ADVANCED COMPOSITE MATERIAL FOR EARTHQUAKE RESISTANT URM BUILDING

A DISSERTATION

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

of

MASTER OF TECHNOLOGY

in

DISASTER MITIGATION AND MANAGEMENT

By

DIPALI JINDAL

CENTRE OF EXCELLENCE IN DISASTER MITIGATION AND MANAGEMENT
INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
ROORKEE-247 667 (INDIA)

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CANDIDATE DECLARATION

I hereby certify that the work that is being presented in this DISSERTATION **REPORT**, Entitled- **Advanced composite material for Earthquake Resistant URM Building** in partial fulfillment of the requirements for the award of the Master of Technology in Disaster Mitigation & Management & degree, submitted to the Department of Center of Excellence in Disaster Mitigation & Management of the Indian Institute of Technology Roorkee, India, is an authentic record of my work carried out till month of June, 2014, under the guidance of Dr. Inderdeep Singh, Associate Professor , Department of Mechanical & Industrial Engineering, IIT Roorkee.

The matter embodied in this has not been submitted for the award of any other degree.

Place: Roorkee

Date: June , 2014

Dipali Jindal

Enrollment No. **12552005**

CERTIFICATE

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

15/6/14

Dr. Inderdeep Singh

Associate Professor

Department of Mechanical & Industrial Engineering

Indian Institute of Technology Roorkee

Roorkee, Uttarakhand

India- 247667

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DIPALI JINDAL

ENROLLMENT NO: 12552005

M.TECH:2nd YEAR

COEDMM, IIT ROORKEE

ABSTRACT

Buildings made of "masonry structural system" remain one of the most vulnerable classes of structures, because of the easy availability of materials for this type of construction, this kind of construction is employed in the rural, urban and hilly regions up to its optimum, since it's flexible enough to accommodate itself accordingly to the prevailing environmental conditions. Though this type of construction is mostly preferred and most frequently employed also, yet it is not completely perfect in regard to seismic efficiency. Thus this is treated as non-engineered construction and most casualties are due to the collapse of these constructions in earthquake. The aim of present work is a step towards with regard to illustrate a procedure for retrofitting of a seismic band using GFRP (glass fiber reinforced polymer) in URM brick masonry building & results are analytically using (ABAQUS software).

AS per many studies its being known, unreinforced masonry structures are the most vulnerable during an earthquake. Since masonry has adequate compressive strength, implies, they are designed for vertical loads, the structures behave well as long as the loads are vertical. When such type of structure is subjected to lateral inertial loads during an earthquake, the walls develop shear and flexural stresses. The strength of masonry under these conditions often depends on the bond between brick and mortar (or stone and mortar), which is quite poor. This bond is also often very poor when lime mortars or mud mortars are used.

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

A disaster may be defined as a calamity or mishap leading to loss of property and the most important loss in these is loss of precious human life. "Earthquake "is one of the major occurring disasters in India. Occurrence of earthquakes though natural, but loss of life and property is mainly due to manmade construction. Construction practices using masonry forms the oldest form of building construction in India because of ease of availability of materials and its flexible nature of accommodating itself as per the prevailing environmental conditions. Though this type of construction is mostly preferred and most frequently employed also, yet it is not completely perfect in regard to seismic efficiency. Thus this is treated as non-engineered construction and most casualties are due to the collapse of these only in earthquake. . Masonry buildings in India are generally designed on basis of IS 1905-1987-"Code of practice for structural use of unreinforced masonry". In layman language, URM can be defined generally as masonry that contains "NO REIN- FORCING" in it. These kind of buildings were used to be constructed in an era when reinforcing was not so common. Some of the poorest people in the villages used to live in thatch-type houses consisting of wooden vertical posts and rafters connected with coir rope ties. In India, procedure for seismic analysis and design of these buildings has still not received adequate attention in spite of the fact maximum damage and causalities in past earthquake is the collapse of these buildings.

Basically masonry is a non-homogeneous, composite material in nature. It constitutes of mainly masonry units like bricks, blocks, random rubble stones etc and mortar joints. Generally, masonry behaviour is governed by the mechanical properties of its components, the interconnection between them, arrangement of bricks and construction material used of building, for e.g. concrete frames, steel beams, columns and timber floors.

As its know that masonry is weak in tension, so when subjected to ground motion it suffers damages varying from very slight damage to total collapse.

`1.2 NEED FOR EARTHQUAKE RESISTANT OF URM BUILDING

As we know, though earthquakes are natural, but damaged caused is manmade, thus it is concluded that there is an existing relationship between type/quality of construction, peak ground acceleration and damage. Generally construction practices are divided in to three categories:

a) Engineered (for seismic loads)
b) Engineered (for gravity loads)
c) Non-Engineered

In India large percentage of b) and c) construction practices takes place.

URM buildings are highly vulnerable in nature, and many times these structures have witnessed huge damage leading to collapse. This kind of construction is one of the most flexible construction practices which is picked up by the people easily, in accordance of their ease for constructing it and also easy availability of materials. Therefore there is an ardent need of improving the seismic performance of these structures to reduce future causalities due to earthquake.

Every year, it`s seen a number of houses are dissevered into kindling wood and toothpicks by number of disastrous events. Even though, generally the houses are constructed in a manner so as a replacement of the destroyed dwellings possess the same kind of structural properties to stand up to nature's forces .In many parts of world, especially in lesser developed regions , the similar condition exists. Resources of finance are often limited. So, if we talk about post trauma, there are situations faced with the dilemma of reconstructing the destroyed house in a condition that will again destroy during the next disaster.

Also —point to be noted is meaning of "DISASTER-PROOF" is not that they will have capability to stand up to direct meteor strike or an atomic bomb. For example, a term known as "fireproof" is used to describe different kind of construction, and on other part it`s also true that a fire of high-enough intensity can destroy almost anything. The objective behind this is to build a structure that is sufficiently "fireproof" so as to endure the normally expected fire, and thus minimizing, or eliminating if possible, damage to the property and occupants.

1.3 EARTHQUAKE RESISTANT FEATURES

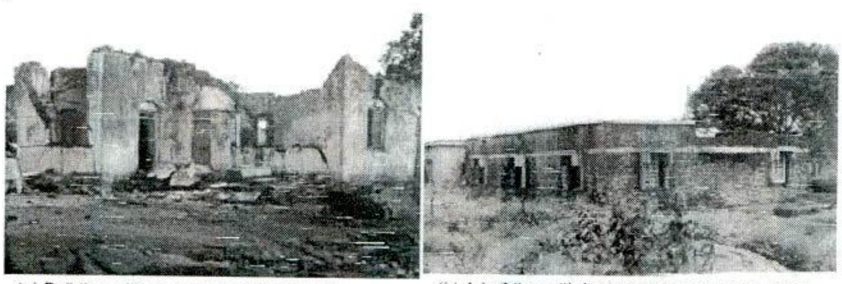
1.3.1 Horizontal seismic bands

The most important earthquake resistant feature are horizontal seismic bands because these when provided hold the whole building as a single unit with walls tied together. In a typical masonry construction types of bands are:

a) Lintel band
b) Roof band
c) Plinth band
d) Gable band

Among above four bands, lintel is one of the great importances, because," Lintels, provide support to the masonry construction, and shall be designed in a manner to carry loads from masonry (allowing for arching and dispersion, where applicable) and loads received from any other part of the structure."

Main function of lintel band is to provide support to the walls that are loaded in weak direction from the walls that are loaded in strong direction by tying the walls together leading in reduction of unsupported height of walls, hence improving their stability in weak direction. For example,in year 1993 earthquake with intensity of shaking IX on MSK scale hit Killari village, Latur(Central India). Many masonry houses experienced partial or complete collapse (Figure 1.1 a). On the other part, there was a building in the village that too of masonry, but it sustained the ground shaking very well with rarely any damage because of the presence of a lintel band in it.



(a) Building with no horizontal lintel band collapse of roof and walls

(b) A building with horizontal lintel band in Killari village: no damage

Fig 1.1 1993 Latur Earthquake one masonry house in Killari village had horizontal lintel band and sustained the shaking without damage

(Reference: EERI Special Earthquake Report by Department of Civil Engineering ,IIT Kanpur)

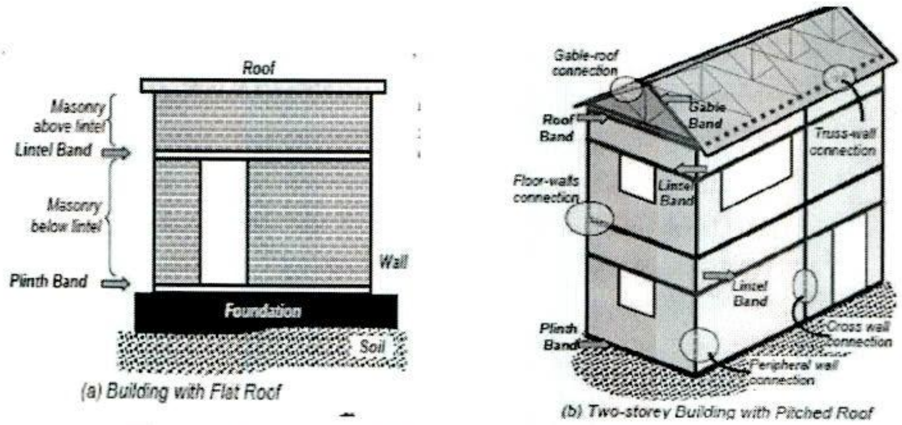


Fig 1.2 Horizontal bands for improving seismic resistance

(Reference: IITK-BMTPC Earthquake Tip 14)

1.4 OBJECTIVES

The main objective of the present work done is to propose analytical results like pattern of frequency analysis, buckling in a URM building. The main objectives of the thesis are:

i. To model traditional as well as earthquake resistant building with lintel made up of concrete fabricated with GFRP ABAQUS.

ii. To perform frequency analysis in order to check the adequacy of models using ABAQUS 6.10

iii. To state the use of GFRP as a retrofitting material over steel.

iv. To state benefits of using FRP.

1.5 STRUCTURE OF THESIS

The work in this thesis report is organized in following manner:

Chapter 1 introduces the general idea of what URM building implies.

Chapter 2 presents brief past literature reviews regarding different techniques used till date to retrofit masonry building.

Chapter 3 presents overview of modelling techniques, analysis procedure and steps in ABAQUS/CAE.

Chapter 4 Experimental work done.

Chapter 5 presents analytical modelling and simulation of models by doing frequency analysis.

Chapter 6 deals with summary and conclusion drawn from present study.

CHAPTER 2
LITERATURE REVIEW

Throughout the world a large number of researches have been done in order to study the different methods for repairing /strengthening of masonry structures. Work done in this is field so far is discussed below:

2.1 RESTORING OF STRENGTH USING MASONRY REPLACEMENT

Budescu *et al.*, 2001 gave a method with objective of preserving of the mechanical efficiency and improving of the continuity of the masonry structures, by, replacing all the affected areas of the walls where major deterioration has occurred with similar materials to the original structure.

Bothara and Brzev, 2011 provided a solution by strengthening masonry walls with buttress with the advantage of preventing the failure mechanisms related to the lateral deformations and a good behavior in case of horizontal forces . The strengthening technique consists in adding additional supports (buttress) in vertical plane of vulnerable walls to out-of-plane loads.

Mack and Speweik,1998; Hassapis, 2000; Secondin, 2003 conducted an experiment and provided a strengthening solution which is based on improving and reinforcing the damaged mortar joints due to leaking roofs or gutters, capillarity actions causing rising damp, extreme weather (freeze/thaw cycles), cracks along the joints due to differential settlements. The decision of repointing is related to some obvious signs of deterioration, such as disintegrating mortar, cracks in the mortar joints, missing bricks and stones, damp walls or damaged plasterwork. The technique consists in removing, cleaning, washing, filling the mortar joints with a new mortar. The main targets are: increasing the compressive and the shear strength,improving the appearance and reduction of deformation.

Trujilio Leon, 2007; Islam, 2008 provided the strengthening actions which consist in sewing, tying together of cracked or damaged areas of masonry using different materials. One of the most common applications of stitching is to re-tie a wall on each side of a crack using steel ties laid into joints at different intervals. Sewing involves also injecting mortar in order to form a bonded contact between the reinforcement and the masonry elements as well as to prevent metal corrosion. The main targets are: increasing the mechanical properties and the element ductility.

2.2 TECHNIQUE REGARDING SURFACE EXTERNAL TREATMENTS

El Gawady *et al.*, 2004 The strengthening actions consist in spraying overlays made of a mixture from a mineral matrix on the masonry wall surface over the mesh of reinforced bars. The size of the shotcrete in terms of thickness can be adapted as per the requirements for the protection to seismic actions. The overlay of shotcrete is usually reinforced with wire welded with fabric to the approx minimum ratio for crack control. In order to transfer the shear stress on the entire surface of the shotcrete, shear dowels are fixed using epoxy resins or cement grout in holes drilled into masonry wall. However, there is no consensus regarding the bonding between the bricks and the shotcrete material or the need of using the anchor system (different diagonal tests shows that are not major improvements of the response to brick-shotcrete bonding). Moreover, it is recommended wetting the masonry surface before applying the shotcrete. This treatment does not affect the cracking or ultimate load, it only limits extended the inelastic deformations.

Ţăranu, 2006; Singh and Paul, 2006 provided use of an orthotropic composite material matrix based on cement mortar of high resistance consist multiple layers of steel meshes. Ferrocement tensile strength depends on the nature of mesh, orientation and reinforcement thickness.

Bothara *et al.*, 2002; Arya, 2005 to prevent out –of-plane wall collapse a continuous RC band called *ring beam* or *collar beam* at different building levels providing horizontal bending strength.

El Gawady, 2004) Diagonal and vertical stripes are placed on both sides of the element. For URM for external reinforcement steel plates can be used. Taghadi *et al* (2000), studied this method and it follows the behavior of the tested specimen's to-in-plane actions, obtaining an increase of strengthening to this type of actions and it provides energy dissipation mechanism.

Vintzileou and Skoura, 2009 timber/wood was used on the external sides of the wall,. To detect the changes of RC masonry structures using this system, compression and diagonal compression (shear) tests were conducted. Results concluded: shear capacity of walls was increased due to favorable effect of reinforcement with wooden elements. walls , and also the minor increase in ultimate load up to 20% due to the lateral .

Guide lines..., 2006 in order to improve strength and stiffness, and obtaining a continuous confinement it's suggested a self supporting RC cover should be applied surrounding the structural elements which are subjected to high compression stresses and lateral deformation. This is also called as jacketing in which a RC belt is used as an overlay starting from foundation in order to maintain load path continuity resulting in fixation of reinforcement to the wall using steel connectors and staples. It was further found that results were much better when jacketing was applied on both sides of wall.

Apart from above, FRP jacketing is another way of improving ductility of masonry walls. FRP is capable to address masonry weak parameters like strength, damage, and deterioration.

"Composite material "generally means reinforcing material embedded to a material called matrix, which has much lower strength and stiffness.

Rai, Agnihotri and Singhal (2011)

The authors studied the behaviour of unreinforced masonry (URM) walls subjected to both in plane and out-of-plane loads simultaneously during an earthquake . The out-of-plane ability of wall is extremely crucial after being damaged primarily due to in-plane forces for its overall stability and safety. A non-linear structural finite element modelling in ABAQUS/CAE was done to examine the behaviour of unreinforced masonry wall under combined loading considering the parameters like aspect ratio and slenderness ratio. Macro modelling approach is used to model the masonry because the study is concerned with the global behaviour of the masonry wall.

2.3 FIBER-REINFORCED COMPOSITES

- FRP-"fiber reinforced polymer or plastic" it's defined as a composite material made of fibers and polymer matrix. The most common fibers used are glass, carbon, basalt or aramid and performance of these composites depends on their length, shape, orientation, and composition of fibers and also on mechanical properties of matrix.

- Another terminology used is "fiberglass" which is defined as a thermosetting plastic organic compound that is strengthened with glass fibers.

Plastic resins are of two types:

- Thermoset
- Thermoplastics

At higher temperature, thermosets possess the capability to maintain their formed form without getting melted and reshaped whereas thermoplastics can soften at given temperature even.

The big reason behind masonry damage is material characteristics and exposure conditions. Add- on to this construction especially URM construction practices are vulnerable and most of the times cannot resists demand of external loads like of earthquakes, wind pressure, soil pressure etc. In regard to these problems, FRP, if used in appropriate way, can be used to overcome a number of these problems in order to ensure minimum social and economic loss and stronger structural system. Retrofitting/repairing/strengthening of a structural unit implies increment in one or more than one structural parameters: stability of member, ductility, stiffness, capacity in terms of tensile, shear flexural or compressive.

2.4 FRP COMPOSITES AS MASONRY RETROFIT MATERIAL

In order to enhance structural capacity FRP has the tendency to be used as both as a flexural as well as shear strengthening element, or in restoring the original strength of damaged elements subjected to out-of-plane and in-plane load.

2.4.1 TYPES OF FIBERS

For infrastructure applications three types of fibers are most commonly used:

a) carbon

b) **glass**

c) aramid

Above three, "glass" fiber is considered most for masonry strengthening as many experiments shown that CFRP offers less significant improvement as compared to GFRP.

Table 1.Comparison between properties of fiber resin and steel

	Young's modulus E [GPa]	Tensile strength σ_r [MPa]	Strain at failure ε_r [%]	Coefficient of thermal expansion α $[10^{-6}\ ^{\circ}C^{-1}]$	Density ρ $[g/cm^3]$
E-glass	70 - 80	2000 - 3500	3.5 – 4.5	5 – 5.4	2.5 – 2.6
S-glass	85 - 90	3500 - 4800	4.5 – 5.5	1.6 – 2.9	2.46 – 2.49
Carbon (high modulus)	390 - 760	2400 - 3400	0.5 – 0.8	-1.45	1.85 – 1.9
Carbon (high strength)	240 - 280	4100 - 5100	1.6 – 1.73	-0.6 - -0.9	1.75
Aramid	62 - 180	3600 - 3800	1.9 – 5.5	-2	1.44 – 1.47
Polymeric matrix	2.7 – 3.6	40 – 82	1.4 – 5.2	30 – 54	1.10 – 1.25
Steel	206	250 – 400 (yield) 350 – 600 (failure)	20 – 30	10.4	7.8

2.5 BENEFITS and FEATURES OF FRP

1) STRONG and LIGHT WEIGHT

FRP/composites possess high tensile strength in nature and are much stronger than the bars of steel of comparable area. Also they have high strength to weights ratios and are light weight in nature so leads in reduction of transportation cost.

2) DIMENSIONALLY STABLE

FRP/Composites have high dimensional stability beneath varied physical, environmental and thermal stresses.

3) CORROSION RESISTANCE

FRP/Composites has quality of not getting corroded, rot or rust implying they have capability to sustain attack from moist chemicals leading to long life and low maintenance.

4) MINIMUM FINISHING

FRP/Composites are themselves used as for coating purposes such that they play dual role in providing strength as well as of effective finishing.

5) FLEXIBLE TO DESIGN

From industrial fishing boat hulls and deck to truck fenders from parabolic TV antennas, from outside lamp housings to seed hoppers FRP/Composites offers a huge flexibility nature.

CHAPTER 3

MODELLING TECHNIQUES and ANALYSIS PROCEDURE

3.1 GENERAL

Though masonry is an ancient and simple and most commonly used building material, still effective methods for modeling its structural behavior is an active research issue.

Once the structural model has been made, it is possible to perform analysis to determine the different forces in the structure. There are different methods of analysis which provide different degree of accuracy.

In this chapter, the finite element software is used for simulation of masonry behavior, and for that software used is ABAQUS. This program is basically finite element software that helps to solve problem varying from simple linear to complex non-linear simulation.

3.2 MODELLING TECHNIQUES

As we know, masonry is generally a composite material, comprising of brick and mortar, which makes its behavior cumbersome to be predicted. This problem arises because of various probable modes of failure, complicated material constitutive models, and distinction in qualities of construction. In this regard, mainly two types of techniques known as micro-modelling and macro-modeling are mostly used for simulation of non-linear behaviour of masonry.

Micro-modelling means the representation of bricks, mortar, and interfaces of them and is used in detailed form. This technique requires performing a number of experimentation for calibrating parameters of material like modulus of elasticity, Poisson's ratio etc.

Whereas in macro-modelling, there is no difference between brick, mortar and their interface and modeling of masonry is done as a continuum anisotropic material. The masonry modelling is done as single material using its average properties. The average stresses in the continuum anisotropic material i.e. masonry are related to the average strains in this modelling technique.

This modelling technique is relatively simple to use and useful for the study of global behaviour of large elements and less experimental tests are required for calibrating the material properties.

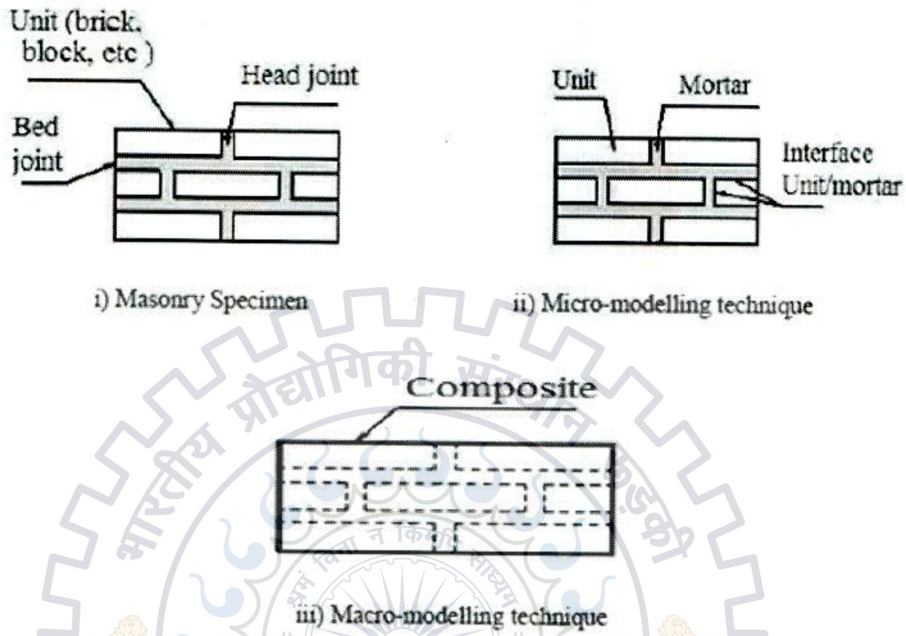


Fig 3.1Micro and Macro modeling techniques

(Reference: DS Simulia., 2011. Abaqus/CAE user's manual)

3.3 STEPS OF ANALYSIS

The complete analysis of FEM software ABAQUS is divided in to three different stages: Preprocessing, Simulation, and Post processing:

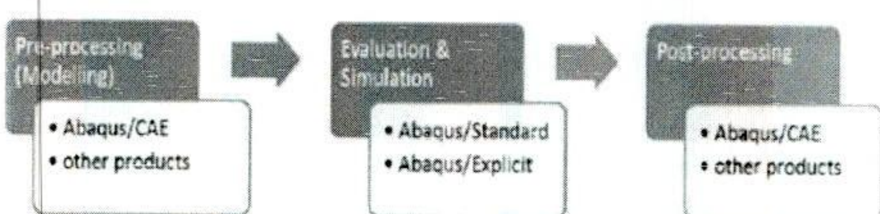


Fig.3.2 Abaqus software process

(Reference: DS Simulia., 2011. Abaqus/CAE user's manual)

3.3.1 Preprocessing

This stage involves defining of the model of physical problem and creates an ABAQUS input file. The model is a graphical representation of the physical problem. This stage is also called modelling stage.

3.3.2 Simulation

The simulation is a background process and it is the stage in which Abaqus/Standard solves the numerical problem defined within the model. The complicacy of problem being analyzed and power (i.e. processor) of computer being used, decides the total time involved to complete an analysis, which ranges from few seconds to a number of days. This stage is also referred as Finite element analysis stage.

3.3.3 Postprocessing

Once the simulation has been completed then results can be evaluated using reports, images, animations etc. from the generated output file. This stage is also referred as visual rendering stage.

3.4 PRE-PROCESSING AND POST PROCESSING

ABAQUS/CAE

ABAQUS/CAE is a computer aided engineering software application used for pre-processing as well as for post-processing. The software is divided in to functional units called modules. Each module contains only those tools that are relevant to specific portion of modelling task.

The order of the modules in the model tree corresponds to logical sequence that you follow to create a model. These modules are :

Part: where individual parts are created by sketching or importing their geometry.

Property: materials and sections of each part are defined.

Assembly: create and assemble the part instances which are oriented in to different coordinate system in to global coordinate system.

Step: where analysis step is created and output requests are specified.

Interaction: where mechanical interactions (such as contact) between the regions is managed.

Load: where loads and boundary conditions are defined.

- ***Mesh**:* where a finite element mesh is generated.
- ***Job**:* where jobs are created and their progress is monitored.
- ***Sketch**:* where a sketch is created.
- ***Visualization**:* where it is possible to view output database.

As we progress from one module to other, the model is built. After the completion of model, ABAQUS/CAE generates the input file (.inp) to be simulated to the ABAQUS analysis product. The input file (.inp) is read by ABAQUS/Explicit or ABAQUS/Standard and information is sent to ABAQUS/CAE to allow monitoring of the job progression. At the end of the job, the output database is generated and it can be read using the visualization module in ABAQUS/CAE.

3.5 ANALYSIS PROCEDURE

The simulation is the stage in which Abaqus/Standard or Abaqus/Explicit solves the numerical problem defined in the pre-processing step.

3.5.1 Abaqus/Standard

Abaqus/Standard is able to solve a wide range of linear and nonlinear problems that involve either static or dynamic response of elements. Usually, models generated in Abaqus are non-10 linear and can involve many variables. This procedure is solved using implicit integration i.e. solved using multiple coupled equation using stiffness matrix. This method is computationally expensive, so repetitive calculations are likely to occur which occupies a lot of disk space.

CHAPTER 4
EXPERIMENTAL SETUP

4.1 MATERIALS:

1. Concrete for casting concrete cube
2. GFRP- glass fiber reinforces polymer
3. Epoxy Resin

EXPERIMENTAL WORK PART-I

➢ CASTING OF CONCRETE CUBES:

For testing purpose 10 cubes were casted of M20 grade having ratio of Cement: fine aggregate. Coarse aggregate as 1.1.5.3

Wt. of Coarse aggregate	54.54 kg
Wt. of fine aggregate	27.40 kg
OPC-43	18.17 kg
w/c ratio	0.52
water quantity	9.4484 kg

Above ratio was mixed in rapid mixer and finally paste thus created was filled in moulds and allowed to dry for 24 hours after which those were taken out of moulds and soaked under water for curing.

On 7th ,14th and 28 days tests were then carried out on 3 blocks naming 1,2,3 for calculating failure load.

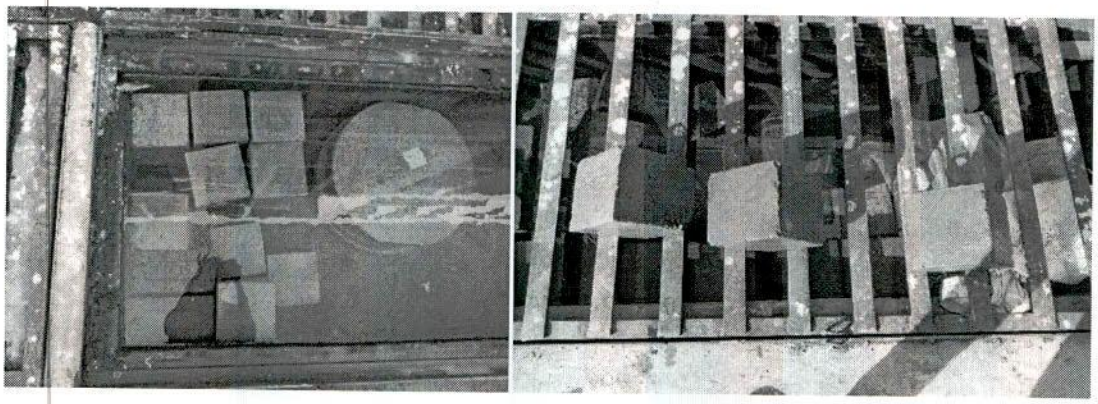


Fig.4.1 a)Curing of blocks   b) sun drying of blocks before testing

Fig.4.2 Weighing of Blocks before testing

(Courtesy: Civil Engineering Lab, IIT Roorkee)

Max. load taken by cube 1 = 38 tonnes

Max. load taken by cube 2 = 40 tonnes

Max. load taken by cube 1 = 40 tonnes

Fig 4.3 Tested blocks

(Courtesy: Civil Engineering Lab, IIT Roorkee)

Area of cross-section of cube =15*15= 225 cm^2

$$\text{Since, Compressive strength} = \frac{\text{Max. Load at failure}}{\text{Area of cross-section}}$$

Therefore,

1. Compressive strength of cube 1= $\frac{38 \times 1000 \times 9.81}{225 \times 100}$ = 16.4808 N/mm^2

2. Compressive strength of cube 2= $\frac{40 \times 1000 \times 9.81}{225 \times 100}$ = 17.44 N/mm^2

3. Compressive strength of cube 3= $\frac{40 \times 1000 \times 9.81}{225 \times 100}$ = 17.44 N/mm^2

Average compressive strength of 3 cubes = Compressive strength of (1+2+3)/3

= 17.120 N/mm^2

Average maximum load taken by 3 cubes = Max.load (1+2+3)/3

= 39.33 tones

= 39330 kg

4.2 DEVELOPMENT AND CHARACTERIZATION OF GFRP COMPOSITES

Under this section, the materials and method used for the primary processing of the polymer matrix composites is described. It presents the details of the manufacturing and characterization of the composite laminates.

4.2.1 LAMINATE MAKING

There are a number of primary manufacturing processes for composite material,. Hand lay-up, compression molding. Pultrusion etc. can be used to make composite laminates. In this case, a flat plate mild steel mold was developed using the standard processes of shaping, drilling and welding.

The first two plates of the mold were assembled using a nut-bolt arrangement which also helps in application of required pressure. The mold was designed to make GFRP Composite laminates of 360 x 360 mm dimensions of varying thickness.

4.2.2 MATERIAL USED FOR POLYMER MATRIX COMPOSITES

The polymer matrix composite material consists of matrix and reinforcement.

(a) **Reinforcement**:

Glass fibers are known for their resistance to chemical attack, stability, hardness, high strength and stiffness, flexibility, non-flammable nature, Corrosion resistance, and low price. Woven glass fiber mat is used as reinforcement.

(b) **Matrix material**

i) Epoxy resin: the term "epoxy refers to a chemical group consisting of an oxygen atom bonded with two carbon atoms which in turn are already bonded. The simplest epoxy is a three member ring structure known by the term "alpha –epoxy" or '1.2-epoxy".

In the present work Araldite LY556 is used which is an unmodified liquid epoxy. The curing is done with hardener HY951 (aliphatic primary.). Due to the very low cure shrinkage, Araldite LY556/ Hardener based glass fiber laminate is dimensionally stable and practically free from internal stresses.

4.3 EXPERIMENTAL WORK PART-II

- After the completion of concrete cubes 28 days casted time, the two blocks out of left casted blocks were again tested as shown:

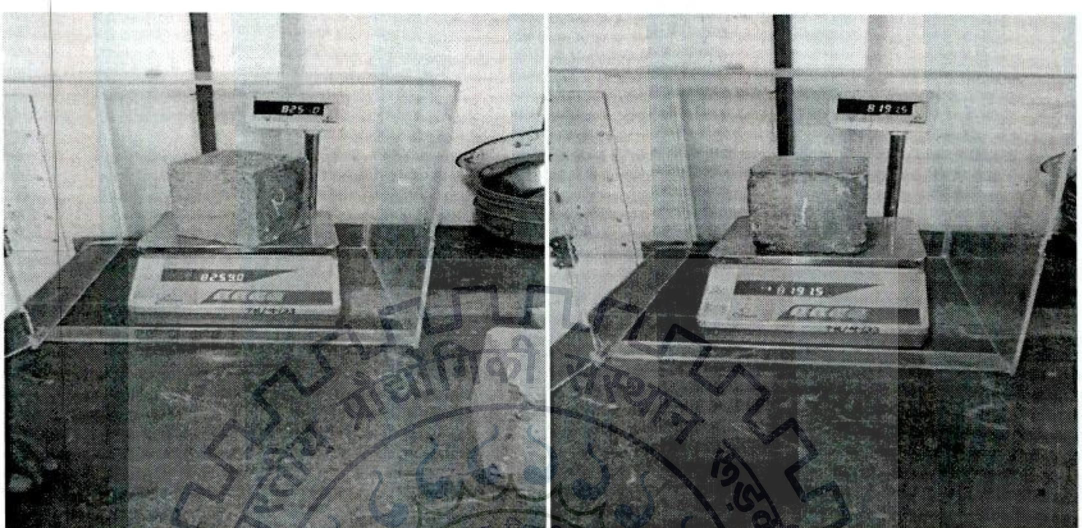


Fig.4.4 weighing casted blocks after 28 days.

(Courtesy: Civil Engineering Lab, IIT Roorkee)

After weighing the two blocks were tested on 2000kN compression testing machine, as shown in fig.

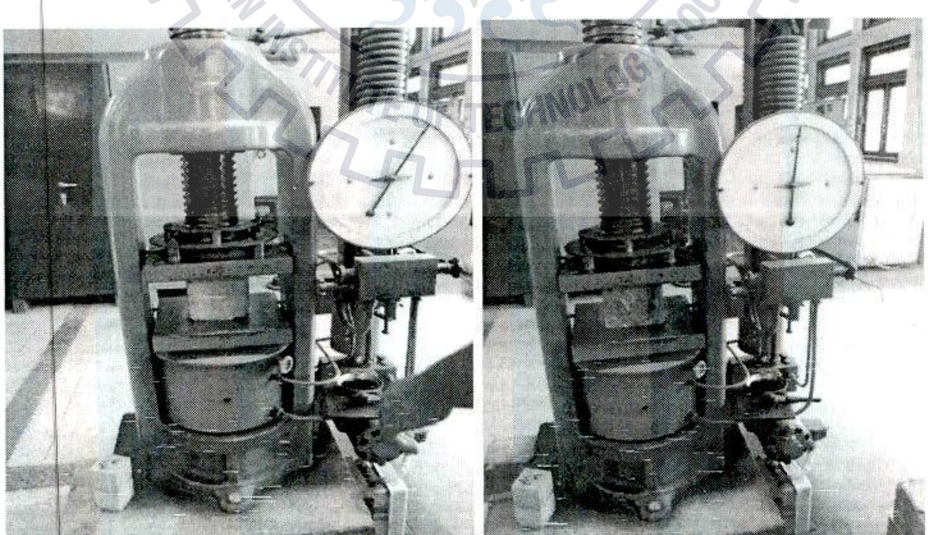


Fig 4.5 testing of blocks

(Courtesy: Civil Engineering Lab, IIT Roorkee)

Max. load taken by cube 1 = 50 tonnes

Max. load taken by cube 2 = 49 tonnes

Therefore,

1. Compressive strength of cube 1= $\frac{50 \times 1000 \times 9.81}{225 \times 100} = 21.80\ N/mm^2$

2. Compressive strength of cube 2= $\frac{49 \times 1000 \times 9.81}{225 \times 100} = 21.36\ N/mm^2$

Average compressive strength of 2 cubes = Compressive strength of (1+2+)/2

= 21.58 N/mm^2

Average maximum load taken by 2 cubes = Max.load (1+2)/2

= 49.5 tonnes

= 44905.645kg

- For the rest blocks , as GFRP was not available in sufficient quantity , one block was taken for testing purpose. Firstly GFRP was taken and cut in the following manner of cube size side in a manner of two plates per cube.

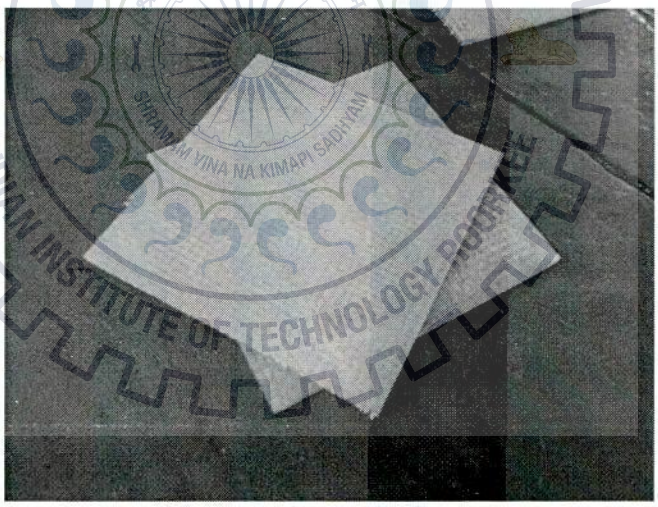


Fig .4.6 GFRP plates cut in dimension of 150mm*150 mm

(Courtesy: Mechanical and Industrial Lab, IIT Roorkee)

- Before their application to the concrete these were firstly roughened and also concrete surface was also cleaned properly in order to achieve proper fixate.
- In order to fix these GFRP to concrete surface, a mixture of epoxy and hardener was made in an equal ratio.

Fig 4.7 Mixture of epoxy and hardener

(Courtesy: Civil Engineering Lab, IIT Roorkee)

- This mixture was then applied over the two selected concrete face as well as on the GFRP to be pasted.

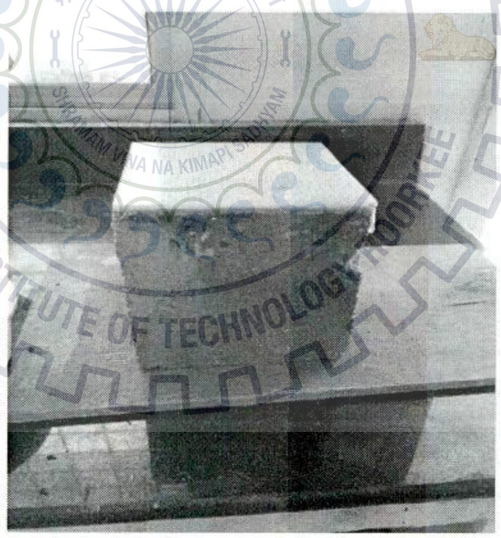


Fig 4.8 GFRP fixed over one surface of cube

(Courtesy: Civil Engineering Lab, IIT Roorkee)

- After application of epoxy fully on both surfaces, GFRP was fixed as shown and in order to prevent slippage of them from concrete they were provided support too.

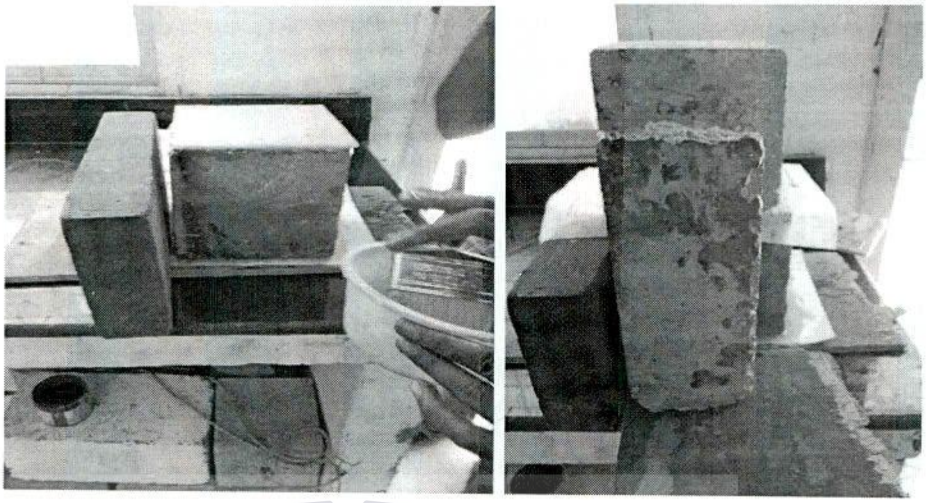


Fig 4.9 GFRP fixed over both surface of cube and support provided

(Courtesy: Civil Engineering Lab, IIT Roorkee)

Max. load taken by cube 1 = 79tonnes

Therefore,

1. Compressive strength of cube 1= $\dfrac{79\text{x } 1000\text{x}9.81}{225\text{x}100} = 34\ \text{N/mm}^2$

From the figure below it was seen that maximum load taken by GFRP cube was 79tonnes, and also after maximum failure load there was no effect on GFRP plate,

Only the slight damages occur on the cube implying if this approach can be used froe fabricating lintel then such will lead in increasing time of initial start of building oscillation.

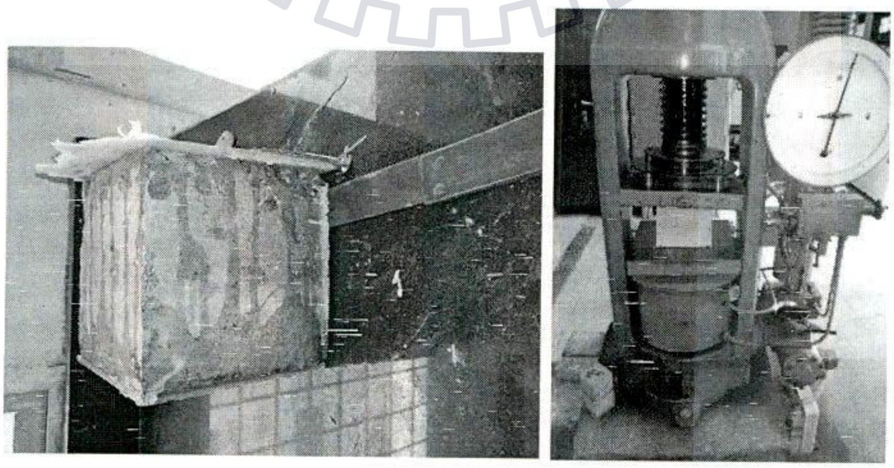


Fig 4.10 GFRP fabricated cube and testing

(Courtesy: Civil Engineering Lab, IIT Roorkee)

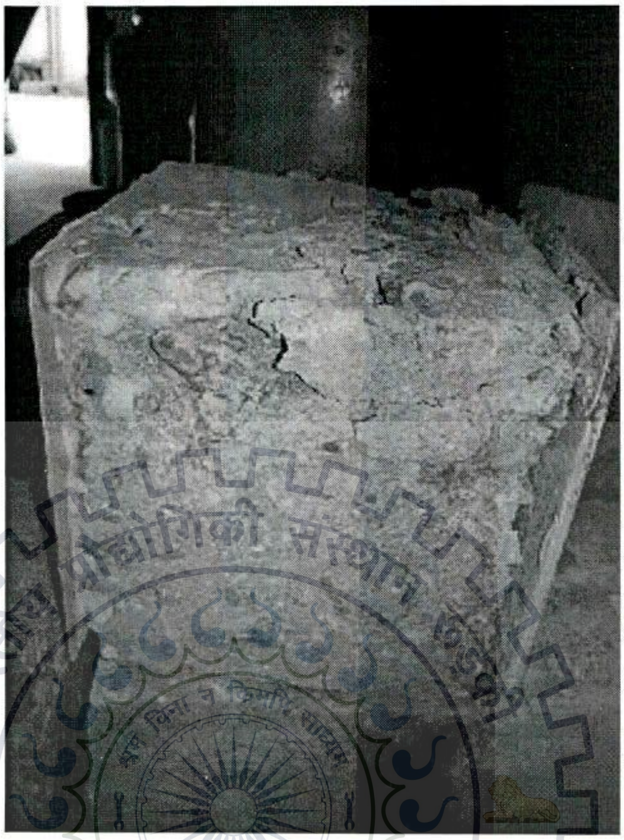


Fig 4.11 Tested GFRP without any damage to the plate.

(Courtesy: Civil Engineering Lab, IIT Roorkee)

CHAPTER 5
ANALYTICAL MODELLING, MATERIAL PROPERTIES AND COMPARATIVE STUDIES OF BRICK MASONRY MODEL

5.1 INTRODUCTION

The past earthquakes gave us many lessons in context to the effect of structural plan on the seismic behaviour of masonry buildings. The subsequent analysis of causes of damage due to past earthquakes clearly shows that apart from quality of structural material, building configuration plays also an important role. The regular structure buildings with walls properly connected at the roof level performed have performed well during past earthquakes. The regular structural layout transmits the load in a clear and undisturbed way from element to element. During an earthquake the induced seismic energy will dissipate uniformly over the entire structure and if elements are not properly connected then it causes stress concentration, which results in more damages and even total collapse of the structure.

Masonry buildings are box-type structural systems composed of vertical and horizontal structural elements. Wall acts as vertical structural element and floor and roof acts like horizontal structural elements. Transfer of vertical gravity loads takes place from the floors and roof, which acts as horizontal flexural element, to the bearing wall. Finally from the bearing wall the loads are transferred to the foundation system and then in to the ground. During earthquake, floors and roof act as horizontal diaphragm, which is responsible for distributing the inertia forces among the walls in direct proportion to their relative stiffness. For transferring inertia force developed at the roof level to the supporting wall, the roof system should be properly anchored with the load bearing walls. In case, if the walls are not connected together at roof or floor level then out-of-plane drift will cause separation along vertical joint at the corner of the wall junction.

Also from the two pictures below it's depicted that the most flexible form of construction which people used to opt is brick masonry construction of single storey in which they provide a door and add-on to it a window.

a)

b)

Fig.5.1 a) and b) Single storey brick masonry building

(Courtesy: IIT Roorkee)

In above buildings if we notice over the opening nothing is provided i.e. front wall is continued just like as ,now the question is if such building is constructed in an area of seismic zone IV then due to opening provided in such building without any beam or lintel provided over it, will it survive or at what frequency it'll start vibrating with the ground motion or will the occupants be able to save themselves before the building gets damaged or collapsed completely."?

A lot of retrofitting measures have been suggested till date for strengthening masonry building either by providing steel reinforcement at corners ,or reinforced slab and many above as mentioned in the literature review and the practice which is taking place basically since not very long time is use of composite materials for example FRP.

But the thing is most of time experiments done till so far includes FRP wrapping over the walls, providing FRP plates in cross form over the walls etc. In short, though many measures are already been there for retrofitting of masonry but in this study I have tried to just present a proposed application of FRP as a covering to lintel band without use of steel reinforcement so as to endure URM building a retrofit measure in such a way that it will lead to the increment of shaking of building time so that till the time occupants gets chance to get out of there and save themselves.

5.2 BRICK MASONRY MODEL DIMENSIONS

Brick masonry is one of the oldest forms of construction. For analysis three models were modelled in ABAQUS 6.10 one without any earthquake resistant features ,one with only concrete lintel and other with a concrete lintel fabricated using GFRP.

Plan dimension (inner): 4.23 m× 4.46 m

Total height: 2.63 m

Masonry Roof: 0.02m thick

Door: 1.0 m×1.5 m

Window: 0.75 m×1.0 m

Wall thickness 0.23 m

Properties of material used are in modeling and analysis is discussed later in this chapter only. Below is the plan of traditional building block of masonry.

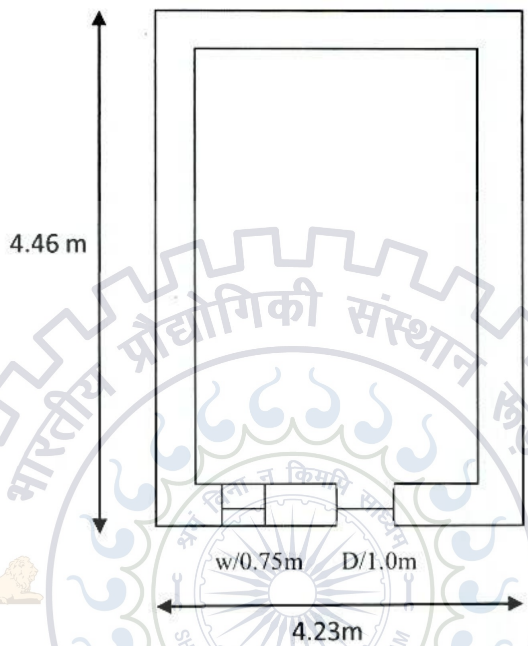


Fig.5.1 Plan of traditional block masonry model

5.3 MODELLING

5.3.1 Traditional block masonry model

The structure is modelled using a finite element software Abaqus/CAE. The walls were modelled using 8-noded linear brick elements (C3D8R).The encastre boundary condition was considered between the structure and ground and ties connection between the structural members such as between roof and wall.

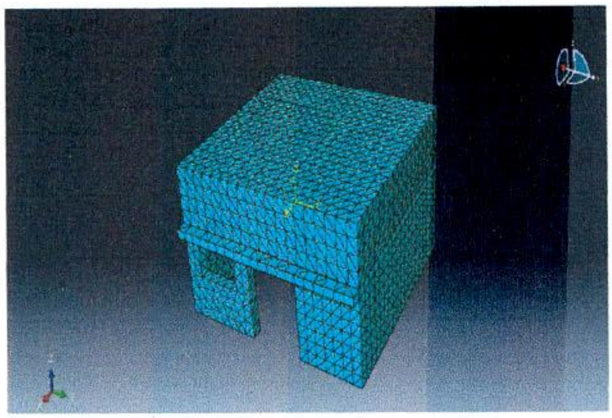


Fig.5.2 Finite element model of traditional block masonry building

5.3.2 Masonry model with GFRP fabricated concrete lintel

The structure is modelled using a finite element software Abaqus/CAE. The walls were modelled using 8-noded linear brick elements (C3D8R). The encastre boundary condition was considered between the structure and ground and ties connection between the structural members such as between roof and wall.

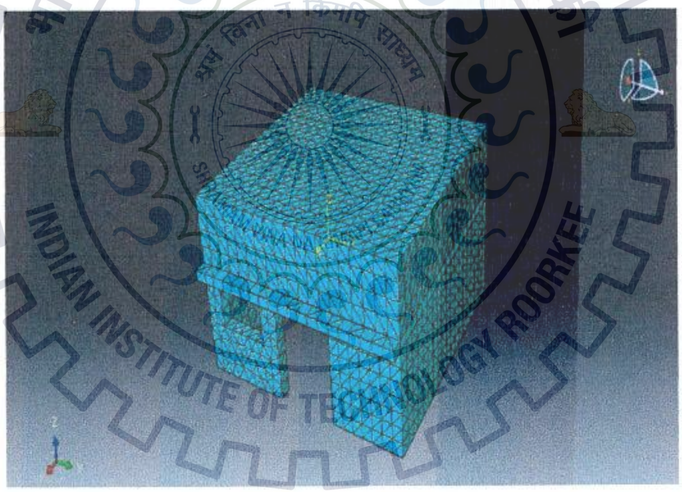
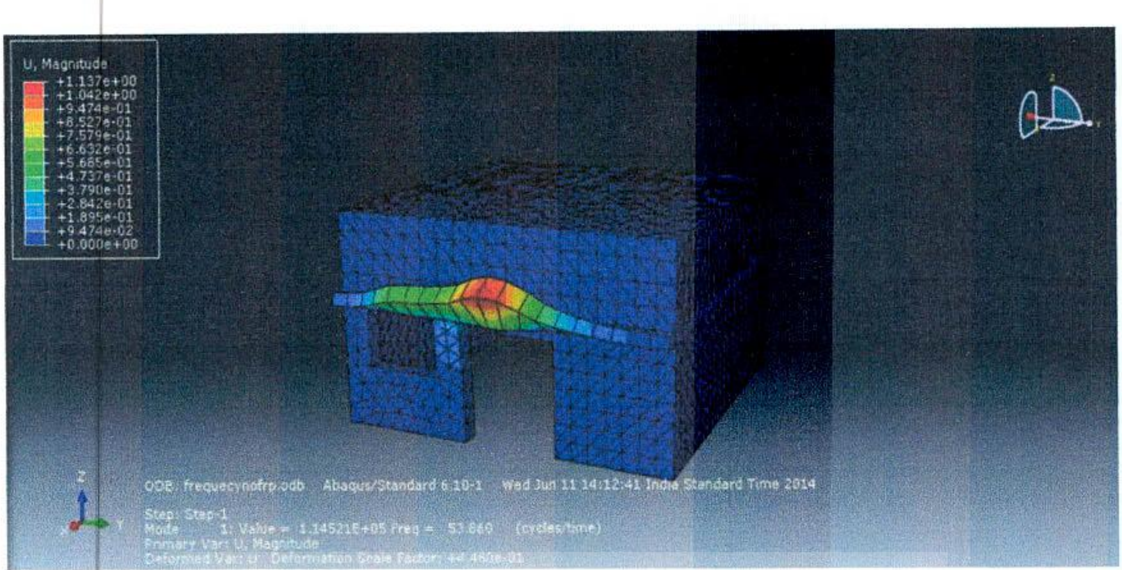


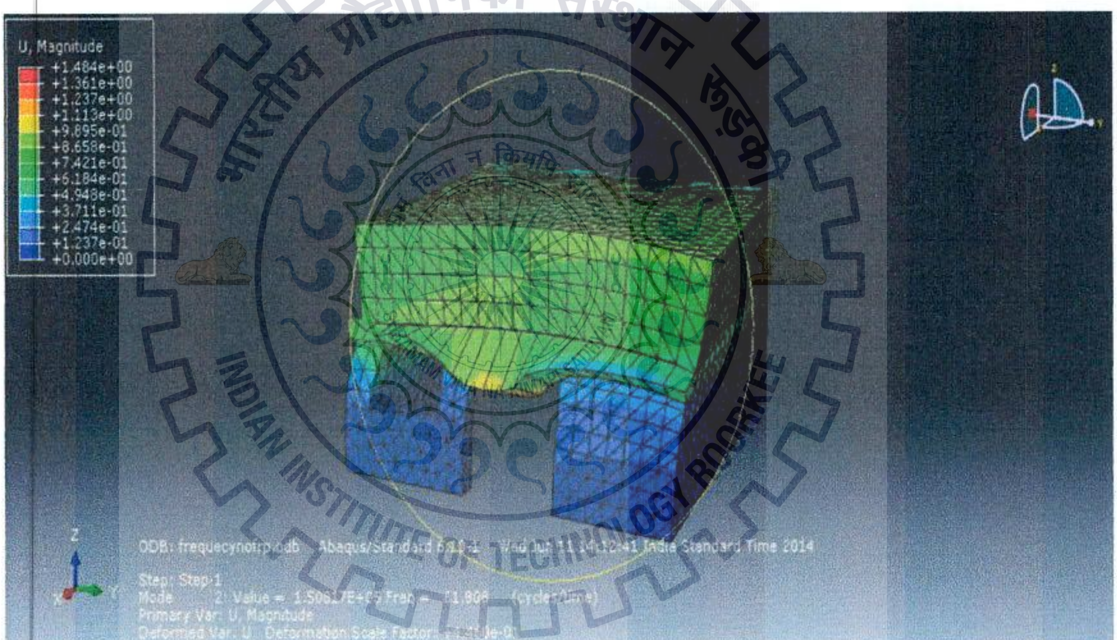
Fig.5.3 Finite element model of traditional block masonry building with GFRP fabricated concrete lintel

5.4 FREQUENCY ANALYSIS

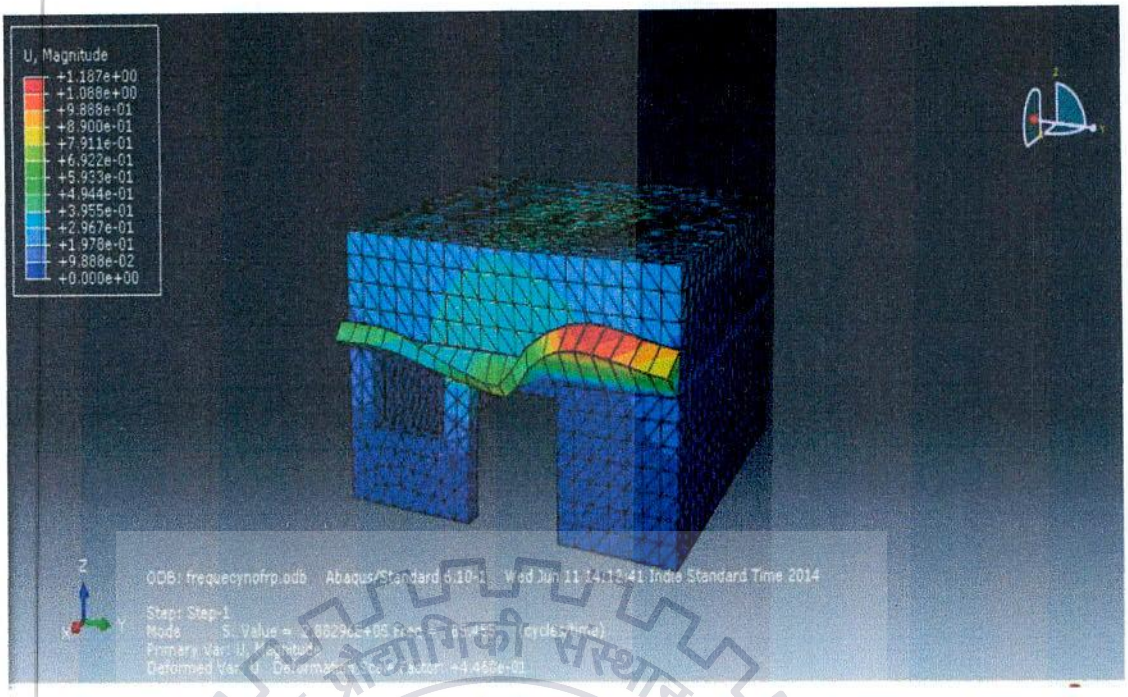
In order to check accuracy of models, frequency analysis is carried out. The natural periods and modes of vibration of masonry model were computed by ABAQUS.



MODE 1 (T= 0.0185 sec)



MODE 2(T=0.0161sec)



MODE 5 (T=0.0117 sec)

MODE 8 (T=0.00953 sec)

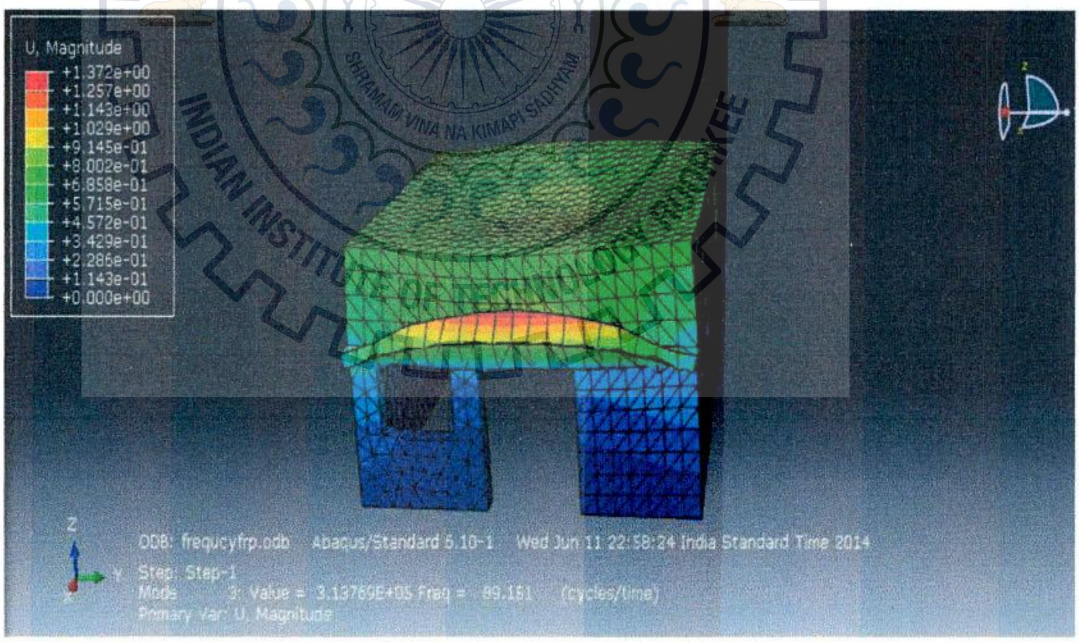
Fig. 5.4 Modes of vibration of traditional block masonry model

Step Name	Description
Step-1	

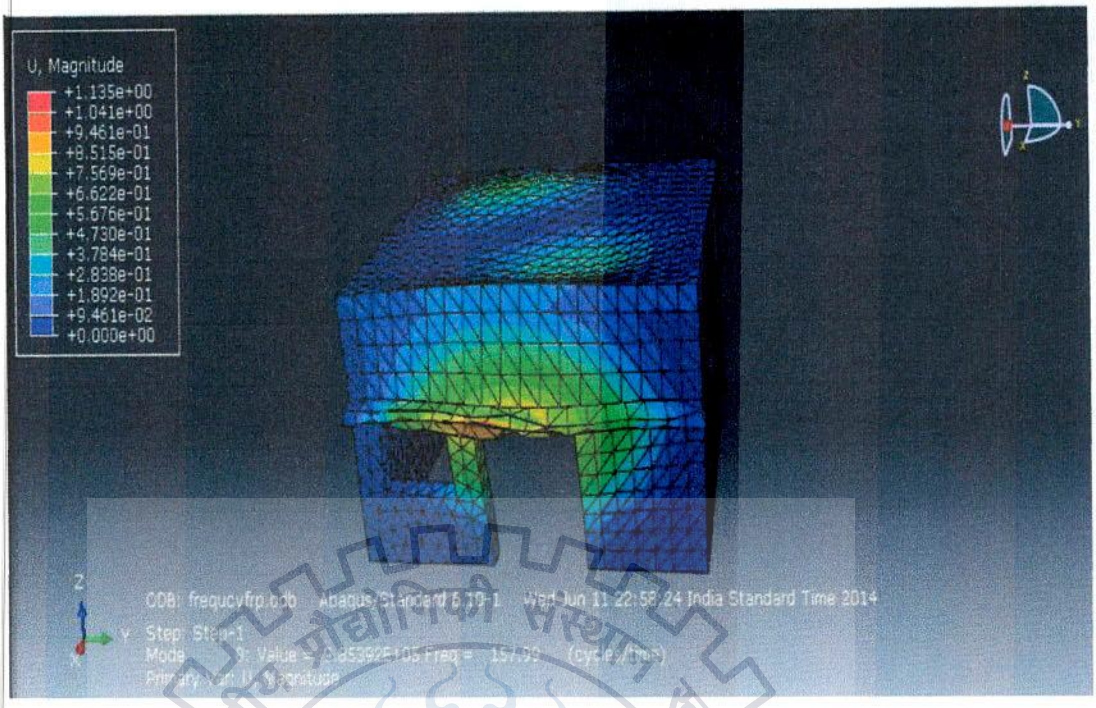
Frame

Index	Description
0	Increment 0: Base State
1	Mode 1: Value = 1.41113E+05 Freq = 59.787 (cycles/time)
2	Mode 2: Value = 1.54823E+05 Freq = 62.624 (cycles/time)
3	Mode 3: Value = 1.87766E+05 Freq = 68.965 (cycles/time)
4	Mode 4: Value = 2.66518E+05 Freq = 82.164 (cycles/time)
5	Mode 5: Value = 2.94521E+05 Freq = 86.373 (cycles/time)
6	Mode 6: Value = 4.11650E+05 Freq = 102.11 (cycles/time)
7	Mode 7: Value = 4.39292E+05 Freq = 105.49 (cycles/time)
8	Mode 8: Value = 5.33310E+05 Freq = 116.23 (cycles/time)
9	Mode 9: Value = 6.16884E+05 Freq = 125.00 (cycles/time)
10	Mode 10: Value = 6.61088E+05 Freq = 129.40 (cycles/time)

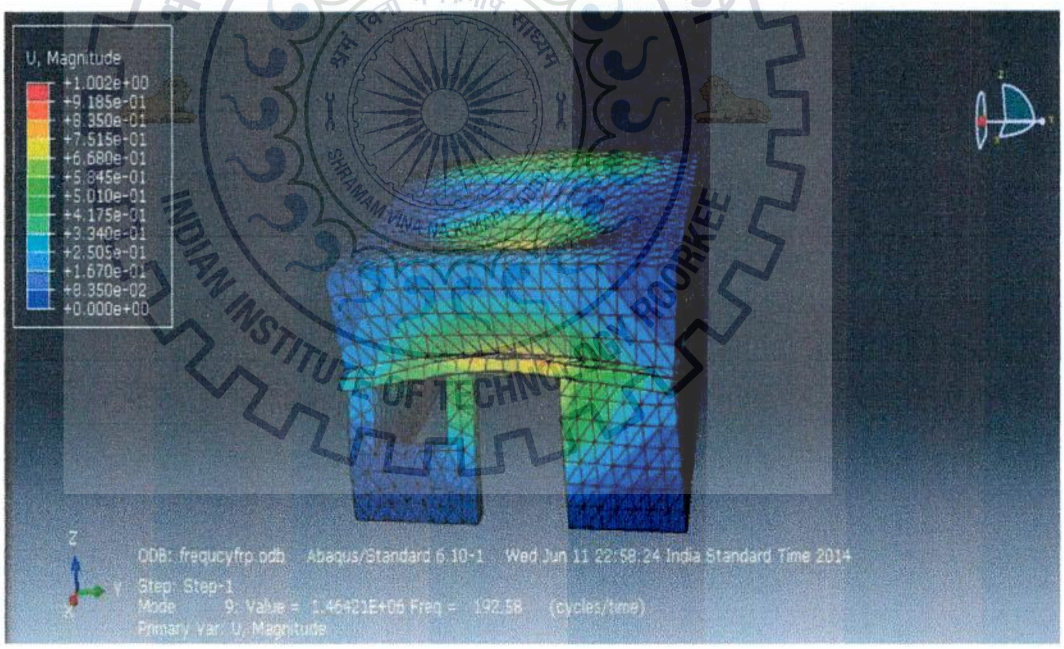
Fig.5.5 Eigen value output for traditional block masonry model



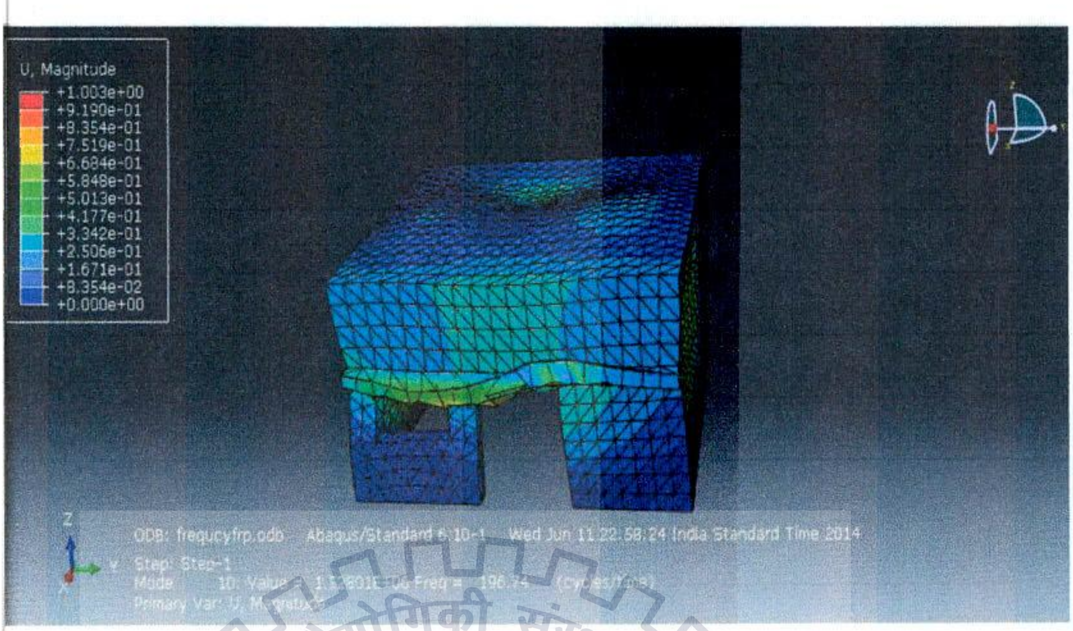
MODE 3(T=0.0132 sec)



MODE 8(T=0.0054 sec)



MODE 9(T= 0.0052 sec)



MODE 10(T= 0.0051 sec)

Fig.5.6 Modes of vibration of traditional block masonry model with grfp fabricated concrete lintel

Index	Description
0	Increment 0: Base State
1	Mode 1: Value = 1.78466E+05 Freq = 67.235 (cycles/time)
2	Mode 2: Value = 2.12636E+05 Freq = 73.390 (cycles/time)
3	Mode 3: Value = 3.13769E+05 Freq = 89.151 (cycles/time)
4	Mode 4: Value = 4.98405E+05 Freq = 112.36 (cycles/time)
5	Mode 5: Value = 6.37718E+05 Freq = 127.10 (cycles/time)
6	Mode 6: Value = 7.80117E+05 Freq = 140.57 (cycles/time)
7	Mode 7: Value = 9.59433E+05 Freq = 155.89 (cycles/time)
8	Mode 8: Value = 9.85392E+05 Freq = 157.99 (cycles/time)
9	Mode 9: Value = 1.46421E+06 Freq = 192.58 (cycles/time)
10	Mode 10: Value = 1.52801E+06 Freq = 196.74 (cycles/time)

Fig.5.7 Eigen value output for traditional block masonry model with gfrp fabricated concrete lintel

5.5 PROPERTIES OF MATERIALS

5.5.1 Masonry units

- fired bricks having compressive strength >3.5 MPa
- Lime sand (1:3) or clay mud of good quality for brick work.
- When lintel is provided cement sand mortar to be used (1:6).
- Mass density of masonry used in modeling 2100 kg/m^3.
- Young's modulus of elasticity = 2.27E10

5.5.2 Concrete

The material behaviour of concrete block masonry was replicated by available "concrete damaged plasticity" constitutive model in Abaqus. The properties incorporated in modelling were taken from available literature. M15 grade of concrete is used in lintel and R.C slab.

Hence,

- Characteristic compression strength f_{ck} of M15 grade is 15 MPa.
- Density of the concrete is 2400Kg/m^3.
- The Poisson ratio of 0.2 is used in this analysis.

The modulus of elasticity of concrete is calculated based on the empirical formula

$$E = 5000 \sqrt{f_{ck}}$$

where, f_{ck} is the characteristic compression strength MPa.

5.5.3 REINFORCEMENT –GFRP

In many parts, glass FRP (GFRP) is chosen for fortifying of masonry. The lower elastic modulus of GFRP, as compared to carbon FRP (CFRP), is not as limiting in masonry strengthening applications as it might be in concrete structures because it is more compatible with the low elastic modulus of masonry. In addition, GFRP material costs are substantially less than carbon or aramid materials.

GFRP properties used in this modeling are being taken from the experimental results done in civil engineering lab of Indian Institute of Technology Roorkee by one of the PHD scholars.

- Mass density = 1826 kg/m3.
- E1= 23 MPa
- E2= 18 MPa
- Poisons ratio=0.25
- G12= 9 GPa
- G13= 9Gpa
- G23= 4.5 GPa

According to the values obtained from the above two model analysis following comparison is obtained in their natural frequencies:

Table 2 Mode and natural frequency table of two models a) Without GFRP b) with GFRP.

Model 1 (without FRP)	Model 2 (with GFRP)
Mode 1: Value = 1.41113E+05 Freq = 59.787 (cycles/time)	Mode 1: Value = 1.78466E+05 Freq = 67.235 (cycles/time)
Mode 2: Value = 1.54823E+05 Freq = 62.624 (cycles/time)	Mode 2: Value = 2.12636E+05 Freq = 73.390 (cycles/time)
Mode 3: Value = 1.87766E+05 Freq = 68.965 (cycles/time)	Mode 3: Value = 3.13769E+05 Freq = 89.151 (cycles/time)
Mode 4: Value = 2.66518E+05 Freq = 82.164 (cycles/time)	Mode 4: Value = 4.98405E+05 Freq = 112.36 (cycles/time)
Mode 5: Value = 2.94521E+05 Freq = 86.373 (cycles/time)	Mode 5: Value = 6.37718E+05 Freq = 127.10 (cycles/time)
Mode 6: Value = 4.11650E+05 Freq = 102.11 (cycles/time)	Mode 6: Value = 7.80117E+05 Freq = 140.57 (cycles/time)
Mode 7: Value = 4.39292E+05 Freq = 105.49 (cycles/time)	Mode 7: Value = 9.59433E+05 Freq = 155.89 (cycles/time)
Mode 8: Value = 5.33310E+05 Freq = 116.23 (cycles/time)	Mode 8: Value = 9.85392E+05 Freq = 157.99 (cycles/time)
Mode 9: Value = 6.16884E+05 Freq = 125.00 (cycles/time)	Mode 9: Value = 1.46421E+06 Freq = 192.58 (cycles/time)
Mode 10: Value = 6.61088E+05 Freq = 129.40 (cycles/time)	Mode 10: Value = 1.52801E+06 Freq = 196.74 (cycles/time)

Table 3 Time period calculations a) Without GFRP b) with GFRP.

Model 1 (without FRP)	Model 2 (with GFRP)
1. Time period=0.0167 sec	Time period=0.0148 sec
2. Time period=0.0159 sec	Time period=0.0136 sec
3. Time period=0.0145 sec	Time period=0.0112 sec
4. Time period=0.0121 sec	Time period=0.0088 sec
5. Time period=0.0115 sec	Time period=0.0078 sec
6. Time period=0.0097 sec	Time period=0.0071 sec
7. Time period=0.0094 sec	Time period=0.0064 sec
8. Time period=0.0086 sec	Time period=0.0063 sec
9. Time period=0.0080 sec	Time period=0.0051 sec
10. Time period=0.0077 sec	Time period=0.0050 sec

SEISMIC DATA: (as per IS 1893 (part 1):2002

(i) Seismic zone = zone IV

(ii) Zone factor (Z) =0.24, Zone factor given is for maximum considered Earthquake (MCE) and service Life of structure in a zone. The factor 2 is used so as reduce the Maximum considered Earthquake (MCE) zone factor to the factor for design basis Earthquake (Table 2)

(iii) Importance factor (I) =1

(iv) Response Reduction Factor =2.5 for Concrete band
= 1.5 for Masonry building

The value of R for building is given in Table 7: IS 1893 (Part 1); 2002.

(v) Soil medium type, for which average response acceleration coefficient are as

$S_a/g=$ {

1+15T,0.00<=T<=0.10

2.50, 0.10<=T<=0.55

1.36/T,0.55<=T<=4.00

}

(v) Direction of seismic force = E- W Direction.

Using the above details for calculation, below formulae were further used to calculate base shear.

$A_h = (ZI\ S_a)/\ (2Rg)$

The total design lateral base shear (V_B) along the direction of motion is given by $V_B = A_h W$

Substituting the values ,it was found that due to GFRP application base shear of building was increased, hence its fair to use GFRP .

CHAPTER 6
SUMMARY AND CONCLUSIONS

6.1 SUMMARY

Casting of concrete cubes and their compressive strength check done to obtain the results of whether the cube casted is of proper mix or not and plus in accordance to this failure load was also calculated and the results of failure load of casted cubes were compared to that of the failure load of cube fabricated with GFRP.

Modelling of traditional as well as earthquake resistant half scale block masonry building is carried out analytically in ABAQUS. Model-1 is modelled in traditional manner without any earthquake resistant features while Model-2 is modelled with earthquake resistant features, which includes seismic band at lintel level throughout the building.

Frequency analysis is carried out for both the models and deformed shapes corresponding to different modes are observed. The time period obtained analytically for both the models are compared with empirical formula given in IS 1893 (Part-1): 2002.

6.2 CONCLUSIONS

The conclusions from the above study are summarized below:

- The failure load was increased in case of casted cube fabricated with GFRP, and this implies that because of applying GFRP its confinement was increased and this implies its moment capacity will increase.

- The fundamental time period of the model obtained analytically from frequency analysis was in good agreement for the one having concrete lintel with fabricated GFRP as compare to the model created of complete masonry.

- Since after calculation numerically it's found that after applying GFRP the natural frequency of building was increased, resulting in increment of base shear i.e. the GFRP building will start oscillating at a later stage as compared to the traditional building implying that if an earthquake comes, the occupants will have the opportunity to save themselves as they will be having time to come outside before the building collapse or damage.

6.3 FRP SUITABILITY FOR ITS USE IN STRUCTURAL ENGINEERING APPLICATIONS:

1. The one of the primary and main reason for which civil engineers choose them in the designing of structures is the strength properties of FRPs. As always a material's strength is judged by its ability to sustain a load without excessive deformation or failure. When an FRP specimen is tested in axial tension, the applied force per unit cross-sectional area (stress) is proportional to the ratio of change in a specimen's length to its original length (strain). When the applied load is removed, FRP returns to its original shape or length. In other words, FRP responds linear-elastically to axial stress.

2. The response of FRP to axial compression is reliant on the relative proportion in volume of fibers, the properties of the fiber and resin, and the interface bond strength. FRP composite compression failure occurs when the fibers exhibit extreme (often sudden and dramatic) lateral or sides-way deflection called fiber buckling.

3. FRP's response to transverse tensile stress is very much dependent on the properties of the fiber and matrix, the interaction between the fiber and matrix, and the strength of the fiber-matrix interface. Generally, however, tensile strength in this direction is very poor.

4. Shear stress is induced in the plane of an area when external loads tend to cause two segments of a body to slide over one another. The shear strength of FRP is difficult to quantify. Generally, failure will occur within the matrix material parallel to the fibers.

   Among FRP's high strength properties, the most relevant features include excellent durability and corrosion resistance.

   Furthermore, their high strength-to-weight ratio is of significant benefit; a member composed of FRP can support larger live loads since its dead weight does not contribute significantly to the loads that it must bear. Other features include ease of installation, versatility, anti-seismic behavior, electromagnetic neutrality, excellent fatigue behavior, and fire resistance.

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