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RESEARCH ARTICLE

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Structural health monitoring of clock tower Dehradun by Ultrasonic pulse velocity test and comparing it with Finite Element Model on ABAQUS

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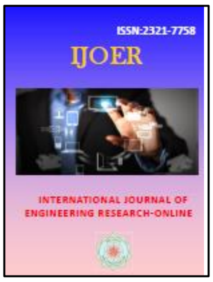


ABSTRACT

Structural health monitoring is a techniques to detect the deterioration, damage or any kinds of material deformation in the structure, which can be with time or due to any of the seismic activities experienced in that particular area. It helps to increase the performance of the structure at a very low cost. Structural health monitoring is generally done for old, prehistoric and heritage buildings which have been with holding the grounds for a very long time. Ultrasonic pulse velocity test is a Non-destructive method by which we identify the flaws in the material so that the serviceability and durability of the structure can be ensured. In this report Non-Destructive tests of Clock tower, Dehradun using Rebound Hammer and Ultrasonic Pulse Velocity test is being done and computational analysis software ABAQUS 6.14 is used for Finite Element Analysis over the structure. The results of ultrasonic pulse velocity are compared to the average stresses and strains acquired from the software to ensure whether Ultrasonic Pulse Velocity Test can be used as an Structural Health Monitoring Device or not.

1 Introduction

1.1 Background

The life of each structure is very unpredictable and inevitable. Much like our own particular presence, its advancement relies upon numerous uncertain occasions, both inward and outer. A few instabilities emerge during construction that is not identified during structural design and analysis. No matter how cautious we are at the time of experimental or computational design and analysis but when it comes to the real life environment, few of the calculation contradict. Once being used, each structure is subjected to develop patterns of loads and different activities. Sometimes the parameters taken during the design have different nature or magnitude when compared to reality. This kind of uncertainties creates a challenge for engineer and designer in providing the safety, maintenance, durability and serviceability to the structure. Characterizing administration levels and organizing maintenance budget depending just on models and shallow perception can prompt unsafe slip-ups and wasteful utilization of assets. Normal assessment can positively decrease the level of vulnerability, yet at the same time introduces vital constraints being restricted to the perception of the structure's surface amid brief circumstances divided by long stretches of inactivity. Structural health monitoring expects to give more solid information on the current status of a structure and identify the appearance of new degradation. By introducing various sensors, measuring parameters applicable to the auxiliary conditions and other critical ecological parameters, it is conceivable to get a photo of the structure's state and advancement. Monitoring is a new wellbeing and administration device that preferably supplements conventional techniques like visual assessment and modelling.

Superstructures like dams, multistory buildings, containment vessels and offshore structures have a great value in the development of our country. The upkeep expenses of these structures is considerably high, and even a little rate lessening in the support cost adds up to noteworthy sparing. A standout amongst the most financially savvy upkeep techniques is structural health monitoring. Early recognition of issues, for example, cracks, delamination, corrosion, spalling of concrete etc., Can help in anticipation of calamitous disappointment and auxiliary weakening destroyed. Structural health monitoring has incredible potential for improving the usefulness, serviceability and expanded life expectancy of structures and, thus, could contribute fundamentally to the economy of the country. The idea of long term observing of structures is advancing accordingly, as it is cost effective and provides advancement of new technology.

1.2 Importance of ultrasonic pulse velocity test

It is a non-destructive method of testing of material utilizing ultrasonic motions for identification of defects in various materials, it has turned into an established test strategy in view of estimations with due respect to all the essential impacting variables. Today it is normal that ultrasonic testing, upheld by extraordinary advances in instrument innovation, give reproducible test comes about inside limited resilience. This expect correct learning of the affecting variables and the capacity to apply these in testing innovation.

Structural health monitoring is generally done in prehistoric and heritage buildings, so any kind of destruction is intolerable. Those are non-destructive techniques in light of the way that auxiliary harm for the most part causes a decline in the structural stiffness, which produces changes in the vibration qualities of the structure. Harm is resolved through the correlation between the damaged and the undamaged conditions of the structure. Without destructing the structure, a brief idea of damage is identified by these methods

1.3 Objectives and scope of studies

The essential target of this review is to recognize the harm prompted in the structures utilizing ultrasonic pulse velocity test, to find the damaged area and decide the seriousness of the damage, so that the life expectancy of the structures can be surveyed and upkeep cost can be diminished.

In this review, the examination was done on various walls of clock tower, Dehradun utilizing ultrasonic pulse velocity test and Rebound hammer test. The yield of ultrasonic pulse velocity test is then looked at with the results of finite element analysis of the structure done on ABAQUS 6.14.

The primary point is to know whether ultrasonic heartbeat speed test can utilized as a structural health monitoring gadget, as the gadget is accessible in the majority of the establishments and is the most temperate technique to do the harm recognition.

2. Literature review

2.1 Structural health monitoring Case study review (hekhar verma1, Dr. Vijay): These study diverse contextual investigations are evaluated on the premise of structural health monitoring devices utilized. Different countries are specified with their significant structures. These structures are by and large ancient structures or the absolute most well-known bit of structural designing expressions including world's tallest building Burj Khalifa. These structures are either observed before or after seismic activities. Structural health monitoring should be possible by utilizing distinctive sensors and gadgets which are mentioned in this specific survey paper.

A desperate need of health monitoring of structures in India is given with a portion of the some good conclusions.

2.2 Finite element analysis of masonry structure part-1 (A.D.Tzamtzis and P.G.Asteris): The most imperative factors that matters the masonry structure are measurement of blocks, width of the joints, material property of both block and cement and nature of workmanship. A far reaching audit of past work on the limited component demonstrating of unreinforced stone work structures, both in the static and dynamic regime, has been led in this piece of the review. It is for the most part concurred that refined models, for example, nonlinear microscopic and anisotropic models are satisfactory to investigate basic structures like masonry shear walls subjected to in-plane loading, though more simplified models like nonlinear macroscopic or anisotropic 3-D models are reasonable to break down whole brick work structures, it is additionally uncovered that two-dimensional formulations with plane stress definition have principally so far been received for the finite element analysis of masonry structures. Encourage, without an appropriate model to speak to its conduct. In the past, brick work was thought to be anisotropic flexible continuum; subsequently, the impact of the mortar joints going about as planes of shortcoming, couldn't be tended to. In fact, it is just as of late that scientific systems, which represent the non-linear behavior of masonry under static loads, have been created.

2.3 Finite element analysis of masonry structure part-2 proposed 3-d non-linear microscopic model (A.D.Tzamtzis and P.G.Asteris): A non-linear finite element model show for the examination of masonry walls, subjected to static and seismic loading conditions, has been displayed in this review. The model created is three-dimensional and considers masonry as a two-stage material, treating blocks and mortar joints independently, accordingly taking into account non-linear deformation qualities and dynamic local failure of both blocks and mortar joints. The impact of the mortar joints has been considered by utilizing interface components to recreate the time-subordinate sliding and detachment along the interfaces. Stress distribution from an in-plane bending test on a masonry panels performed by different people, were imitated to a sensible level of precision by the present finite element model. The precision and capability of the proposed three-dimensional model were additionally shown by utilizing the model to anticipate the non-linear response of an unreinforced masonry walls to in-plane seismic tremor excitations. Analytical and experimental accessible in the literature have been utilized to check the outcomes got from the present finite element model, demonstrating that it is equipped for exact replication of the brick work's conduct.

2.4 Structural Health Monitoring: A Dire Need of India (Gajanan M. Sabnis, Yogesh Singh, Abhay Bambole, Gopal Rai) : This paper numerous parts of Structural Health Monitoring were considered. The need of SHM is shown by the author as SHM gives us some solid purposes behind it to end up noticeably an indispensable piece of a structure. He further explains that India as a creating nation should be more mindful and careful about its Infrastructure and a real occasion can bring about irreversible misfortunes and subsequently ought to be very much educated in time. There are numerous essential structures where instrumentation is as of now being utilized as a part of India like the dams, whose different parameters must be looked upon, yet these are not being finished viably and can be better with new advances. The structures which are a necessity of the society such as hospitals and bridges in hilly areas where it is not possible to cross the monstrously flowing rivers and passages ought to be commanded with observing as their destruction cause a bigger number of misfortunes than some other. Structural health monitoring economically is likewise light and is just 0.5% to 3% onetime cost of aggregate structures cost and 2% to 5% for checking structure more than 10 years. It is finished with a few structures in India yet must be centered more around. Basic Health Monitoring is moderately new idea worldwide and exceptionally later for India. It has turned out to be compelling and productive in numerous nations, now being practices frequently, and has an extraordinary potential and handiness for India for picking up certainty over the structures we are making so improvement happens quicker and with precise outcomes.

2.5 Low cost structural health monitoring of bridges using wireless senspot sensors (Mehdi Kalantari Amir Hossein Mirbagheri) : In this report author had utilized a senspot sensor as a structural health monitoring device. He utilized this sensor in an extension which goes under Maryland highway administration. He additionally expressed that SenSpot sensors give a minimal effort, simple to introduce, adaptable answer for appropriated structural health monitoring on expressway spans. The work exhibited in this report was centered on the research facility and field execution of SenSpot sensors. Specifically, SenSpot sensors were studied in two situations. In the primary situation, sensors were utilized to screen correct operation of bridge bearings. Small sub-degree change in tilt of orientation therefore of temperature change was measured utilizing SenSpot sensors appended to the direction. The readout was contrasted with theoretical values. The examination indicated consistency of the estimations with the theoretical quantities. In an alternate arrangement of investigations, execution of SenSpot strain gages was contemplated in a research facility setting. The review demonstrated that when utilized for strain measurements, SenSpot sensors can measure the quantity when there is a change in loading, which causes a change in structure.

He concluded the study by giving some of the advantages of senspot sensor which are Very easy and fast installation as it is very lightweight, long lifetime (multiple decades), feature-rich devices (SenSpot sensors helps you to measure strain, tilt, pressure, temperature, crack activity, moisture, humidity, etc.), Maintenance-free operation Monitoring with minimal attendance

2.7 PROPERTIES OF BRICK MASONRY FOR FE MODELING (Narayanan S P, Sirajuddin M): A brief study is done on bricks and mortar. Two of the major bricks taken are wire cut bricks and clay bricks. An experimental study is done on the brick to obtain all the essential properties of both the bricks. Then these properties are compared. Properties like compressive strength, modulus of elasticity, density, and water required for mortar. These properties were a great help in my thesis as I have taken all the material properties of clay brick from this particular journal.

3. Methodology

3.1 Model: Structural health monitoring is generally done for old and heritage building to gather information about the current status of the structure, so that the performance of that particular building can be enhanced. I wanted to do a study on a heritage building in Dehradun. The foundation of clock tower was laid by the nightingale of India Sarojini Naidu and the inauguration was done by the iron man of India Lal Bahadur Shashtri. These were some very big names of that independence era, which makes the structure heritage in itself.

Figure 1:Clock tower, Dehradun

3.2 Specifications of clock tower, Dehradun: The design of clock tower is Hexagonal masonry structure. The whole structure is made of bricks and mortar. There is a beam at the top where the bell is hanging. It is giving a support to the roof. All of the factors are considered in the model except the roof and the bell. As it was getting very tough to design it on ABAQUS 6.14. Therefore I have increased the dead load of the structure.

Dimensions of Clock Tower, Dehradun

Height of Clock Tower= 25.15 m

Thickness of wall at ground floor= 0.620 m

Opening at Entrance= 1.58 m

Height of Entrance =2.67 m

Wall length (Face) = 5.674 m

Opening at 3rd floor =1 m * 8.87m

Ground Floor = 5.457m

1st floor = 0.327m

2nd floor =2.396m

3rd floor = 16.937m

3.3 Non-destructive test : As a renowned institution in Uttarakhand, U.P.E.S handles a lot of government projects, therefore civil engineering department of University of Petroleum and Energy Studies were given a project to check the soil bearing capacity for the clock tower, Dehradun.

In August, 2015 the first batch of M.Tech performed all of the tests on clock tower including soil penetration test, rebound hammer test and ultrasonic pulse velocity test.

The whole structure is divided into 3 floors. Height of each floor differs. As the rebound hammer test and ultrasonic pulse velocity test is done at random points over the walls, therefore an average value of compressive strength obtained from rebound hammer and velocity obtained from ultrasonic pulse velocity test is taken on different walls, and according to these average values the condition of the walls are decided.

Average values of Rebound Hammer test and Ultrasonic Pulse Velocity test is given in the table Number 9 and 10 below in *page number 12 and 13.*

3.4 Material properties: Masonry walls are utilized as a part of a wide range of building development in many parts of the world on account of minimal effort material and good insulation properties, simple accessibility, and locally accessible material and skilled labor. Numerical demonstrating of structures with workmanship dividers requires the material properties and constitutive connections of workmanship and its constituents, i.e., blocks and mortar, which are not effectively accessible in view of shortage of controlled trial tests and noteworthy variety in material properties topographically.

Burnt clay bricks are used in clock tower. So all of the properties of burnt clay bricks are considered for the modelling in ABAQUS 6.14.

The density of the brick is 2070 kg/m^3. Poisson's ratio is 0.21. The third most important elastic property of any material required for FEM analysis is Modulus of elasticity. MOE will be different for different walls on each floor because the compressive strength is differing. Compressive strength of the material decides the amount of stress material can withhold under compression. The compressive strength value is taken from the results of Rebound Hammer test given above.

Calculation of Modulus of Elasticity for ground floor

The formula for calculation of modulus of elasticity for masonry structure which includes both bricks and mortar is

$MOE = K_e * f_k$

Where Ke = 750

f_k is the compressive strength of the bricks

For Ground Floor of Clock Tower

Table1:For first floor of clock tower

walls	compressive strength(N/mm^2)	Modulus of elasticity(N/m^2)
wall1	8.34	6.26E+09
wall2	11.5	8.63E+09
wall3	12.21	9.16E+09
wall4	19.75	1.48E+10
wall5	8.34	6.26E+09
wall6	16.716	1.25E+10

Table 2

walls	compressive strength(N/mm^2)	modulus of elasticity(N/m^2)
wall1	5.34	4.01E+09
wall2	7.46	5.73E+09
wall3	7.64	5.73E+09
wall4	10.21	7.65E+09
wall5	5.34	4.01E+09
wall6	8.93	6.69E+09

These values will be used later in ABAQUS 6.14 during the material properties assignment to different sections.

3.5 Finite element analysis on ABAQUS 6.14: The results of ultrasonic velocity test needs to be verified so that it would be evident that ultrasonic pulse velocity can be used as a structural health monitoring device. To provide the evidence a finite element analysis of clock tower is done so that the stress values on different walls can be compared to UPV result values at those particular walls.

As modelling in ABAQUS is very difficult task but as it is known that softwares are used to save our time for the analysis, so it is always better to use a separate software for the 3-D modelling of the structure because they are very handy, easy to use and time saving. In this paper AUTODESK FUSION 360 is used for 3-D modelling.

Here is a pictures of model from the AUTODESK FUSION 360

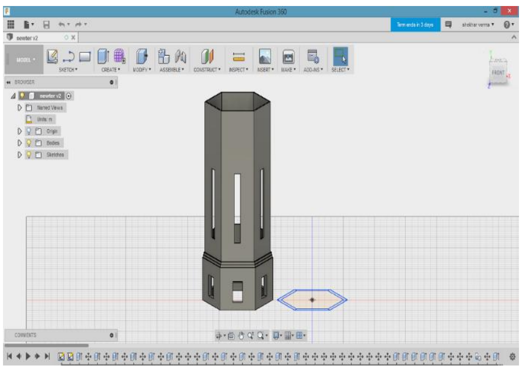


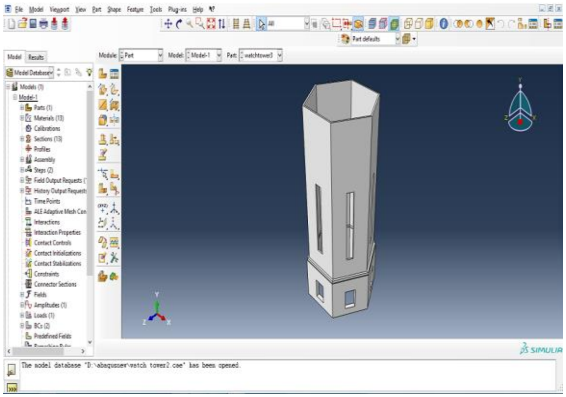
Figure 2

All of the dimensions are taken from the real structure, but there is always a possibility of human error while measurements.

The model from the AUTODEK FUSION 360 is then imported in ABAQUS 6.14.

Here are the steps for importing the file.

- Save the file in *.sat* format because ABAQUS allows only few extensions and *.sat* is one of them
- Open ABAQUS select standard/explicit model and right click on parts on the left side table click on import, select file type *.sat.*



Part imported in ABAQUS 6.14 (figure3)

The main steps for finite element analysis on ABAQUS 6.14 are as follows:-

- After importing the file from AUTODESK FUSION 360, the most important thing is to assign the material properties to the model. Click on Materials and then define the elastic and plastic properties which are already been discussed above.
- After defining properties the next step is to define section, then extend the parts tab and click section assignment. The structure should look like this after assigning the properties.

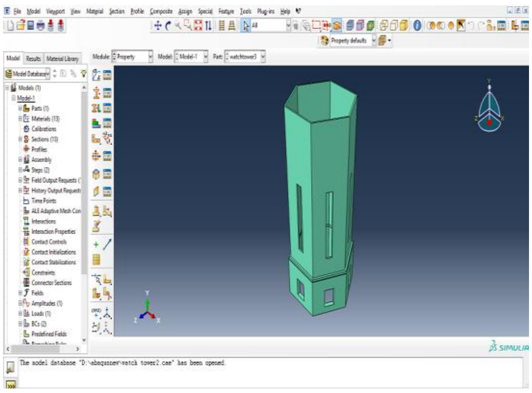


Figure 4

- Go to the assembly tab and double click on instances. Instances is to tell ABAQUS that whether the structure is dependent or independent of mesh. In this case it is mesh dependent.

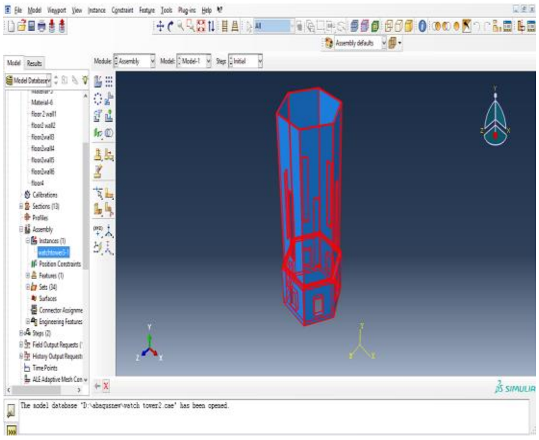
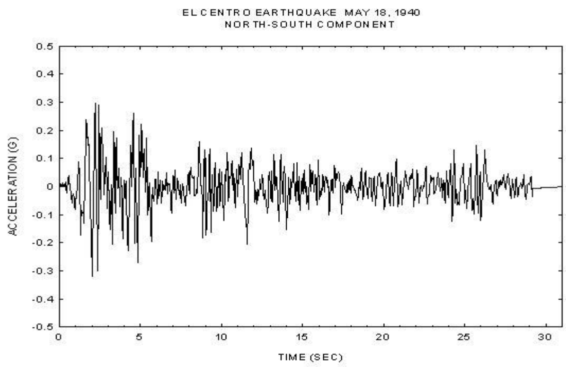


Figure 5

Model after instances dependent on mesh

- Double click on steps to define the loading steps that are occurring on the model. In this case earthquake is taken as the main load. Check dynamic implicit type load under earthquake loads.
- Now as a time history is being given so that structure can feel a real life seismic event. The time history taken is from EL CENTRO earthquake which occurred in western part of America.



(Figure 6)

With reference to

http://www.vibrationdata.com/elcentro.dat

This is the acceleration vs time wave

- Now double click on the field output request, this is for the desired output that you need after the analysis such as stress, strain, energy, displacement.

- Loads are to be assigned now, as the structure does not have any live load so only dead load will be assigned.

Calculation of dead load

The structure is a hollow hexagonal so to calculate the dead load we need the volume of the structure. Only the walls need to be considered to calculate the volume.

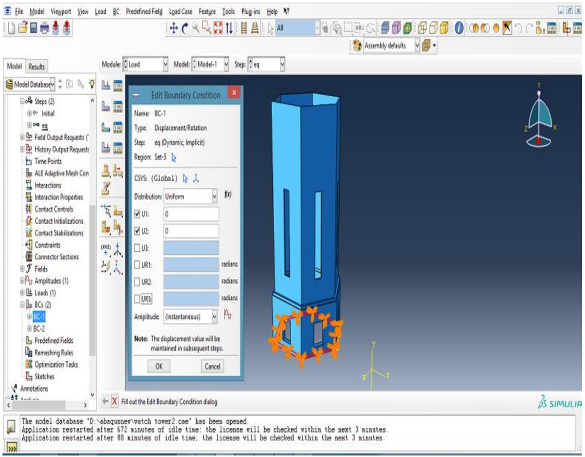
DEAD LOAD = (*AREA OF ONE FACE WALL*6*)**HEIGHT*UNIT WEIGHT OF MASONRY*

Volume = {(0.5*5.67*9.89)-(0.5*4.98*4.28)}*6(*walls*)*25.14(*height*) = ***2621.74 m***^{3}

Unit weight of masonry = 1920 kg/m^3

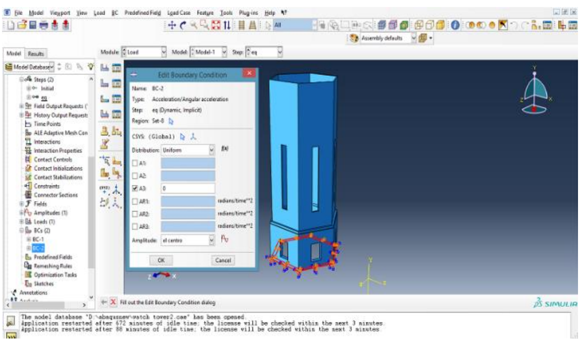
Dead load = ***50.337 E+06 N***

- After loads we need to assign boundary condition for the applied load. Double click on boundary condition and choose displacement and rotation which is required to be measured.



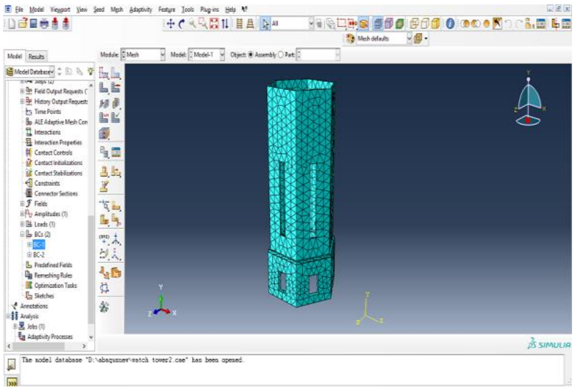
Boundary condition 1 (figure 7)

- In the above shown boundary condition for the movement of model in two direction that is X and Y area made fixed whereas in Z direction it is free to move.



Boundary condition 2 (figure 8)

- In the above condition acceleration is provided in the Z direction.
- Now next step is to do meshing so go to the part tab and the last option will be mesh. Double click on mesh and choose the quadrilateral meshing.



Quadrilateral Meshing (figure 9)

- Create a job and submit it, if there will be any error right click on created job and monitor it but if the job submission is completed then go to results.
- This is the complete process of doing a finite element analysis on this particular structure.

4.6 Results from ABAQUS 6.14

After the submission of a job, the ABAQUS allows us to watch the results. ABAQUS provides a vast amount of results as the finite element analysis is the process of disintegration a larger structure into small discrete elements. The analysis is carried out on these small discrete elements and then integrated together to combine the whole structure so that the analysis and results can be more accurate and precise. This is one of the best method of analysing a structure. But if we are doing it manually then it is very lengthy and time taking therefore software like ABAQUS and ANSYS are used for FEA.

The stress and strain is to be calculated on separate walls so that the average value can be compared with the results of ultrasonic pulse velocity test.

As the mesh is a quadrilateral so each element will have 4 nodes and ABAQUS will give stress and strain at each node. There are more than 7000 nodes in this model.

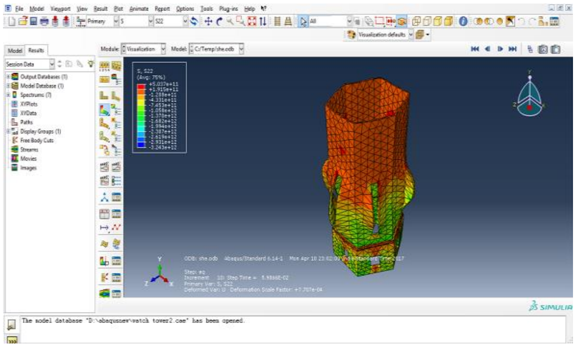


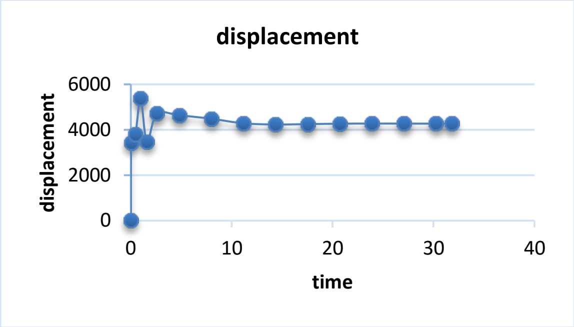
Figure 10

Field output request in ABAQUS gives the values of stress, strain at each node of the structure. But the values of displacement at each node cannot be taken from ABAQUS. The deformed shapes are shown with respect to time give in time history. In these deformed shape shown above in the pictures, the areas are highlighted where there is larger displacement. The red area shows the maximum displacement. From those deformed shapes the maximum values are taken and show in the table below with respect to time.

Table2

time	displacement
0	0
5.91E-02	3.43E+03
0.4777	3.80E+03
0.9809	5.38E+03
1.603	3.48E+03
2.602	4.71E+03
4.812	4.64E+03
7.992	4.49E+03
11.17	4.29E+03
14.35	4.24E+03
17.53	4.25E+03
20.71	4.27E+03
23.89	4.28E+03
27.07	4.27E+03
30.25	4.27E+03
31.8	4.27E+03

So the values of displacement is very high as the magnitude of the earthquake is 7.1 with huge amplitude of acceleration shown in figure of EL CENTRO acceleration vs time graph.



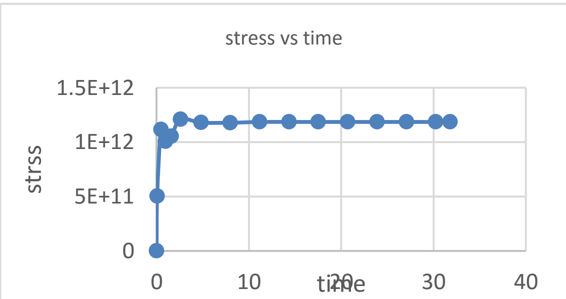
Graph 1: Displacement vs time

The graph has been generated on the basis of the table given above. At 0.005 seconds the amplitude of earthquake is highest so at that point the displacement is highest which can be seen from the graph.

Similarly the maximum stress values are also shown with respect to time to give an idea about at what time it is showing maximum stress.

Table 4 Based on these values graph is shown below

time	stress
0	0
5.91E-02	5.04E+11
0.4777	1.12E+12
0.9809	1.01E+12
1.603	1.05E+12
2.602	1.21E+12
4.812	1.18E+12
7.992	1.18E+12
11.17	1.19E+12
14.35	1.19E+12
17.53	1.19E+12
20.71	1.19E+12
23.89	1.19E+12
27.07	1.19E+12
30.25	1.19E+12
31.8	1.19E+12



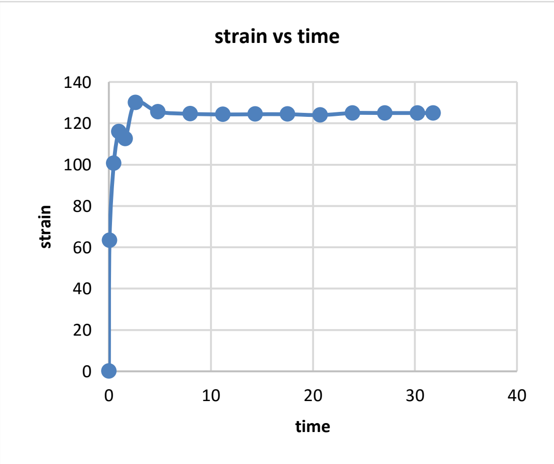
Graph 2: Stress vs time graph

As it is a nonlinear analysis so plastic properties of masonry has to be mention in ABAQUS. The deformation was way too much and the stress was beyond the permissible limit. ABAQUS was not able to submit the file because of this large deformation.

Table 5

time	strain
0	0
5.91E-02	6.33E+01
0.4777	1.01E+02
0.9809	1.16E+02
1.603	1.13E+02
2.602	1.30E+02
4.812	1.26E+02
7.992	1.25E+02
11.17	1.24E+02
14.35	1.24E+02
17.53	1.24E+02
20.71	1.24E+02
23.89	1.25E+02
27.07	1.25E+02
30.25	1.25E+02
31.8	1.25E+02

As explained above that amplitude is highest at 0.005 seconds so the strain is highest at that point.



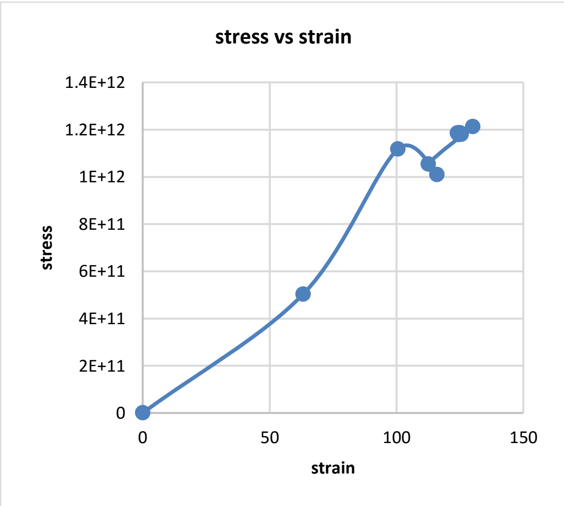
Graph 3: Strain vs time graph

Linear analysis is the one in which stress is directly proportional to the strain, and the ratio of stress to strain follows the Hooke's law. But the proportionality is shown in the graph is linear for a range but after that it becomes non-linear.

Table 6

strain	Stress
0	0
6.33E+01	5.04E+11
1.01E+02	1.12E+12
1.16E+02	1.01E+12
1.13E+02	1.05E+12
1.30E+02	1.21E+12
1.26E+02	1.18E+12
1.25E+02	1.18E+12
1.24E+02	1.19E+12
1.24E+02	1.19E+12
1.24E+02	1.19E+12
1.24E+02	1.19E+12
1.25E+02	1.19E+12
1.25E+02	1.19E+12
1.25E+02	1.19E+12
1.25E+02	1.19E+12

The graph is the direct representation of stress and strain from the above table.



Graph 4: Stress vs strain

This graph represents the non-linearity between stress and strain. Till the value of strain is 100 the line is a linear and after that the strain hardening starts and the materials goes beyond permissible limit.

4. Results

The objective was to compare the values of stress that we got from the finite element analysis performed on ABAQUS to the results of ultrasonic pulse velocity test. This will give a clear indication whether ultrasonic pulse velocity test can be used as a structural health monitoring device.

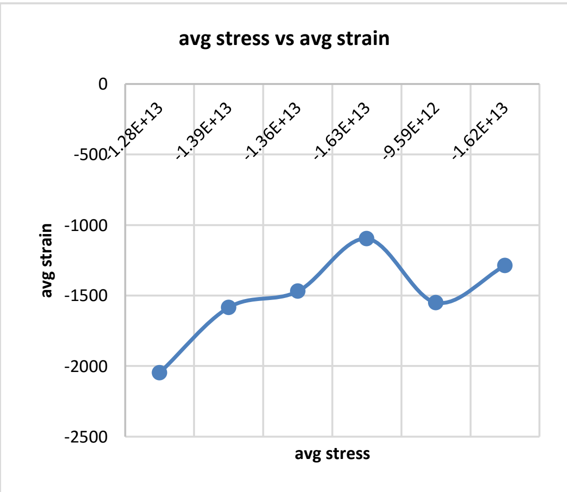
Average values of stress and strain on the ground floor of the structure is modelled in the table below. These values are for different walls but not for whole ground floor. Comparison can only be made with two quantities related to one context.

For Ground Floor

Table 7

walls	average stress	average strain	U.P.V RESULTS
wall1	-1.28E+13	-2047.67	Poor
wall2	-1.39E+13	-1584.41	above medium
wall3	-1.36E+13	-1470	Medium
wall4	-1.63E+13	-1096.66	Good
wall5	-9.59E+12	-1550	Medium
wall6	-1.62E+13	-1287.54	Good

Representing the values of average stress and strain in graph:



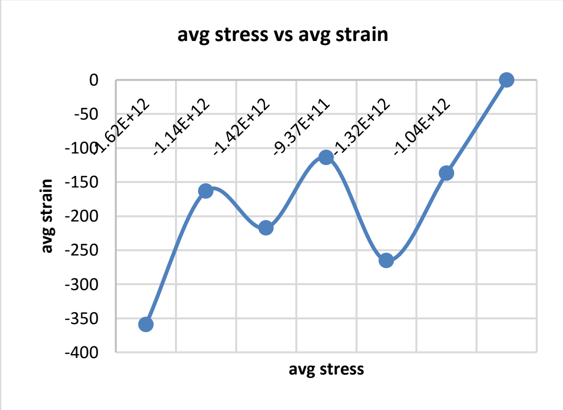
Graph 5: Average stress vs average strain (ground floor)

For first floor

Table 8

walls	average stress	average strain	U.P.V RESULTS
wall1	-1.62E+12	-359.33	Poor
wall2	-1.14E+12	-163.37	Medium
wall3	-1.42E+12	-217.146	above medium
wall4	-9.37E+11	-113.95	Good
wall5	-1.32E+12	-265.12	Poor
wall6	-1.04E+12	-137.21	Above medium

The graph for above values is



Graph 6: Average stress vs average strain (first floor)

The results that were established by comparing the values were quite astonishing as the values were matching. The quality of walls which was determined by ultrasonic pulse velocity test were proved by finite element analysis model on ABAQUS. As U.P.V test was only performed for two floors therefore the comparison is done for these floors only.

Table 9 (ground floor): Average values of rebound hammer and ultrasonic pulse velocity test

Floor	Location	Height from Ground Floor(m)	Rebound No. (Q)	Compressive Strength (N/mm Sq.)	UPV Results	Quality
Ground Floor	Wall 6	1	25.3	16.103	3694	Good
			26	16.92		
			25.9	16.804		
			26.1	17.04		
	Average		25.825	16.716		
	Wall4		27.3	18.56	3773	Good
			32.8	25.83		
			26.1	17.04		
			26.6	17.64		
	Average		28.2	19.75		
	Wall3		24.5	15.19	3156	Medium
			28.1	19.5		
			17.5	8.23		
			14.6	5.92		
	Average		21.175	12.21		
	Wall1,5		18.8	8.34	3312	poor
			18.8	8.34		
			18.5	8.3		
			18.11	8.38		
	Average		18.8	8.34		
	Wall2		20	10.5	3703	Good
			22.9	13.43		
			20.5	10.9		
			21	11.2		
	Average		21.1	11.5		
	Average GF		23.04	13.7		

Table 10 (first floor): Average values of rebound hammer and ultrasonic pulse velocity test

floor	walls	compressive strength	U.P.V results	condition
floor2	wall1	5.34	3213	poor
	wall2	7.64	3359	medium
	wall3	7.64	3359	medium
	wall4	10.21	3689	good
	wall5	5.34	3213	medium
	wall6	8.93	3478	medium

5. Conclusion

When the magnitude of earthquake was 7.1 the values of stress and strain were way beyond the permissible limit but as the magnitude was decreased, the values of stress and strain also started showing variations. It was observed that at 5.1 magnitude the values were under permissible limit and the structure was supposed to be safe.

Masonry is a very old form of construction but still a lot of research is needed to be done. The formulas used as input in the finite element analysis model in ABAQUS were taken from various journals and it cannot be verified. So, further study is needed in this field.

The main objective was to confirm whether ultrasonic pulse velocity test can be used as structural health monitoring tool, which was validated by the results of finite element analysis on ABAQUS.

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