concrete blocks developed by using Kota stone waste gives strength comparable to the commercial available hollow concrete blocks. The compressive strength test results have been found in good agreement with the experimental results.

Keywords – Hollow concrete block, finite element analysis, axial compressive strength.

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CHAPTER – 1
INTRODUCTION

1.1 FINITE ELEMENT MODELLING

Traditionally, the behaviour of concrete is determined by experimental observations and theoretical calculations. Experimental observations are very costly and time consuming. Now, it is recognized that computer analysis can be used to perform analysis which can substitute the experimental observations. By using computer software the behaviour of concrete can be predicted very fast with a higher level of accuracy. By using finite element method, computer software has become very powerful and widely acceptable in every field of engineering. Finite element modelling is such a computer added method of analysis which is being used in structural engineering. In this method the whole geometry of model is divided in to number of elements and then various equations are solved for every element. Finite element modelling is an important tool to be used in analyzing and verifying how an element will behave under different loading conditions. It can be used to calculate forces, deformations, stresses and strains at any point at the body.

In this project Abaqus software was used for modelling of hollow concrete blocks. This is based on Finite Element Method and can solve from a simple linear analysis problem to more complicated non-linear analysis problem. Abaqu consists of three analysis products-Abaqus/Standard, Abaqus/Explicit and Abaqus/CFD.

1.2 HOLLOW CONCRETE BLOCKS

Construction industry is growing at a very fast pace in India. This industry is responsible for waste generation and CO_2 emission. To reduce these adverse environmental impacts various attempt have been made throughout the world. Some conventional building materials and technologies are being replaced by newer building materials and technologies. Hollow concrete block is also such an experiment in masonry construction as a replacement for conventional clay brick. Concrete blocks having core void area larger than 25% of the gross area, are termed as hollow concrete blocks. Conventional clay bricks have proven highly unsustainable which should be replaced and hollow concrete block can provide a solution to this.

Hollow concrete blocks have many fascinating features which make them more useful than conventional clay bricks. Because they are lighter in weight, they can be handled and worked easily and can be transported from one place to another at lesser expenses. These blocks are larger in size; therefore, there is lesser number of joints in masonry work with hollow concrete blocks. Masonry work with lesser number of joints provides more strength, good appearance, saving in the amount of mortar used and faster construction. With the use of hollow concrete blocks with interlocking system use of mortar can be completely eliminated. This interlocking system can also eliminate the use of formwork and will minimize the curing at site. The holes inside the body of blocks make them more thermal insulator than clay bricks. Better thermal insulation reduces the requirement of arrangements made for air conditioning and cooling, that means reduction in operational cost of building. For the similar reason hollow concrete blocks provide good sound insulation and facilitate lesser extra arrangement for sound insulation. In areas where good quality of clay is not easily available for the manufacturing of clay bricks, hollow concrete blocks seem to be a very useful alternative.

During the process of burning of bricks harmful gases get released in surrounding environment which cause hazardous to worker’s health. On the other hand no harmful gases get released in the manufacturing of hollow concrete blocks. But at the same time this should not be forgot that cement is an ingredient for the concrete mix used for hollow concrete blocks, and a huge amount of harmful gases are emitted during the manufacturing process of cement. Hence attempt should be made to minimize the cement content in concrete mix. To achieve this goal some supplementary cementitious materials should be used. Some waste materials can also be used to reduce the amount of cement, sand and aggregates. There is a further reduction in the use of cement because hollow concrete blocks require lesser mortar joints and plastering can be completely avoided.

1.3 PRODUCTION OF KOTA STONE WASTE

Kota stone is produced in Kota and Jhalawar districts of Rajasthan. Its depositions also found in Ajmer, Sawai-Madhopur, Udaipur and Banswara districts of Rajasthan. According to Director of

Mines and Geology, Rajasthan, production of Kota stone was approximately, 28, 68,557 tons in 2005. Its production is continuously increasing day by day. In the process of production of Kota stone various forms of waste is generated such as Kota stone chips, Kota stone slurry, Kota stone dust, cutting and dressing waste, etc. Kota stone slurry is produced in cutting and polishing processes.

1.4 HAZARDOUS DUE TO KOTA STONE WASTE

Industrialization and urbanization are considered symbols of growth as they bring prosperity to a nation, but they are greatly responsible for degradation of human health and environment. The surge in Industrialization and urbanization has largely contributed to the piles and loads of all sorts of solid waste. Almost all types of industrial waste are harmful to the environment as well as to human being.

As a common practice Kota stone slurry is generally dumped on the road side and low lying areas, which get washed and mixed with rainy water during rainy season and causes water pollution. It also causes soil pollution, air pollution leading to adverse effect on crop production and human health. Silicosis is a pneumoconiosis caused by inhalation of silica which is harmful to macrophages that ingest it and releases their enzymes. It is a serious and progressive disease caused by Kota stone waste. Extrinsic allergic, caused by Kota stone dust tends to affect the respiratory units and may have flu like symptoms. In addition, it causes irritation to skin, throat and respiratory tract (coughing and sneezing).

1.5 OBJECTIVES OF THIS STUDY

In this era of science and technology computer added analysis have become very popular in the field of structural engineering. Finite element analysis is a very powerful tool for the solution of complex engineering problems. There are various computer programs available which are based on FEM analysis. Abaqus/CAE has been used in this project for the simulation of laboratory axial compressive strength test of hollow concrete blocks. This report proposes the use of hollow concrete blocks as a replacement to conventional clay bricks. The use of Kota stone waste has been proposed as an ingredient for the manufacturing of hollow concrete blocks. If a waste product can be converted into some value added products then, the problem of shortage of natural resources can also be solved. By looking at the advantages of hollow concrete blocks, it can be said that it has great future potential in construction industry. The proposed model has been calibrated with the experimental test results and the simulation results have been found in good agreement with the experimental results. Hence, the main objective of this M.Tech. thesis is to propose a finite element model of highly sustainable product, Hollow Concrete Blocks. This project encourages the support for the use of waste from stone industry in construction industry.

1.6 SCOPE OF THIS STUDY

Computer analyses are very suitable for today’s world where technology is in such an advance phase. There are numbers of analysis software packages available which can provide fairly good analysis of a prototype and can give results with a reasonable accuracy. The computer analysis can save a lot of time which is wasted in set up of experimental tests and a lot of money which is wasted in those establishments. There is a future scope of research in computer analysis to correctly predict the highly non-linear behaviour of concrete structures with the higher degree of reliability.

Hollow concrete blocks as a masonry unit is being widely used in USA and many European countries, but it has a lesser access in Indian construction industry. Its use is increasing day by day. The results of this study will pave a path for wider use of hollow concrete blocks in India. This study may also provide a profitable and environment friendly solution for Kota stone slurry. The use of Kota stone waste as a construction material will provide a wider field of further research. The use of waste Kota stone slurry powder in hollow concrete block generates further opportunities to study in the area of alternative uses for this waste. The proposed finite element model provides fairly good results and they differ from the experimental results within acceptable range. Further study can refine the model and the accuracy level of analysis can be increased. There are also opportunities to study the different factors that affect the total computational time in Abaqus software and try to reduce this time. Further study can give the solution to the problem of meshing of hollow concrete blocks.

CHAPTER – 2

LITERATURE REVIEW

The most challenging part of FEM analysis is to define the material characteristic behaviour. Concrete is a non-homogeneous mixture of hydrated cement paste, sand and coarse aggregates. The microstructure of concrete can be divided into three parts- hydrated cement paste, coarse aggregate and transition zone, (47). Transition zone is the interfacial zone between hydrated cement paste and coarse aggregates or in other words it is the part of hydrated cement paste located in the immediate vicinity of coarse aggregate particles. Transition zone typically has a higher water cement ratio than that of the entire hydrated cement paste and forms the weakest part of the concrete mixture (47). The initiation and propagation of cracks in the transition zone is the dominant phenomenon of concrete material response. A lot of research has been done to know how the cracks propagate when concrete is placed under loads.

Xiangting Su et al. [15] compared various models for crack propagation and also proposed a new approach for modelling of cracks. The cohesive elements with softening-traction separation relations and damage initiation and evolution laws were embedded between solid elements in regions of interest in the initial mesh to model potential cracks. The simulated crack propagation technique and load-displacement curves agreed well with test results.

Umit Cicekli et al. [16] developed a plastic damage constitutive model for plain concrete and. The constitutive relations were validated using the second law of Thermodynamics. They considered anisotropic damage evolution based on continuum damage mechanics. A detailed numerical algorithm was coded using the user subroutine Umat and then implemented in Abaqus.

Peter Grassl and Milan Jirasek [17] studied the local uniqueness conditions of two types of combinations of stress based plasticity and strain driven scalar damage. They presented a triaxial damage plastic model for the track the failure of concrete in which the plasticity part was based on the effective stress and the damage model was driven by the plastic strain. The model showed good agreement with the experimental results of a reinforced concrete column under eccentric compression.

Anis Mohamad Ali et al. [18] developed stress-strain relationship for concrete under uniaxial compression. They set up different experimental programmers were carried out on concrete specimens to evaluate the various parameters involved. They used curve fitting technique and developed two, three and fourth degree polynomial equation to predict the stress-strain behaviour of concrete. Third degree polynomial showed the best results which were in good agreement with experimental results.

Jansher Sadik et al. [19] developed a model of slab with a circular hole and compared the results with the experimental results. They also conducted parametric studies on plain and reinforced concrete slabs with different percentage of reinforcement. They concluded that the percentage of reinforcement and the location of reinforcement with respect to the slot play a significant role in the stress concentration factor.

Peter Grassl et al. [20] developed a constitutive model based on the combination of damage mechanics and plasticity to analysis the failure of concrete structures. Their model described that there is an increase in strength and displacement capacity with the increase in confinement levels. Their model was also able to predict realistically the transition from tensile to compressive failure and stress-inelastic strain relations with varying ratios of reversible and irreversible strain components.

Honggun Park and Jae-Yo Kim [21] proposed a plasticity model for concrete with multiple failure criteria. In that model, a stress was decomposed into one volumetric and two deviatoric stress components orthogonal to each other and an independent failure criterion was provided for each stress component.

Ali Ahmad [23] used damaged plasticity model and C3D8R elements for the modelling of a reinforced concrete beam. The results obtained by the model were in good agreement with the experimental results.

S. V. Chaudhari and M.A. Chakrabarti [24] compared the results obtained from the damaged plasticity model and smeared crack model for the concrete cube under axial compression. They used C3D8 element for concrete. They concluded that in the case of damaged plasticity model mesh size plays the important role. As the mesh size reduced the accuracy of results was increased. The smeared crack model was found suitable as it desired results at coarser mesh in comparison with damaged plasticity model.

W. I. Goh et al. [25] developed a model for the simulation of axial compressive strength test for foamed concrete and studied the load-displacement curve and crack propagation in concrete. The model was validated by using experimental results. They used Damaged plasticity model to define plasticity of concrete and assigned C3D8R elements for meshing the model. A mesh refining study was performed to get the most suitable number of elements to get accurate results. They got exactly same ultimate compressive strength from experimental as well as from numerical analysis. The stress-strain curve obtained from finite element modelling followed the similar path to that of from experimental observations.

Miss Vindhyashree and Dr. Prema Kumar W. P. [26] simulated the compressive strength test for concrete block masonry prism. There were five concrete blocks placed one above the other and jointed by mortar joints. A uniform pressure was applied on the top surface of prism and the bottom surface was assigned fixed boundary condition. They used C3D8R elements for concrete blocks. The results showed that the percentage difference between the compressive sterngths obtained from experimental observation and that of from numerical analysis was 13.37%.

Lime stones are the natural rocks of sedimentary origin and their primary constitute is calcium carbonate. Lime stones are generally made from the calcareous remains of marine or fresh water organisms embedded in calcareous mud. The action of lime fillers is physical; hence, they have to be physically compatible with the cement in which they are mixed. At higher filler content, the cement must have a much higher fineness than usual [7]. It was first thought that the finely divided lime stone contributes to strength strictly through the filler effect. Now it is revealed that it can react with the alumina phases of cement to form tricalcium carboaluminates analogous to etringite and its monosulphate form which would account for the increase in sulphate resistance of the cement [14]. . The introduction of lime stone in Portland cement improves the early and later age compressive strength [10, 11]. Finally divided lime provides a filler effect and contributes to compressive strength in addition to this it can provide pozzolanic action also [14].
The use of lime stone powder in cement and concrete is of great advantage both for economic and environmental considerations. By reducing Portland cement production CO_2 emissions will

get reduced that will be a great relief for environment. The use of Portland cement containing lime stone as filler has become a common practice in Europe, especially in France.

After analyzing the previous studies it can be said that hollow concrete blocks may provide an energy efficient substitute for conventional clay bricks which has proven to be highly unsustainable. Although; in many cases compressive strength of hollow concrete blocks is rather lesser than that of conventional clay bricks, but they are capable of to fulfill the criteria specified for masonry structures. With the proper quality control hollow blocks of strength higher than clay bricks can be manufactured. They are widely being used as non-load bearing members in infill panels. But many studies show that they can safely be used as load bearing member as well. Hence, the properties of hollow concrete blocks such as lighter in weight, good thermal insulation, good sound insulation, good appearance, faster construction, lesser joints, etc. make them suitable for economical and sustainable construction.

CHAPTER – 3

EXPRIMENTAL OBSERVATIONS

3.1 CHARACTERIZATION OF KOTA STONE WASTE

Kota stone is basically a lime stone, calcareous rocks of sedimentary nature. It is very tough, non-water absorbent and non-porous stone. Physical properties and chemical properties of Kota stone are given in the following tables.

TABLE – 3.1

(Physical properties of Kota stone)[49]

Physical property	Value
Compressive strength	21 to 22 kg/mm^2
Abrasion value	18.12
Water absorption	0.31 to 0.32%
Oil absorption	Nil
Density	2.5 to 2.65 kg/mm^3

TABLE – 3.2

(Chemical properties of Kota stone)[49]

Name of the chemical	Percentage
Lime	38 to 42 %
Silica	20 to 25%
Alumina	2 to 4 %
Other oxide of Mg, Na etc.	1.5 to 2.5 %
Loss on ignition	30 to 32 %

Kota stone slurry has bulk specific gravity of 2.73 and fineness of 275 mm^2 per kg which is in order of fineness of cement.

3.2 MIX DESIGN

Cement, CRF, Kota stone slurry, aggregates and water will be used as constituents of hollow concrete blocks. The proportion of various ingredients will be decided based on some previous studies on hollow concrete blocks, some guidelines by various organizations. There are some correlations between the strength of concrete and strength of hollow concrete blocks. Based on these all, trial mixes were designed for casting of hollow concrete blocks and an optimum mix had chosen with desired properties. The mix proportion for hollow concrete blocks was decided by performing various trials based on NTPC guidelines of fly-ash bricks and Loknath fly ash brick guidelines. Based on these trial results proportions for various ingredients were decided.

3.3 TESTING

The compressive strength of hollow concrete blocks was tested according to the provision of IS 2185 (Part 1):2005. Three samples were tested in universal testing machine under axial compression. To distribute the applied load uniformly two steel plates were placed at upper and bottom faces of blocks.

CHAPTER – 4

FINITE ELEMENT MODELLING

4.1 CHARACTERISTIC BEHAVIOUR OF CONCRETE

The most important part of finite element modelling is to model the material. The accuracy of results largely depends on the properties i.e. material definitions. It is not simple to predict the behaviour of a material like concrete which is both non-homogeneous and anisotropic. The inherent non-linearity and brittleness further make this task more challenging. The distinct behaviour of concrete under compressive and tensile loading also increase the complexity of the constitutive modelling of concrete. For nonlinear analysis of concrete various material models have been developed such as plasticity model, damage model, damage-plasticity model, microplane models etc. In Abaqus, there are three material models to predict the non-linear behaviour of concrete; first is Damaged Plasticity Model, second is Smeared Crack Model and third is Brittle Cracking Model. First two are available in both Abaqus Standard and Abaqus Explicit but the third is available in Abaqus Explicit only. However, these models are simplification of very complex stress-strain response of concrete still they are of represent the main features of stress-strain response of concrete.

4.1.1 STRAIN SOFTENING

Typical failure mode of concrete are crushing in compression and cracking in tension. The failure pattern is characterized by irreversible deformations and degradation of the stiffness which leads decrease in stress under increasing strain for concrete in tension and unconfined or low confined compression. This decrease in stress with increasing strain is known as strain softening. In unconfined or low confined concrete, softening is accompanied by extensive inelastic volumetric expansion. The stiffness degradation and the inelastic volume expansion are significantly get reduced in highly confined concrete.

4.1.2 TENSION STIFFENING

Cracking is considered as the failure pattern in tensile loading. After the occurrence of first crack concrete does not lose its load carrying capacity in total, there is Tension stiffening is a phenomenon used to represent strain softening under tensile behaviour. This can be defined by means of the post failure stress-strain relation or by fracture energy cracking criteria. Generally, more tensioning provides easier solution particularly in case of Abaqus/Standard. If tension stiffening is very less, then it will cause local cracking failure in concrete and will introduce temporarily behaviour in overall response of model. Tensioning stiffening depends on – density of reinforcement, the quality of bond between rebar and concrete, relative size of concrete aggregate compared to the rebar diameter and mesh[53].

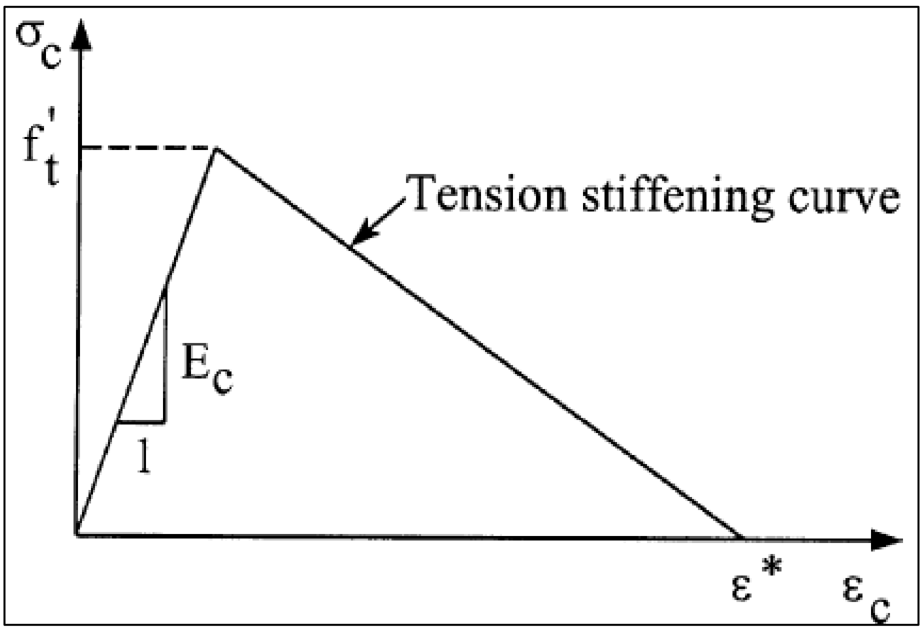

Fig. – 4.1 Tension stiffening curve (Abaqus manual)

4.1.3 STRESS – STRAIN BEHAVIOUR IN TENSON

Under uniaxial tension the stress – strain relationship is linear up to the failure strain till the failure strain $\sigma_{to,}$ is reached at which the first crack forms. After the initiation of cracking stiffness of material starts to decrease; this phenomena is represented by the softening stress-strain response.

4.1.4 STRESS – STRAIN BEHAVIOUR IN COMPRESSION

Under the uniaxial compression the stress – strain behaviour is linear up to the yield stress σ_{co}. After that plastic regime starts; this region is characterized by strain hardening followed by strain softening after the ultimate stress σ_{cu}.

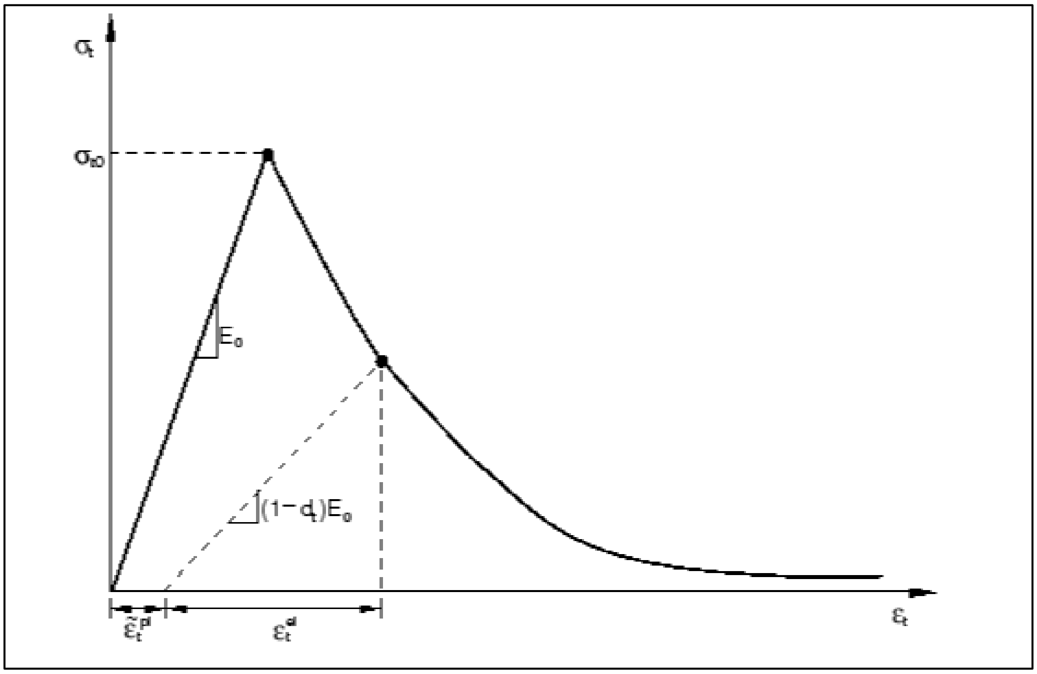

Figure – 4.2 Stress-strain response under uniaxial tension (Abaqus manual)

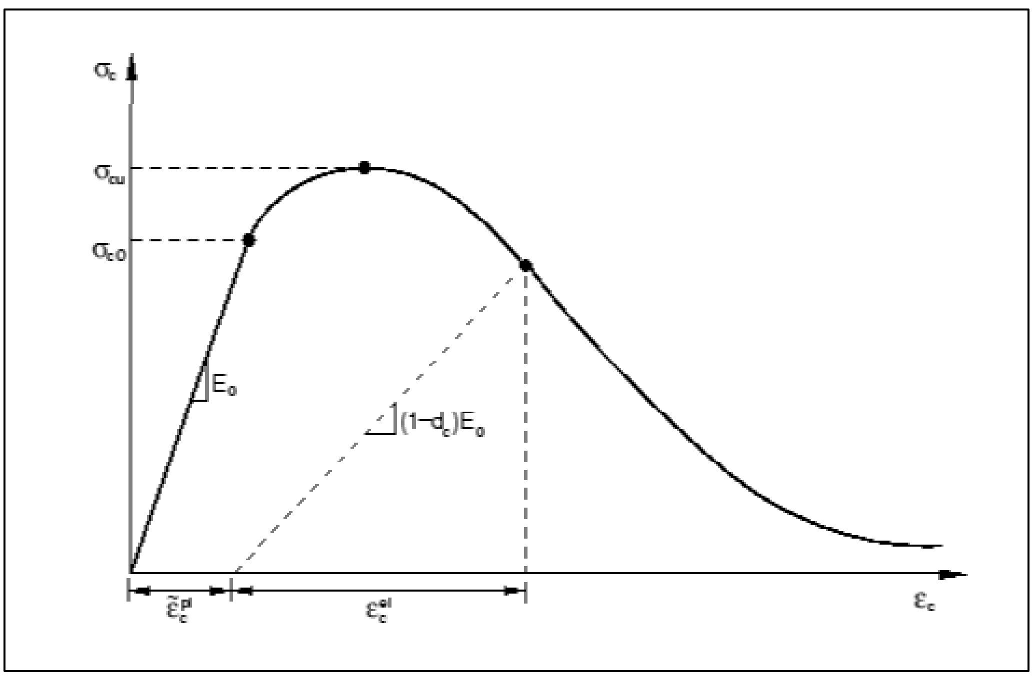

Fig. – 4.3 Stress-strain response under uniaxial compression (Abaqus manual)

4.2 DAMAGED PLASTICITY MODEL

This model uses concepts of isotropic damaged elasticity in combination with isotropic tensile and compressive plasticity. This model can be used for concrete and other quasi-brittle materials. Initially, it was developed for reinforced concrete but it can be used for plain concrete also. It can be used for monotonic, cyclic and dynamic loading under low confining pressure. In this model two main failure patterns are cracking in tension and crushing in compression [53]. This model assumes that elastic modulus of concrete is decreased by the following linear relation-

$$\mathrm{E} = (1 - \mathrm{d})\mathrm{E}_0$$

Where E_0 is the initial elastic modulus of concrete and d is known as stiffness degradation variable. The stiffness degradation variable is a function of stress and uniaxial damage variables d_t and $d_{c.}$ For the uniaxial cyclic condition Abaqus assumes the following relation among d, d_t and d_c.

$$(1 - \mathrm{d}) = (1 - \mathrm{sdt}\,)(1 - \mathrm{sdc})$$

Where s_t, s_c are the functions of the stress state that are introduced to model stiffness recovery effects associated with stress reversals. The degradation of elastic stiffness is represented by two damage variables, d_t and d_c, where subscript t and c represent tension and compression, respectively. The damage variables can take any values from zero, corresponding to undamaged material, to one, corresponding to total loss of stiffness.

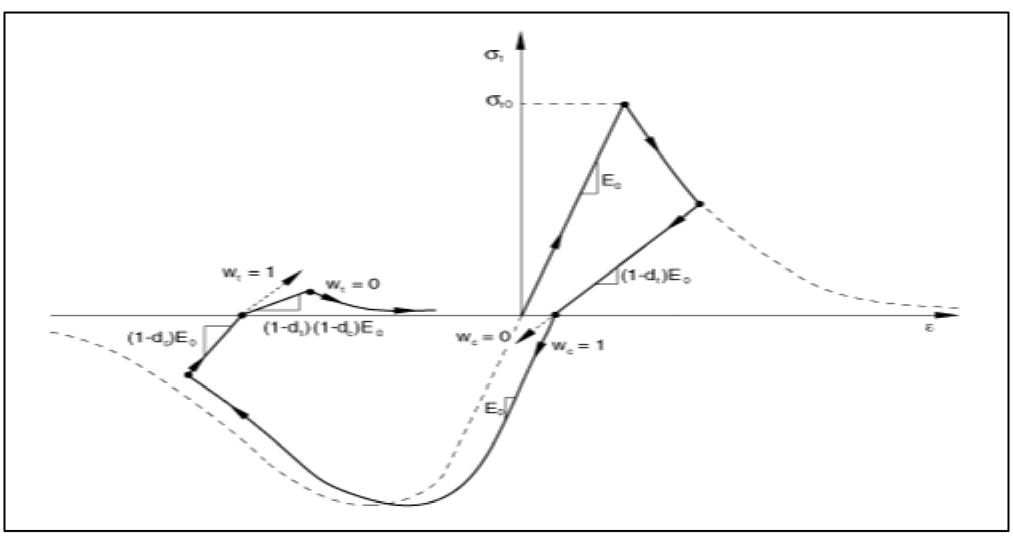

Figure – 4.4 Concrete damaged plasticity modified stress-strain curve (Abaqus manual)

In this model stress-strain behaviour of any material is introduced in terms of values of yield stress and inelastic strain in case of compression and yield stress and cracking strain in case of

tension behaviour. Abaqus convert the inelastic strain ($\tilde{\varepsilon}_c^{in}$) into plastic strain ($\tilde{\varepsilon}_c^{pl}$), automatically by using the following relation given in [53] –

$$\tilde{\varepsilon}_c^{pl} = \tilde{\varepsilon}_c^{in} - \frac{d_c}{(1-d_c)}\frac{\sigma_c}{E_0}.$$

Similarly, the cracking strain ($\tilde{\varepsilon}_t^{ck}$) is converted into tensile plastic strain ($\tilde{\varepsilon}_t^{pl}$) in case of tensile behaviour by using the following relation [53] –

$$\tilde{\varepsilon}_t^{pl} = \tilde{\varepsilon}_t^{ck} - \frac{d_t}{(1-d_t)}\frac{\sigma_t}{E_0}.$$

4.3 GEOMETRY OF MODEL

Hollow concrete blocks are manufactured in plants in various sizes. As per the guidelines of IS: 2185 (part 1) the nominal dimensions of concrete blocks should be as follows:-

Length: 400 mm, 500 mm or 600 mm

Height: 200 mm or 100 mm

Width : 50 mm, 75 mm, 100 mm, 150 mm, 200 mm, 250 mm or 300 mm

The most common used size is 400 mm x 200 mm x 100mm in India. In this project also this most common used size was used for the model. Hollow blocks may contain one, two and more number of holes. Hollow concrete blocks with two holes are the most common; hence in this project also hollow concrete blocks with two holes were used.

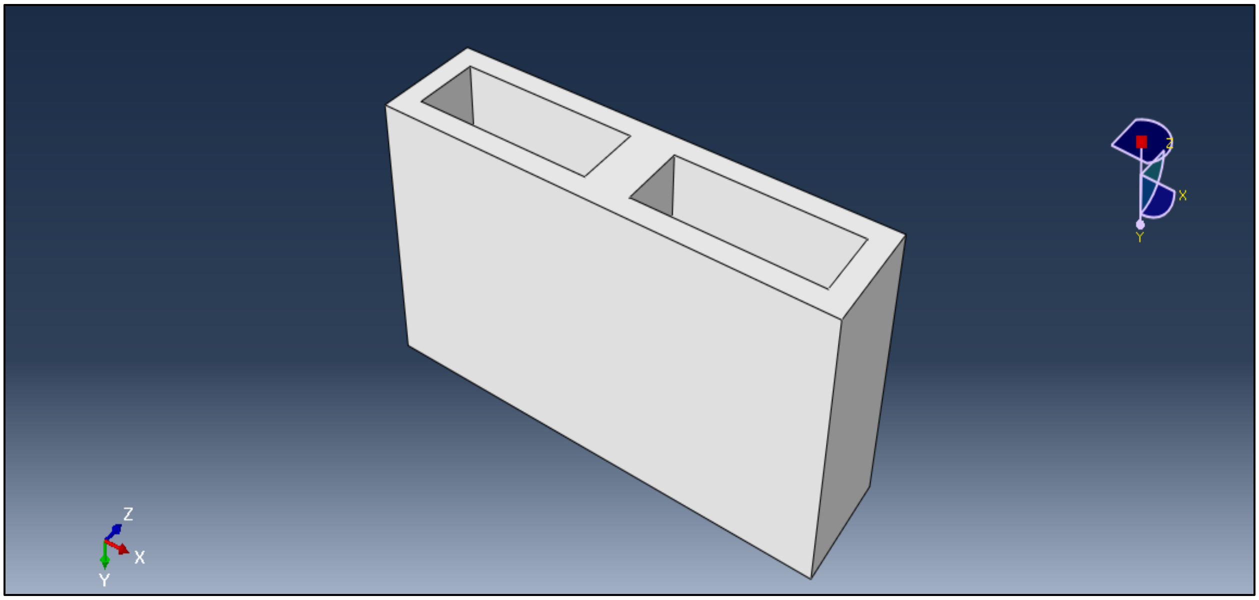

Figure – 4.6 Geometry of the model

4.4 MATERIAL PROPERTIES

For the elastic region of characteristic curve of concrete “Elastic” option has been used from Abaqus’s material library. To define the elasticity only two parameters are required - Elastic modulus of concrete and Poisson’s ratio. Value of Elastic modulus has been taken as per the formula given in IS 456: 2000.

$$E = 5000\sqrt{fck}\ N/mm2$$

Where, f_{ck} is the characteristic strength of concrete in N/mm^2.

Most literature suggests that value of Poisson’s ratio of concrete lies between 0.15 and 0.20 [47]. For this project a value of 0.15 has been selected for concrete. To define the plasticity, Damaged plasticity model has been adopted for concrete. There are various parameters which are required to capture the constitutive behaviour of concrete. These parameters include damage parameter in compression (d_c), damage parameter in tension (d_t), dilation angle (ψ), flow potential eccentricity (m), initial uniaxial/biaxial ratio (σ_{co}/σ_{bo}), the ratio of second stress invariant on the tensile meridian (K_c) and viscosity parameter (ν). The initial values for these parameters were assigned based on several reported studies. The correctness of the model was checked by comparing the results with the experimental data. For this, at first the material properties were applied on the model of concrete cube model and when the correct material properties were obtained the model was expanded to study the axial compressive behaviour of concrete hollow blocks. Following are the values of various parameters for material definition used in this project-

TABLE – 4.1

(Constitutive parameters for damaged plasticity model for concrete)

Dilation angle	Eccentricity	f_{co}/f_{bo}	K	Viscosity
28°	0.1	1.16	0.667	0

TABLE – 4.2

(Characteristic stress-strain values for concrete in axial compression)

Compressive stress (σ)	Inelastic strain	Damage parameter in compression (d_c)
2.56	0	0
3.12	0.0000056	0
4.56	0.0000098	0
5.87	0.000045	0
6.12	0.000088	0
5.58	0.00012	0.05
4.34	0.00078	0.156
3.09	0.0021	0.357
2.44	0.008	0.676

TABLE – 4.3

(Characteristic stress-strain values for concrete in axial tension)

Tensile Stress	Cracking Strain	Damage Parameter in Tension (d_t)
0.789	0	0
1.050	0.0000034	0
1.890	0.0000077	0
0.756	0.000067	0.089
0.616	0.00011	0.225
0.445	0.00078	0.525
0.256	0.0022	0.77
0.057	0.0046	0.921

4.5 LOADING

The axial compressive test can be simulated by force loading as well as displacement loading. In this report both these methods were used for a concrete cube to know which one is better. This approach is used to calibrate the model with experimental results and then better one of both was used for Hollow concrete blocks. For force loading uniform pressure were applied at the upper face of the concrete cube. In the case of displacement loading a displacement was applied in the negative Y-direction.

After analyzing both types of loading it was seen that the axial compressive test can be better simulated by applying displacement. Hence, to develop the model for hollow concrete block displacement loading has been applied. Displacement was increased step by step at a constant rate.

4.6 BOUNDARY CONDITIONS

To simulate the laboratory experiment boundary conditions were assigned to the model. At the bottom face fixed boundary condition were applied. All the six degrees of freedom were restrained at this face, for this “Encaster” boundary were selected from Abaqus library. As earlier said, a displacement was provided at the top face to simulate the displacement loading. All the degrees of freedom except in Y-direction were restrained at the top face of model. The value of displacement was increased in every successive step until failure has occurred.

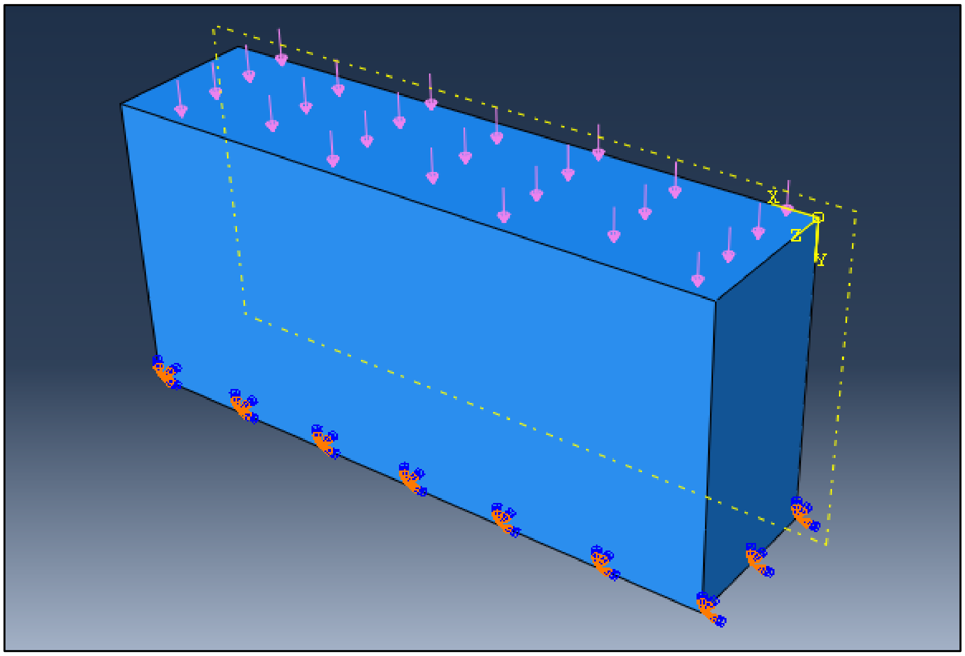

Fig. – 4.7 Force loading

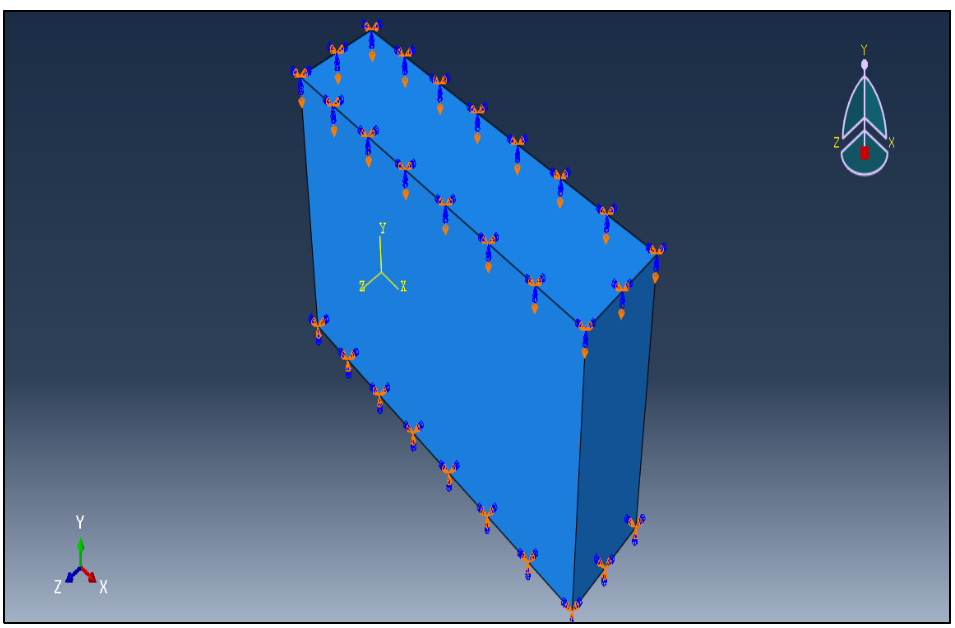

Fig. – 4.8 Boundary conditions at top face

4.7 MESHING

The finite element meshing is used to subdivide the entire model into small domain, known as elements over which a set of equations solved. The accuracy of Finite Element modelling depends on the accuracy of meshing. Meshing of simple and regular geometries is an easy task in Abaqus, but for complex and irregular shapes it becomes tougher. Because of holes in the concrete blocks its direct meshing is not possible with hexagonal elements. Partition and bottom up mesh technique has been adopted to mesh the model with hexagonal elements. To check how much time can be saved if meshing would have been done without partition and bottom up mesh, tetrahedron elements also were used, because automatic meshing was possible with these elements. This made the modelling procedure faster and simpler and provided a uniform mesh.

A mesh refining study has also been performed with both types of elements. Starting with coarser mesh, mesh size was continuously reduced until there was negligible difference in the results of successive mesh sizes. In mesh refining study, an attention was paid on the total time taken in the analysis.

4.8 ELEMENT TYPES

Abaqus provides a wide variety of elements for the analysis of different types of problems. The selection of element type requires some basic knowledge of Finite Element Analysis. Abqus uses numerical techniques to integrate various quantities over the volume of each element, thus allowing complete generality in material behaviour. It uses Gaussian quadrature for most elements to evaluate the material response at each integration point in each element. Some continuum elements can choose to use full or reduced integration and it can have a significant effect on the accuracy of the element for a given problem (Abaqus user's manual). Quadrilateral and hexahedra elements are the most suitable for general analysis problems but these elements are geometrically less versatile and cannot be used for complicated geometrical shapes. To use these elements for complicated shapes advanced meshing technologies such as Partition, Bottom-up mesh technique have to be applied. There may be a requirement to change the meshing algorithm with hexagonal mesh in complicated geometries. This requires extra time and makes the modelling procedure more complex. On the other hand, tetrahedron elements can be used with complex geometries and automatic meshing is possible almost in all cases. In this project two different types of elements i.e., hexagonal and tetrahedron elements were used to know the effect of element type in meshing. As, previously said it was not possible to mesh the model with hexagonal elements automatically, hence with these elements partition techniques were used to get uniform mesh. After several trials the most suitable partition strategy was applied to the model. According to Abaqus library, the C3D8R element which is a 3D 8-node linear brick element with reduced integration was used. C3D8R elements were selected based on the previous research studies.

While meshing with tetrahedron elements automatic meshing was possible, hence no modification was done in the model. According to Abaqus library, the C3D10 element which is 3D, 10 node Quadratic tetrahedron element was assigned to the model. These elements take more time in analysis than the C3D8R elements. This happens because C3D8R is a reduced element and uses reduced integration methodology while C3D10 uses full integration at each integration point at each element, hence C3D8R performs faster calculation. An attempt was made to compensate this increased analysis time with the time saved in modelling process because of uniform and automatic meshing was possible in this case.

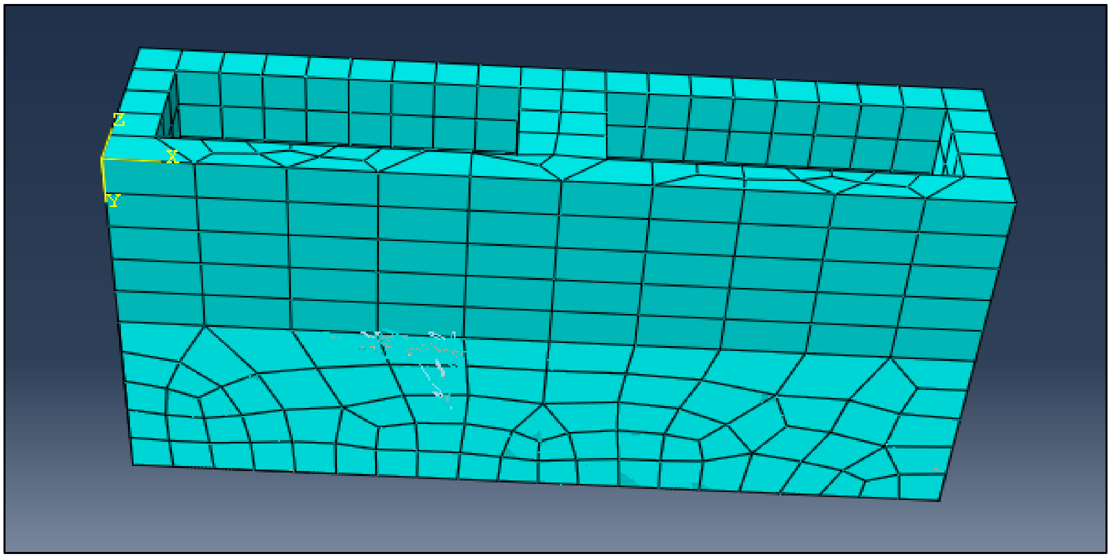

Figure – 4.9 Meshing with hexagonal element

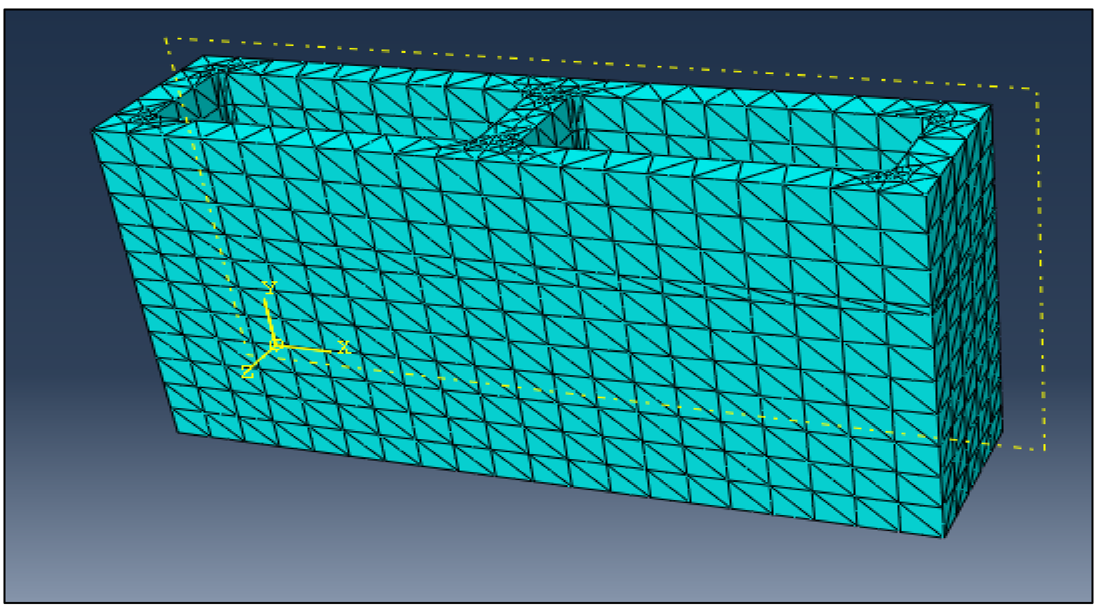

Figure – 4.10 Meshing with tetrahedron elements

CHAPTER – 5

COPMARISION BETWEEN EXPERIMENTAL AND ANALYTICAL RESULTS

5.1 EXPERIMENTAL RESULTS

The results obtained from the numerical simulation were compared with the results obtained from experimental studies. The results obtained from experiments of three samples of hollow concrete blocks are as follow as-

Table – 5.1

(Experimental results)

Number of specimen	Surface area (in mm^2)	Maximum load (in KN)	Strength (in N/mm^2)
1	40000	190.00	4.75
2	40000	200.89	5.02
3	40000	203.61	5.09

The average compressive strength of the three samples was 4.95 N/mm^2, which is comparable to the commercially available hollow concrete blocks. Hence, the Kota stone waste can be used as an ingredient in hollow concrete blocks. The results obtained from numerical model vary with element type and number of elements. The model with hexagonal elements and mesh size 5 mm give the strength of hollow blocks as 4.9 N/mm^2, which is closest to the experimental value. Hence, ultimate loads obtained from hexagonal mesh were higher than the experimental results up to the mesh size of 10 mm, for lower sizes of mesh those were lower than the experimental results. The closest result at the higher side was obtained from the model with the tetrahedron elements and 10 mm size of mesh, the value of which is 5.05 N/mm^2. Numerical models with tetrahedron mesh provided higher ultimate load for all sizes of mesh.

5.2 MESH REFINING STUDY

To study the effect of different element types, two types of elements were selected which are most suitable for this analysis- hexagonal and tetrahedron elements. Mesh refining study was performed to get the results as accurate as possible. Different mesh sizes ranging from 2.5 mm to 40 mm were tried for both types of elements. With the increase in number of elements or decrease in the mesh size, the gap between the experimental and numerical results decreases in both the cases, but this difference is lesser in case of hexagonal mesh for corresponding mesh sizes. In both the cases the values of ultimate load obtained from 5 mm and 2.5 mm mesh sizes were exactly same; hence further reduction in mesh sizes was not recommended. Table 5.2 shows the results of hexagonal shape elements with varying number of elements. Similarly, the results of tetrahedron shape elements have been shown in Table 5.3.

In numerical analyses, the computing time also plays a significant role; hence trials have been made to get balance between the accuracy and total time taken in the analysis. With increase of number of elements, there is an increase in computing time. The percentage increase in time between successive mesh sizes increased with the decrease in mesh sizes. This increase in time was more with the tetrahedron elements. As earlier said that there was saving in time in meshing with tetrahedron elements, hence for 40 mm and 30 mm mesh sizes the total time in the analysis was comparable for both type of elements. With finer meshes tetrahedron elements took more time than hexagonal elements and the differences between these two got increased with reduction in mesh sizes.

Table -5.2

(Comparison between experimental and analytical results with hexagonal meshing)

Mesh size	Experimental results (in KN)	Analytical results (in KN)	Percentage difference from experimental results
40 mm	198.12	234.857	18.543
35 mm	198.12	228.733	15.452
30 mm	198.12	216.630	9.345
25 mm	198.12	209.528	5.758
20 mm	198.12	206.306	4.132
15 mm	198.12	204.967	3.456
10 mm	198.12	202.546	2.234
5 mm	198.12	196.03	-1.055
2.5 mm	198.12	196.03	-1.055

Table – 5.3

(Comparison between experimental results and analytical results with tetrahedron meshing)

Mesh size	Experimental results (in KN)	Analytical results (in KN)	Percentage Difference from Experimental Results
40 mm	198.12	238.86	20.567
35 mm	198.12	231.18	16.687
30 mm	198.12	218.10	10.087
25 mm	198.12	215.693	8.870
20 mm	198.12	207.168	4.567
15 mm	198.12	204.313	3.126
10 mm	198.12	202.106	2.012
5.0 mm	198.12	202.106	2.012
2.5 mm	198.12	202.106	2.012

In both the cases there is no difference in the maximum load when mesh size decreased from 10 mm to 2.5 mm, however there is tremendous increase in the computing. The time taken in analysis with the tetrahedron elements is higher than that of hexagonal elements in all the cases. However, this increase in time can be compensated by the time saved in meshing. Because of the complicated shapes of hollow blocks, meshing with hexagonal elements require extra time in partition, bottom up meshing and seeding definition. But this saving in time is effective only up to mesh size 25 mm, after that there is tremendous increase in computing time in case of tetrahedron elements.

5.3 LOAD-DISPLACEMENT CURVE

If we consider the values of maximum load then, accuracy level is higher with hexagonal elements for the respective mesh sizes. On the other hand if we talk about the load-displacement curve, then tetrahedron elements give better results. The load-displacement curves obtained from the numerical model with tetrahedron elements exactly follow the experimental load-displacement curve. The model with 10 mm element size exactly follows the experimental Load-displacement curve. At the lower displacements all the models give the almost same results, as the displacement increases the load- displacement curve obtained from the numerical analysis start to get deflect from the experimental Load – displacement curve.

In case of hexagonal elements also the Load - displacement curve follows the path of experimental curve. Unlike the tetrahedron elements, hexagonal elements give delayed peak, i.e. maximum load occur at higher displacements except the models with element size 35 mm and 40 mm. This delay in maximum load decreases with the increase in mesh size, even the models with 35 mm and 40 mm size give maximum load at lower displacements. In this case, models with higher element size gives better results in comparison to models with lower mesh size. The model with mesh size 25 mm can be selected which give load – displacement curve somewhat similar to the experimental load – displacement curve and the difference between the maximum loads is only 5.758%, which can be accepted with the reasonable accuracy.

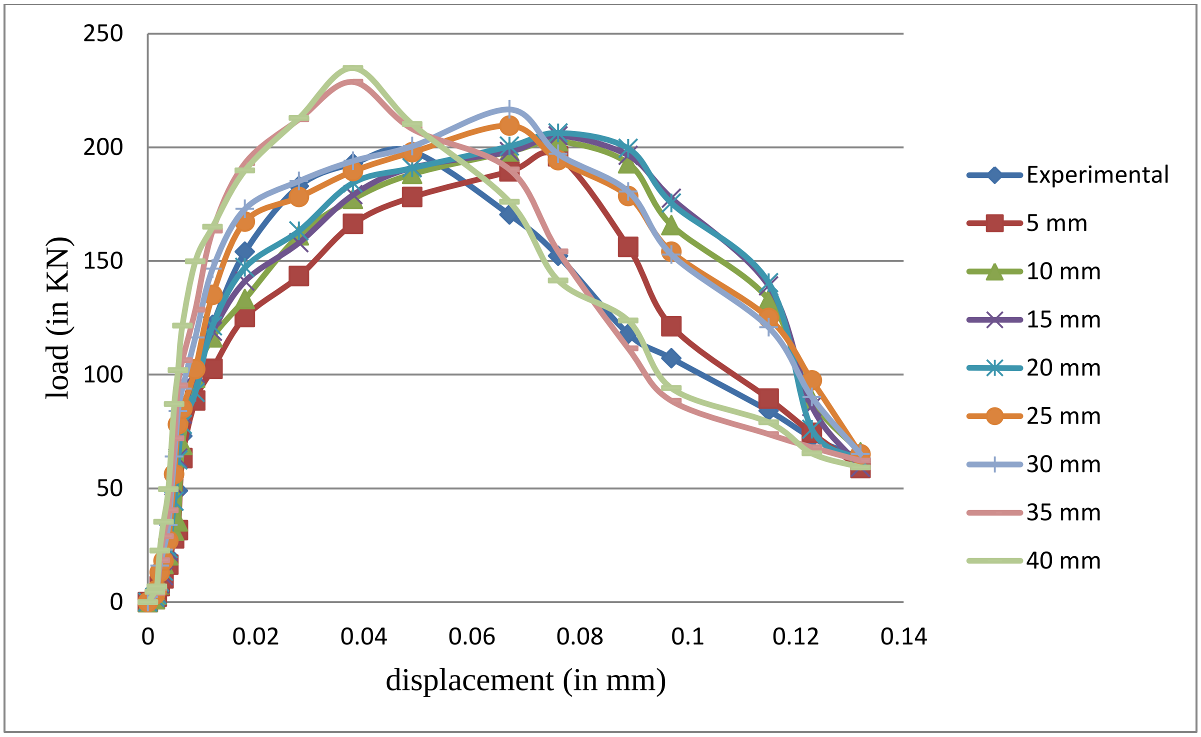

Fig. – 5.1 Load-displacement curve for hexagonal elements

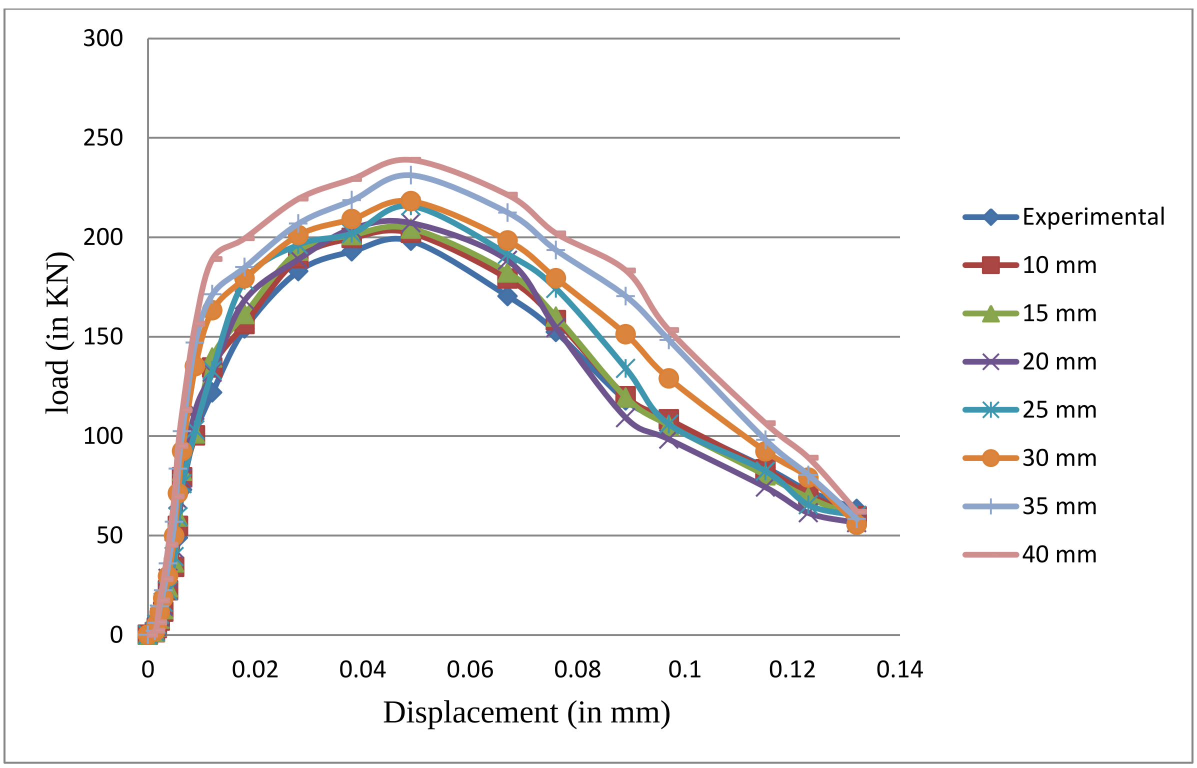

Fig. – 5.2 Load – displacement curve for tetrahedron elements

5.4 STRESS DISTRIBUTION IN THE BODY OF HOLLOW BLOCKS

Although there were differences among the stress values for different mesh conditions, yet the stress distribution was exactly same for all of them. The stress value found to be the maximum at all the four corners of blocks. It means crack will appear at the corner first and will propagate throughout the height of block. After that the crack propagation will move towards the center of the block.

In the experimental testing also crack appear at the corner. Although, according to numerical simulation, all the four corners are equally liable to crack and crack occur simultaneously at all of them. In experimental testing, sometimes crack occur at only one corner and material get failed. This may happen due to imperfection of the test specimen, uneven surface, uneven pressure distribution, etc.

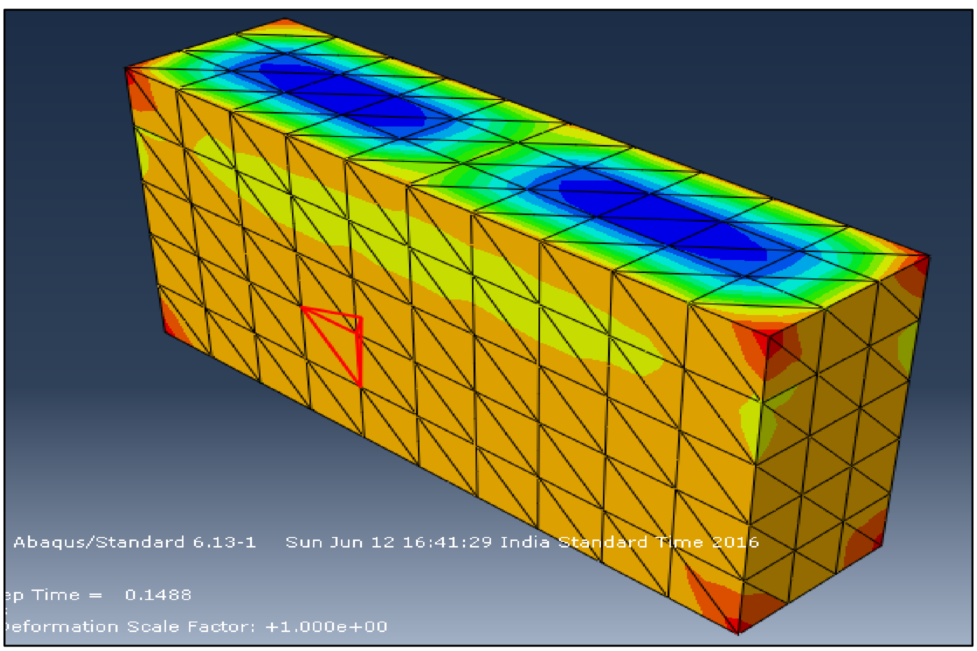

Fig. – 5.3 Stress distribution at the surface of hollow concrete block obtained from finite element analysis

CHAPTER – 6
CONCLUSIONS

The purpose of this dissertation was to study the various facts about the modelling of concrete and to propose a numerical model for the hollow concrete blocks. To raise the issue of sustainable construction Kota stone waste has been used to make the hollow concrete blocks. The following conclusions were made after this study –

- Damage plasticity model can predict the behaviour of plain concrete with a reasonable accuracy. But for crack propagation study one should adopt smeared cracked model.
- There is no requirement of applying rigid bodies on the upper and bottom surfaces of hollow concrete blocks, direct loads can be applied. This simplifies the modelling process and results with acceptable accuracy can be obtained.
- The percentage difference between the values of compressive strength was least with the hexagonal elements. The error can be reduced up to -1.055% with mesh refining study. Models with coarser mesh give the earlier peak and those with finer mesh give the delayed peak.
- Tetrahedron elements can also give fairly accurate results for compressive strength and the minimum error was 2.012%. The load-displacement curve obtained from these elements followed the experimental load-displacement curve more accurately.
- With tetrahedron elements there is overestimation of strength with all sizes of mesh, whereas hexagonal mesh with mesh size 5 mm and 2.5 mm gives results on the conservative side.
- As mesh changed from coarse to finer, the accuracy of results increased but at the cost of computational time.
- In both the cases, 10 mm mesh size can be adopted for a reasonable level of accuracy. Because computational time increases at very high rate when mesh size is less than 10mm. Therefore, if very high level of accuracy is not required, 10 mm mesh size can be used.

- If accurate value of ultimate load is the most controlling factor in analysis, then hexagonal meshing is the best option. It gives accurate results on conservative side with lesser computational time.
- Hollow blocks obtained from Kota stone waste give the compressive strength of 4.95N/mm^2, which is comparable to the compressive strength of commercially available hollow concrete blocks in market; hence they can be used at least as non-load bearing members.

Therefore, it can be concluded that the proposed model works quite well and the differences between the experimental and finite element results are within the expectable limits. Further studies are required to reduce the computational time. With the 2.5 mm mesh size total computational time was 8 and 10 hours with hexagonal and tetrahedron elements, respectively. Further research is required to reduce this computational time and this can be done by the simplification of model. In the modelling of hollow concrete blocks, meshing is very critical, because of two holes in the geometry, hence, there should be some mechanism for the simplification of meshing process.

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