MICRO MODELLING OF MASONRY WALL

USING ABAQUS

FINAL YEAR PROJECT UG 2016

By

RAFAY JAHANGIR-NUST2016188805

MEHRAN HAMEED-NUST2016143439

WALEED AHMAD KHAN-NUST2016177144

NUST Institute of Civil Engineering (NICE)

School of Civil and Environmental Engineering (SCEE)

National University of Sciences and Technology (NUST), Islamabad, Pakistan

2020

This is to certify that the

Final Year Project Titled

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Submitted by

RAFAY JAHANGIR-NUST2016188805

MEHRAN HAMEED-NUST2016143439

WALEED AHMAD KHAN-NUST2016177144

has been accepted towards the requirements

for the undergraduate degree

in

CIVIL ENGINEERING

____

Dr. Ather Ali

Assistant Professor

NUST Institute of Civil Engineering (NICE)

School of Civil and Environmental Engineering (SCEE)

National University of Sciences and Technology (NUST), Islamabad, Pakistan

Dedication

To our teachers, beloved parents, mentors and colleagues who have always encouraged us in hard times, who have taught us to never give up and always believe in hard work.

Acknowledgements

In the name of Allah, who is the most Beneficent, the most Merciful.

We are heartily grateful to all those who guided us throughout the project. Without their help and assistance, this would have been impossible.

Special thanks to Dr Ather Ali, who was always with us throughout this journey. There has never come a day when he failed to provide assistance. He helped us in understanding the complex modelling and analysis in ABAQUS software. We are in debt to him for his constant support.

To all the lab staff at structural engineering lab at NICE who compromised with us.

To Mr. Bibarg (MS Structures) who also assisted us in understanding some concepts of numerical modelling in Abaqus.

And to everyone who's involved with this project directly and indirectly, we thank you for such a wonderful contribution.

ABSTRACT

Numerical modelling has been done on the historical masonry structures. Mainly, two types of modelling is associated with masonry structures. Micro modelling and macro modelling. For large structure, macro modelling is adopted and for small scale modelling, the suitable technique is the micro modelling. All this is done to simulate the masonry structure and investigate its response on loading condition and how they behave in such conditions, how their crack propagates, what are their weak zones. This study will be going to numerically model two panels. One of solid wall and the second one with opening at the center in Abaqus 2020 software. The main idea is to analyze the response of these wall panels under certain loading pattern and investigate its behavior and its propagation of cracks. The weak zones will be identified in both cases and difference in the behavior of the two and their response against the loading will be observed and retrofitting techniques will be discussed.

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CHAPTER 1
INTRODUCTION

1.1 General

Numerical modelling of masonry has been extensively used as a tool to investigate the behavior of brick walls under certain loading conditions. Masonry can be modelled as a two phase composite material i.e. the brittle elastic component (brick) and the mortar component that exhibits the inelastic strains due to damage phenomena [1].

Modelling of masonry structures has now become more important need to investigate the strength of the already existing structures, testing them under different loading conditions and for the building of new masonry structures. Different patches of walls are modelled and analyzed to know about their failure mechanism and their general response under certain loading scenarios [13].

The structural behavior of masonry is greatly dependent and determined by its parameters like its shape, geometry of its member, chemical and physical properties of its elements. These mentioned reasons make the analysis process of the masonry structure, a difficult task [2].

For the modelling of structures, the most advanced and commonly used approach is FEM, the Finite Element Analysis. The possibilities based on FEM Analysis fall into two categories that are; modelling at micro level (which can be extended to detailed micro modelling) and modelling at macro-level. A hybrid model can also be generated that analyzes small details of a specific structural component in a very complicated structure.

Micro-modelling is that type of modelling in which the localized areas and effects are under study and is applied where a complete knowledge about the geometry and materials are available. Detailed micro modelling has more degree of accuracy but the modelling effort and the time for calculation is much more as compared to the other modelling techniques.
Whereas in macro modelling all elements of the structure of materials are included into a single

continuum. Most commonly used because of quick calculation time than that of micro modelling [2].

1.2 Problem statement

The general behavior of masonry structure under certain loading conditions is quite complex. It is very unpredictable to anticipate its behavior under conditions of loading for example like that of seismic loading. The main problem is to investigate where the weak spots lie when a panel of wall undergo loading conditions. After modelling and analyzing the masonry structure which, in our case, are different panels of masonry wall, we can find the spots and places where the strength of the wall is greatly comprised and where should the retrofitting be provided. Mainly our research is intended towards the enhancement of masonry wall in term of its strength. Moreover, we can also be in position to try and add a new material in the composition of wall and investigate its behavior under loading and compare with conventional composition of wall and see the difference between the two. Hence the behavior of masonry wall with a new material composition can also be investigated. Our research is going to cater to these problems by modelling and analyzing the behavior under loading of different panels of masonry wall.

1.3 Research objectives

The main objective of this research are:

- To model the masonry wall panel with and without opening using ABAQUS software by applying simplified micro modelling technique.
- Analyzing and comparing the behavior of the above two models under pressure loading.
- Retrofitting the models with FRPC panels and then investigating its behavior again.
- Using parametric study to know about its response i.e. the crack pattern, the load displacement curve, effect on its strength, under the pressure loading.
- Strength comparison of these models.

1.4 Limitations

The main limitation of this research study is associated with the irregularities of mortar during the modelling process of masonry wall panel. In reality, the mortar is not uniformly distributed all over the wall (not equally placed at all joint surfaces). While in modelling, we assume it to be equally distributed along the joint surfaces. So there is always a difference between the masonry wall panel in reality and its numerical model which implies that the numerical model will not always correspond to the masonry wall panel in reality and there will always be errors and differences associated with the modelling results. Furthermore, we will only be doing the simplified micro modelling technique surpassing the modelling and computational efforts because of time constraints that will be explained in detail in the coming chapters.

CHAPTER 2
LITERATURE STUDY

2.1. General

The literature study is comprised of three parts. The types of numerical modelling, the historical background of numerical modelling on masonry walls and the use of FRCP and GRCP panels to enhance its strength (retrofitting).

There are many other techniques as described in the start like macro modelling or detailed micro modeling but for our convenience, the technique we are acting upon is the simplified micro modelling technique which is going to be discussed further.

The previous researches provided a detailed account on how the numerical modelling has been done on different masonry structure, what techniques for modelling have been adopted and what are their investigation/ observations. Furthermore, to investigate the effects of different input parameter on the general response of the masonry structure, parametric study was done.

2.2. Modelling strategies

Because of the increased capacity of computers, it has now been possible to integrate the response of the material like masonry and do simulation in the modelling softwares considering their linear or nonlinear behavior. One of the method used is the Finite Element Method FEM which involves the basic unit called as finite element. Finite element does not represent the whole structure but rather its fragment parts.

Other methods in work are Discrete Element Model DEM, Discontinuous Deformation Analysis DDA & Structural Element Model SEM. DEM and DDA are commonly used for the application of rock mechanics similar to problems related to masonry. They can also be used for analyszing and investigating the failure mechanism of the masonry structure.

For this research work, we will be using the Finite Element Modelling strategy because it the most advanced one and mostly softwares have been using the FEM for the analysis purpose.

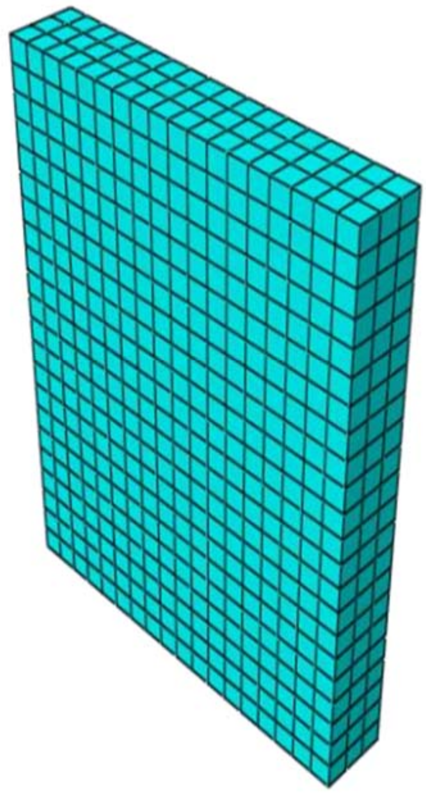

Figure 2.1. Finite element method – meshed masonry wall

2.3. Types of numerical modelling

The types of numerical modelling of masonry structures are being discussed in the following paragraphs.

2.3.1 Micro modelling

In it, the mortar and masonry units are described by the continuum finite elements and the interface is represented by a discontinuous element to account for slipping planes and cracks [2]. The main purpose of the kind of modelling is to represent the small details of the masonry structure on the basis of their properties of the constituent elements and interface. The micro modelling technique is commonly used for the analysis of the structural element of the whole masonry structure like load bearing wall. It is not commonly used in large systems although it is a best way to represent the realistic behavior of masonry walls. However the researches were more focused on a inventing a technique which will provide a quick solution to the large systems and is supported on a low capacity computers. Simplified micro modelling is one of them. [14]

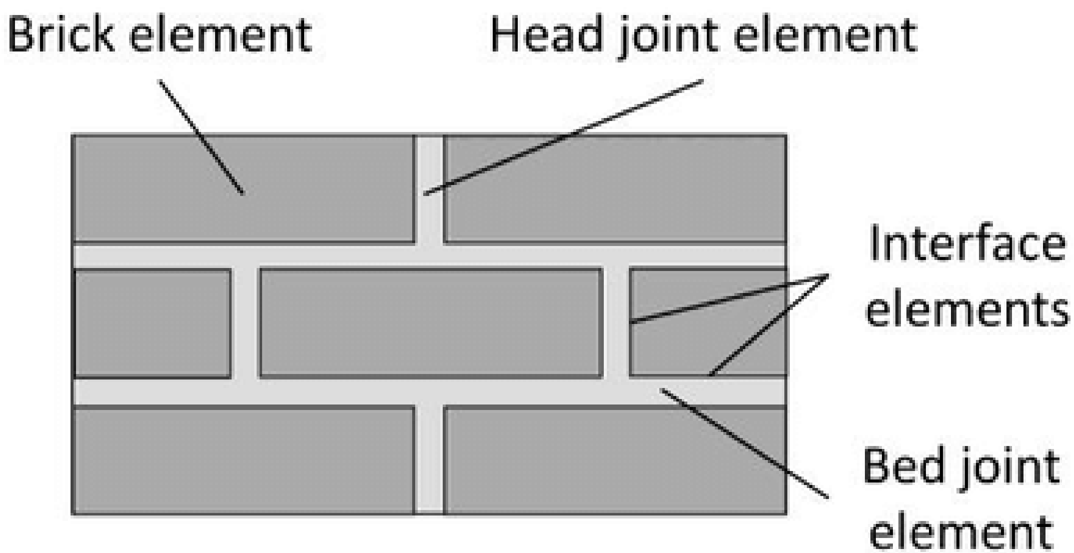

Figure 2.2. Detailed micro model of masonry

2.3.2 Simplified micro modelling

At micro modelling level in FEM, the better method which is commonly used is the simplified micro modelling. In it, the units are extended by including the mortar thickness, the extended units are displayed as a progression of continuum components and the link between the extended units is demonstrated as arrangement of discontinueum components. It is used to address the disadvantages caused by the detailed micro modelling which includes the heavy computational efforts thus increasing the time and limiting the simulation to a very small masonry units or elements [3].

It is also found from the literature that the in micro modelling the global behavior gives accurate results when compared with that of the detailed micro modelling [4].

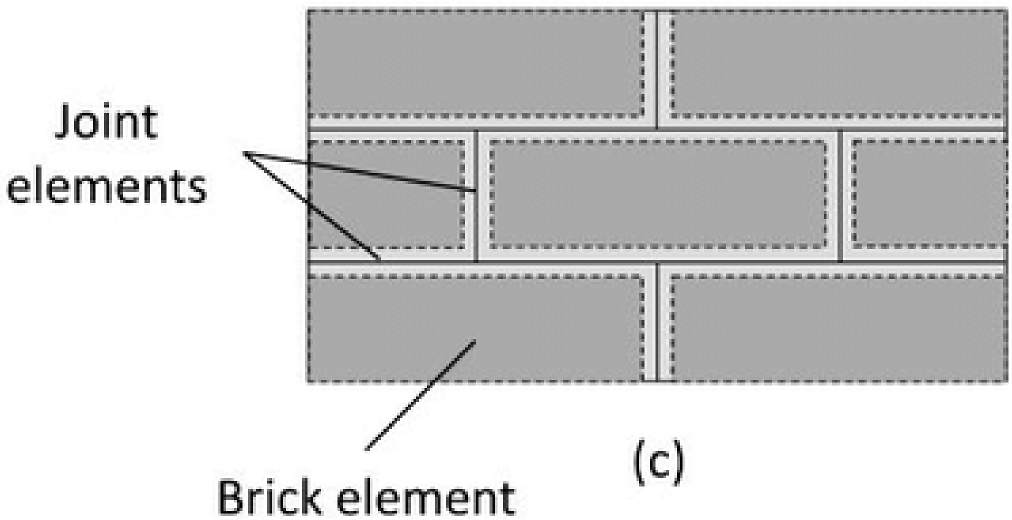

Figure 2.3. Simplified micro model of masonry

2.3.3. Macro modelling

Some authors have also adopted the this technique using macro mechanical model also called as homogenous or continuous models. In this type of modelling, all the elements of the assembly is represented in a single continuum. It is the most commonly used technique while dealing with large structures and requiring less and fast calculations. In large scale masonry structures, there is no need to describe the interaction between mortar and units in detail. Because of this, macro modelling may give an approach towards the depiction of structural response of the masonry [2].

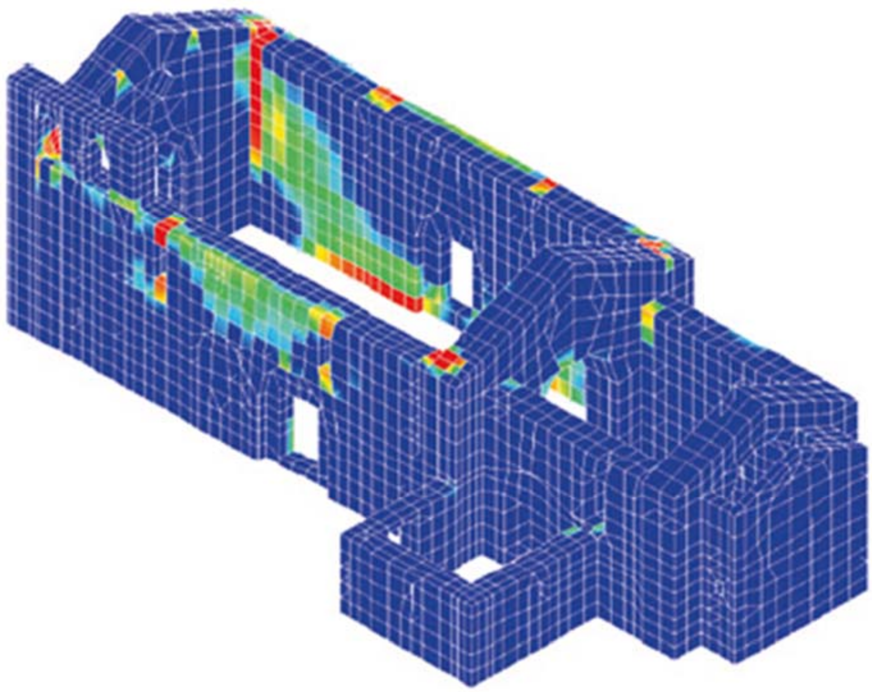

Figure 2.4. Micro modelling of large system (Gondar Church)

This model is not suited for small details of the masonry structures or the element itself. Many researchers have made macro models that reduces the degree of freedom and thus, the time for calculation for the analysis of the response of the masonry structures [14].

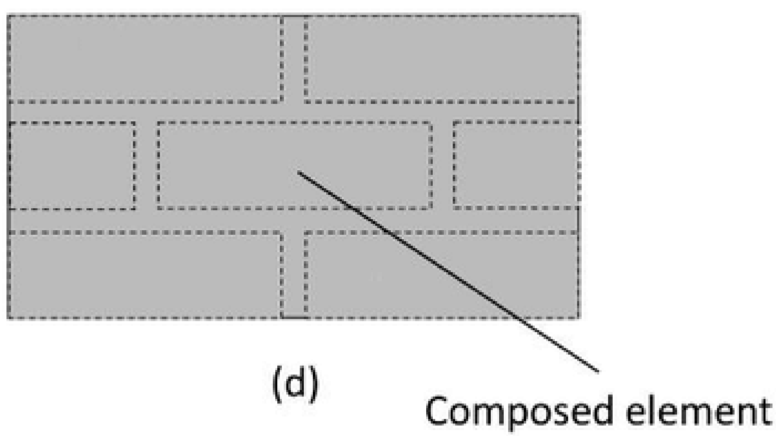

Figure 2.5. Macro model of masonry

2.4. Historical background of numerical modelling of masonry

Many researchers have conducted the numerical modelling to look into the complex behavior and response of different masonry structures. Some of the research works on numerical modelling is being discussed in the coming paragraph.

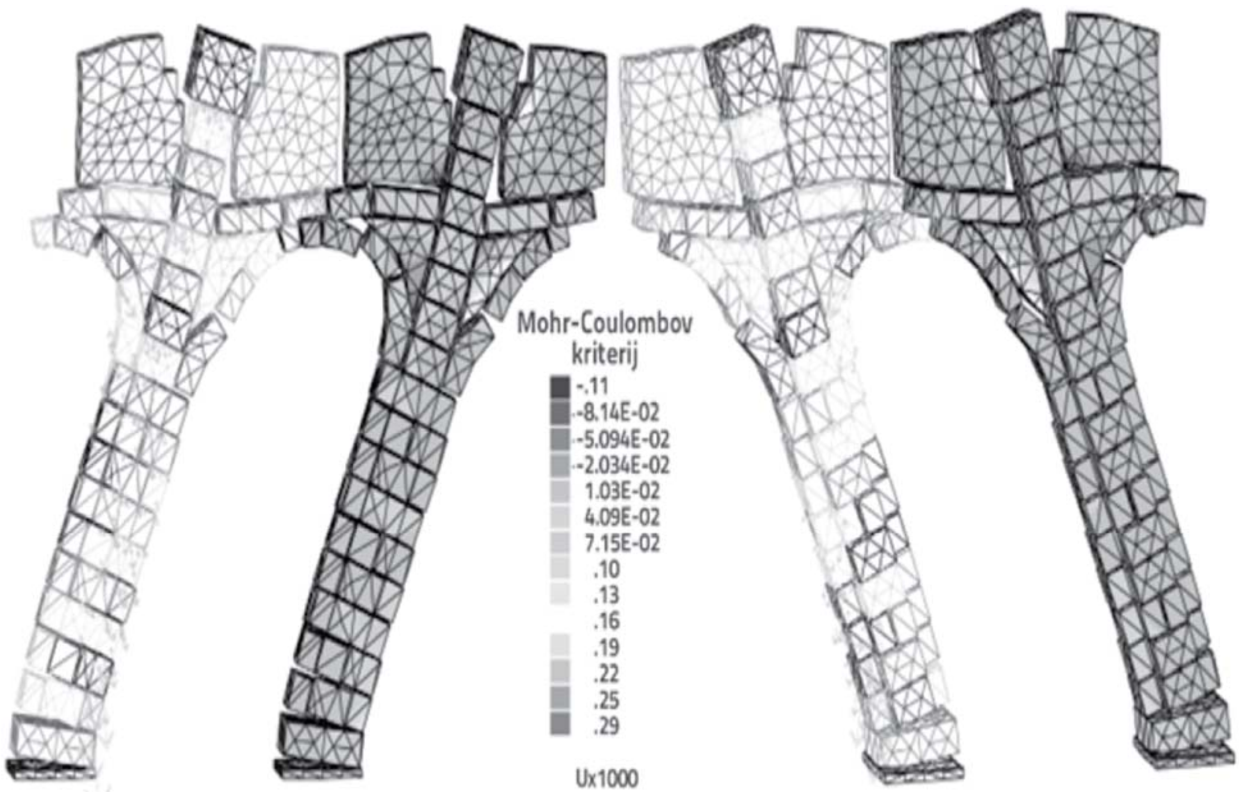

Figure 2.6. Simplified micro level of pillars at the Saint Vincent

Arya [5] and Page [6] modelled the masonry structure by taking masonry units as continuum elements and mortar joints as interface elements which is simplified micro modelling. Then this technique was further proceeded by Lotfi and Shing [7] to investigate the behavior of masonry by taking into account the fracture of mortar joint in the model using interface elements. However the simulation and results were not satisfactory under high compression stress. Lourenço and Rots [8] formulated a model by accounting for three yield effects that are cap model for compressive failure, tension cut-off for tensile failure and Mohr-Coulomb failure envelope for shear failure. Shing and Cao [9] worked on the masonry shear wall and prepared a smeared crack model for accounting of fracture behavior of the masonry elements and checking their tensile and shear response. Oliveira and Lourenco [10] further proceeded with the Lourenco and Rots [8] model for modelling and accounting for the cyclic behavior of the interface element. Some authors have also used the detailed micro modelling technique on the analysis of the stone masonry structure while simplifying the masonry into its basic components [2].

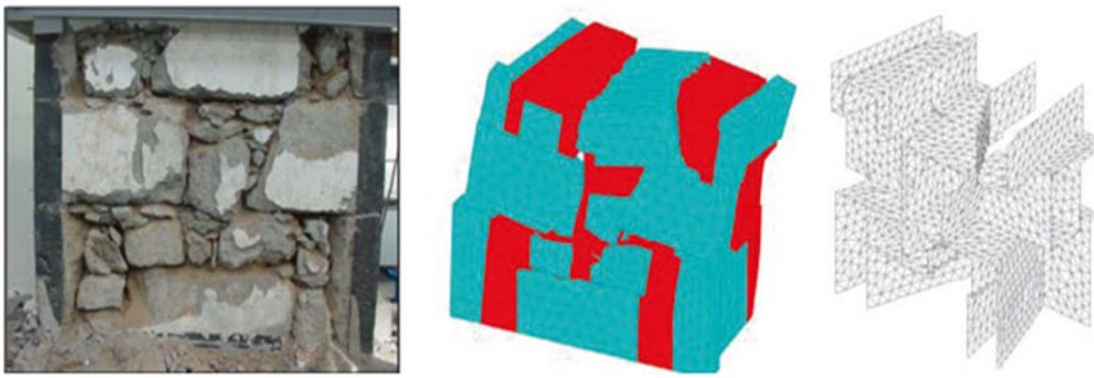

Figure 2.7. Detailed micro modelling on stone masonry

The work of Oller should also be mentioned because he learned the numerical modelling of masonry wall which is the basic of this research [15]. Berto et al. investigated the behavior of masonry prism under axial pressure by modelling and analyzing in 2D and 3D using micro modelling technique [16]. Chaimoon and Attard used the micro modelling technique to derive a formula for investigating the behavior of masonry wall when it undergo shear and compression failure [17].

2.5. FRCP panels for retrofitting

The numerical modelling proved to be very reasonable since the results obtained from modelling matches with that obtained by performing experiments. This cuts off the cost of testing the material experimentally since the same can be done on softwares. In this way numerical modelling provides a cheap solution to these problems. The overall stress and strain curves of the modelled masonry structure clearly matches with that, found by experimentation. Hence, as far as the application of FRCM overlays are concerned, it proves to be very useful since it simplifies the design procedures intented for the strenghening of masonry strcututes [11].

It has also been investigated that the use of FRCP panels have resulted in the decrease of stresses in the masonry wall panel since the tensile stresses were transferred to the FRCP panel grid. Moreover it has also been concluded that the most efficient one is the vertical strips of FRCP since it transferred most the tensile stresses. Shear strength has also been noted to increase when the masonry is strengthened with FRCP overlays [12].

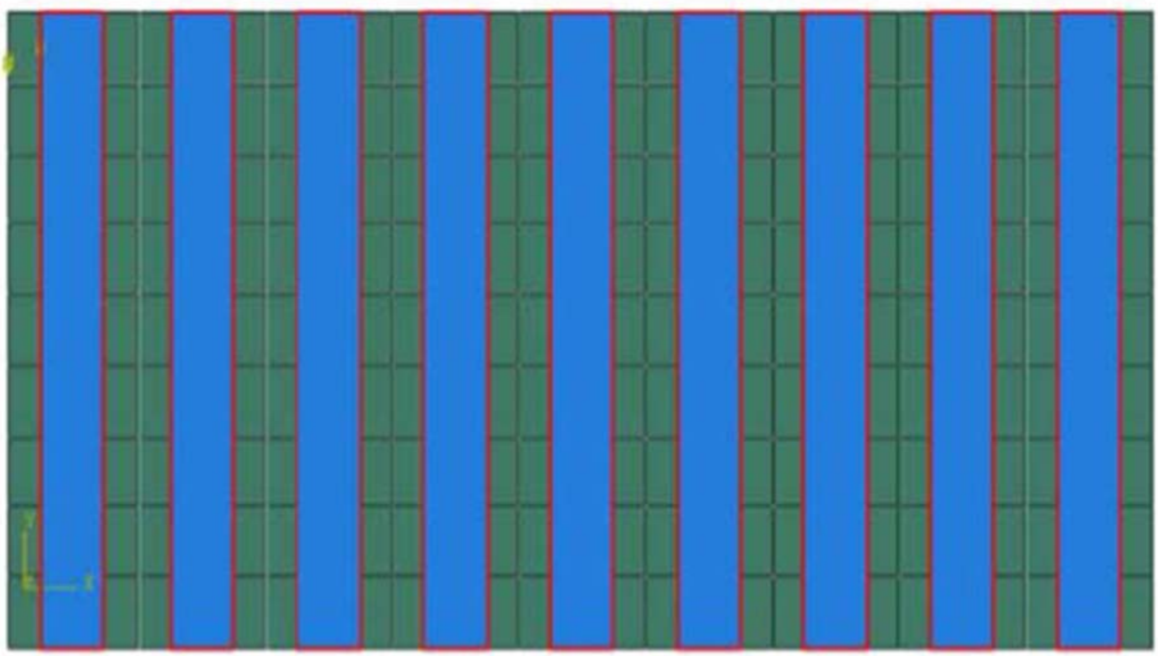

Figure 2.8. Modelled wall strengthened with vertical FRP Strips

2.6. GFRP composites

Another material used for the strengthening of masonry wall is the Glass fiber reinforced polymers composites which is a light weight thin material that has shown great performance when retrofitted with URM walls. Studies have shown that the use of grfp composites in masonry wall has resulted in the great deal of increase in shear resistance of the masonry wall

[12]. It was also shown in the same study that the walls strengthened with gfrp performed very well when undergone through the design basis seismic loading scenario.
One of the main reason for using the gfrp is that it offers a very high strength and young's modulus than a normal steel meshes hence the provision of masonry structure is established with the use of gfrp composites. It has also been reported in research that the use of grcp on both sides of the wall resulted in increasing the flexure strength up to 32 times its own weight of the wall [19].

Figure 2.9. GFRP wrapped wall

CHAPTER 3
VALIDATION OF MODEL

3.1. General

To validate our numerical model, we used the data and results given in ASTM E 519-02 for experimentally tested masonry wall. The wallet test was also performed numerically on our masonry model with ABAQUS. This was done to validate our model i.e. to check whether our model is correctly modelled or not. The input parameters for modelling the masonry wall panel were taken out from the literature [20] where the walls of same dimensions and geometry as ours, were tested experimentally according to ASTM 519-02. The test experimentally performed on the wall panel is known as 'Wallet Test'. Finally, the general crack pattern, time displacement curves and time reaction curves were generated and compared with that of the numerically tested model. In this way, our numerical model was validated with the help of lab experimentations.

3.2. Comparison between numerical and experimental results

In the coming figures, the displacement-reaction curves for the hollow and solid wall panels are given.

The following displacement-reaction curve was found from the literature review [20]. The blue line (non-retrofit as in our case) is basically the curve which is the basis for the validation of our model. It is the result of wallet test.

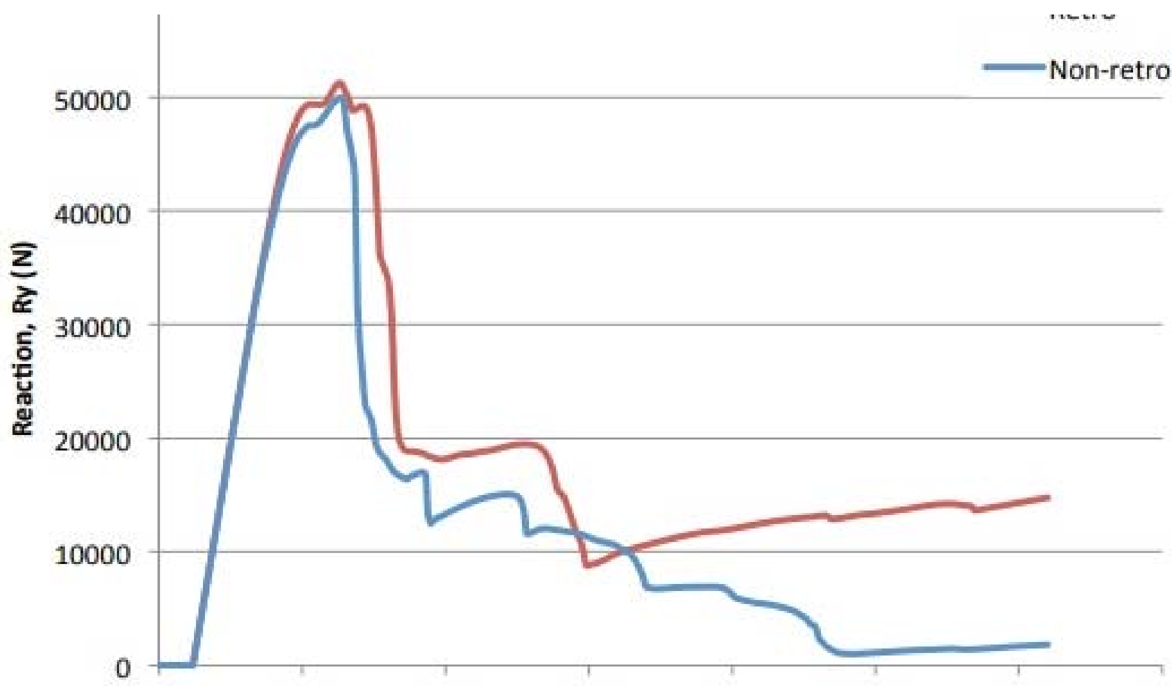

Figure 3.1. Displacement vs reaction curve (blue line) from literature

Now, let’s have a look at the figures depicting the numerical results of the same wall modelled in Abaqus to check for the validation of our model.

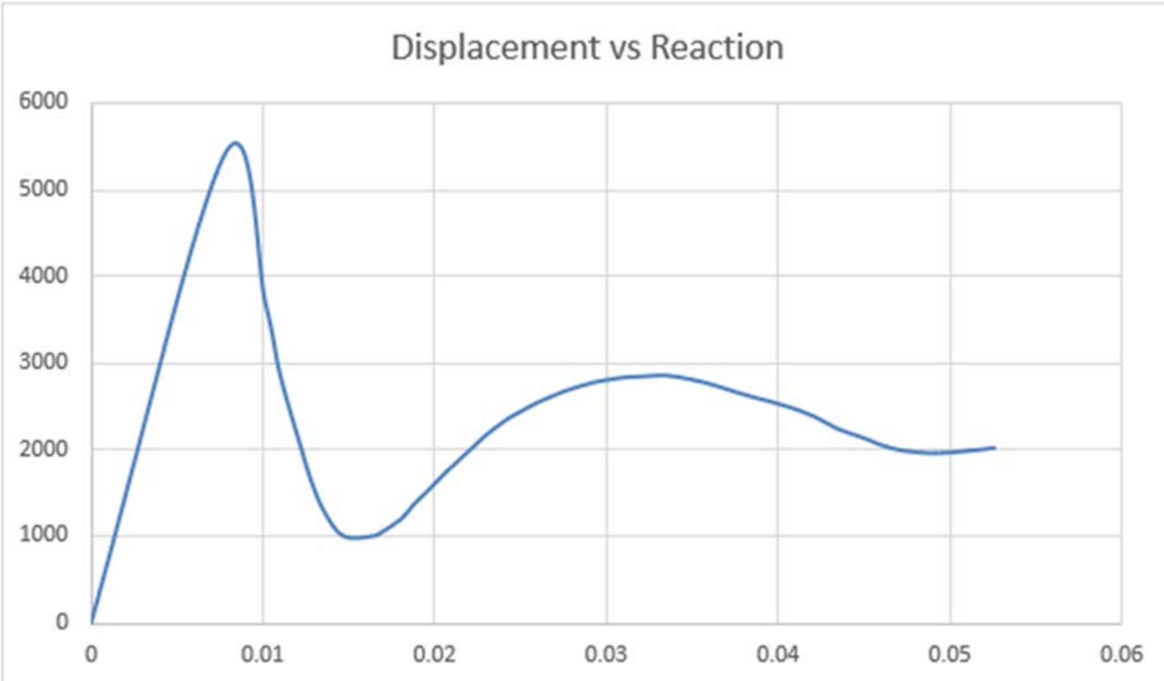

Figure 3.2. Displacement vs reaction curve of numerical model

The displacement is given in centimeters while the reaction is given in Nx10.

3.3. Conclusion

The comparison of the above graphs concludes that our numerical model is in line with the literature study and is coinciding with the experimental results of the wallet test. Thus our model is validated. As it is quite evident that the graphs are identical to each other with just 6% difference in the results with the online literature [20].

3.4. Input parameters

These are the input parameters/specification or material properties of our model for further analysis which are found in the literature after successfully verifying our model with the experimental results. These values are used throughout the research from modelling to analysis.

3.4.1. Young's Modulus and Poisson's Ratio

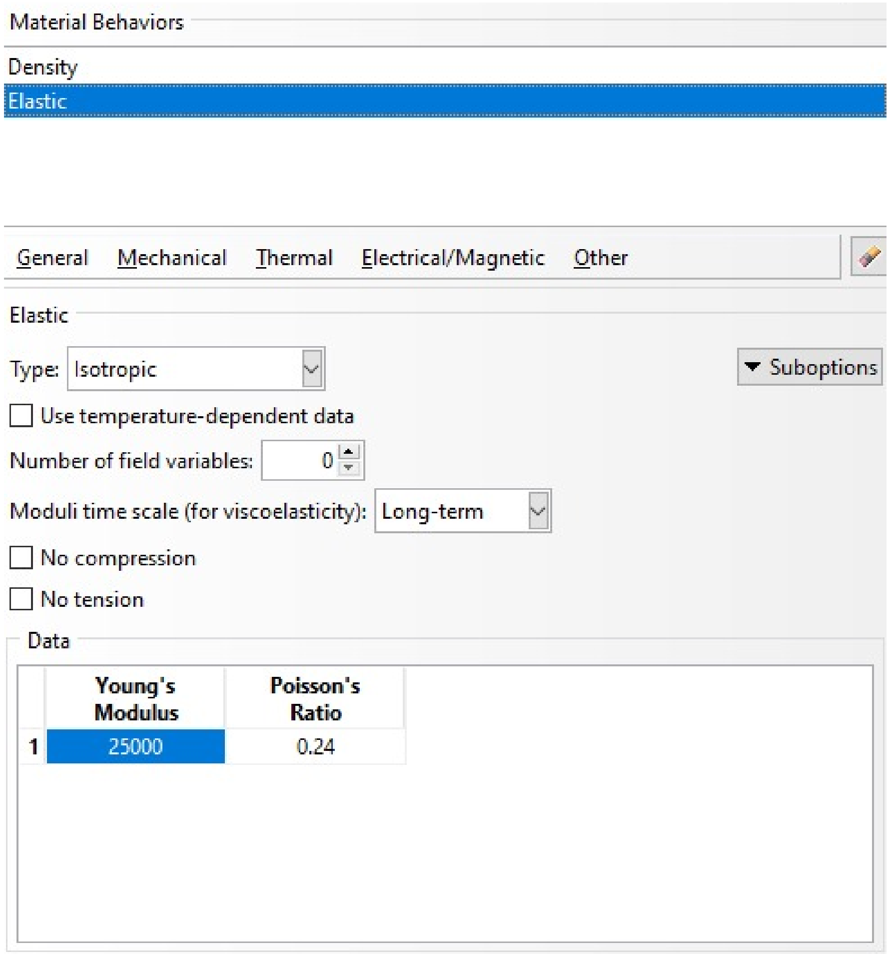

Figure 3.3. Elasticity of model

3.4.2. Coefficient of friction

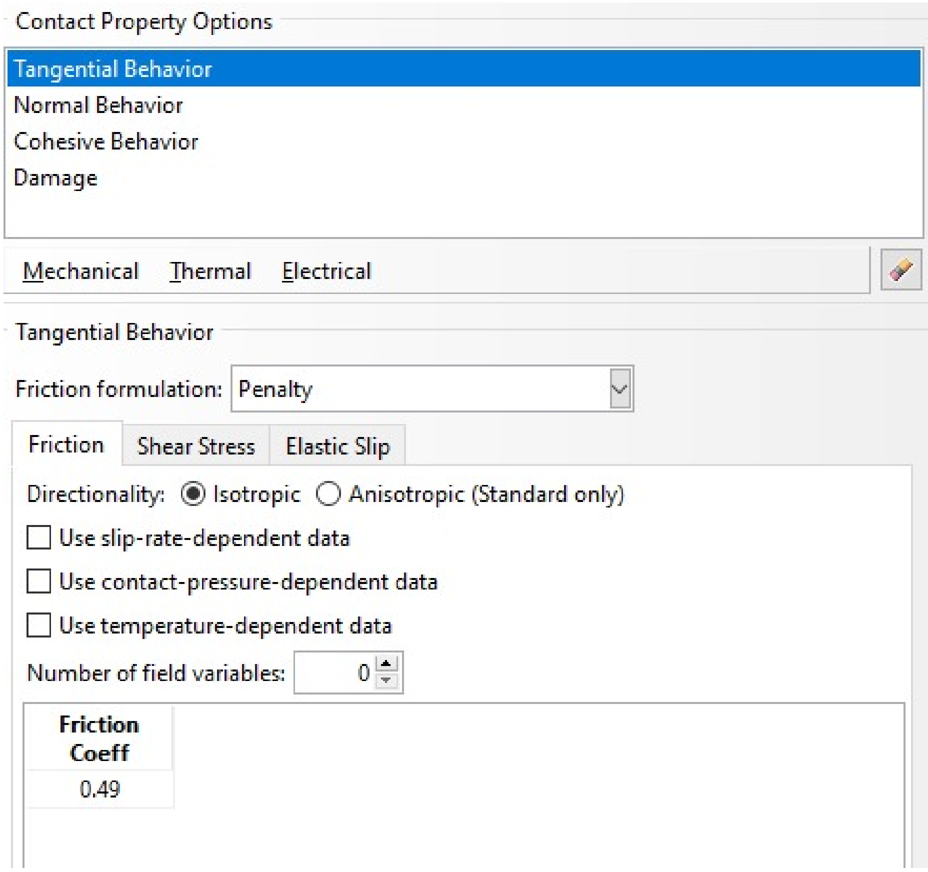

Figure 3.4. Frictional coefficient

3.4.3. Viscosity coefficient

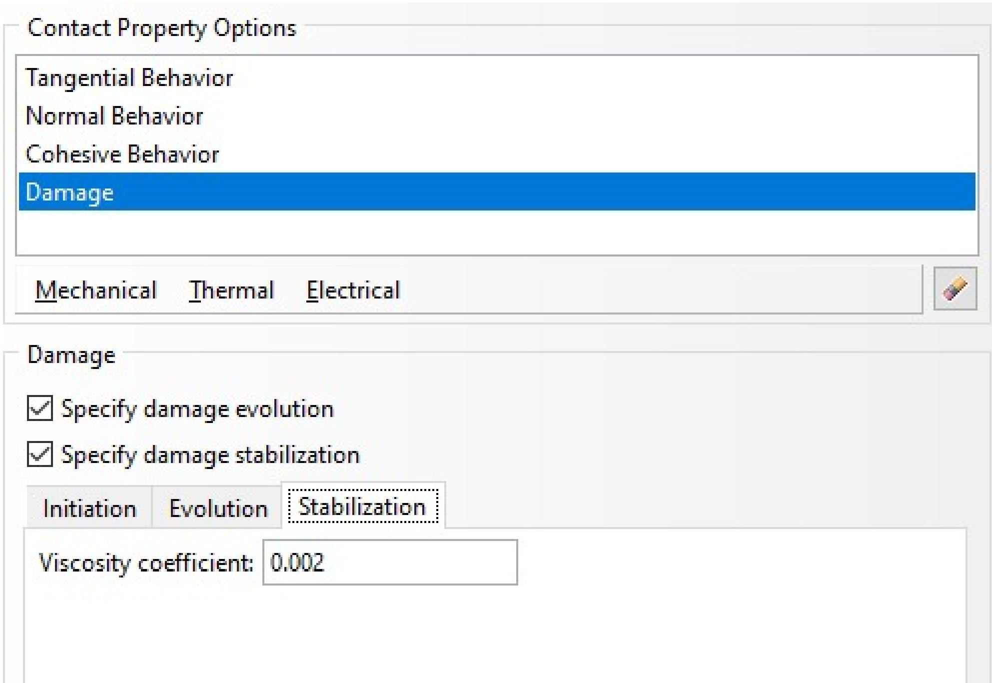

Figure 3.5. Viscosity coefficient

3.4.4. Mass density

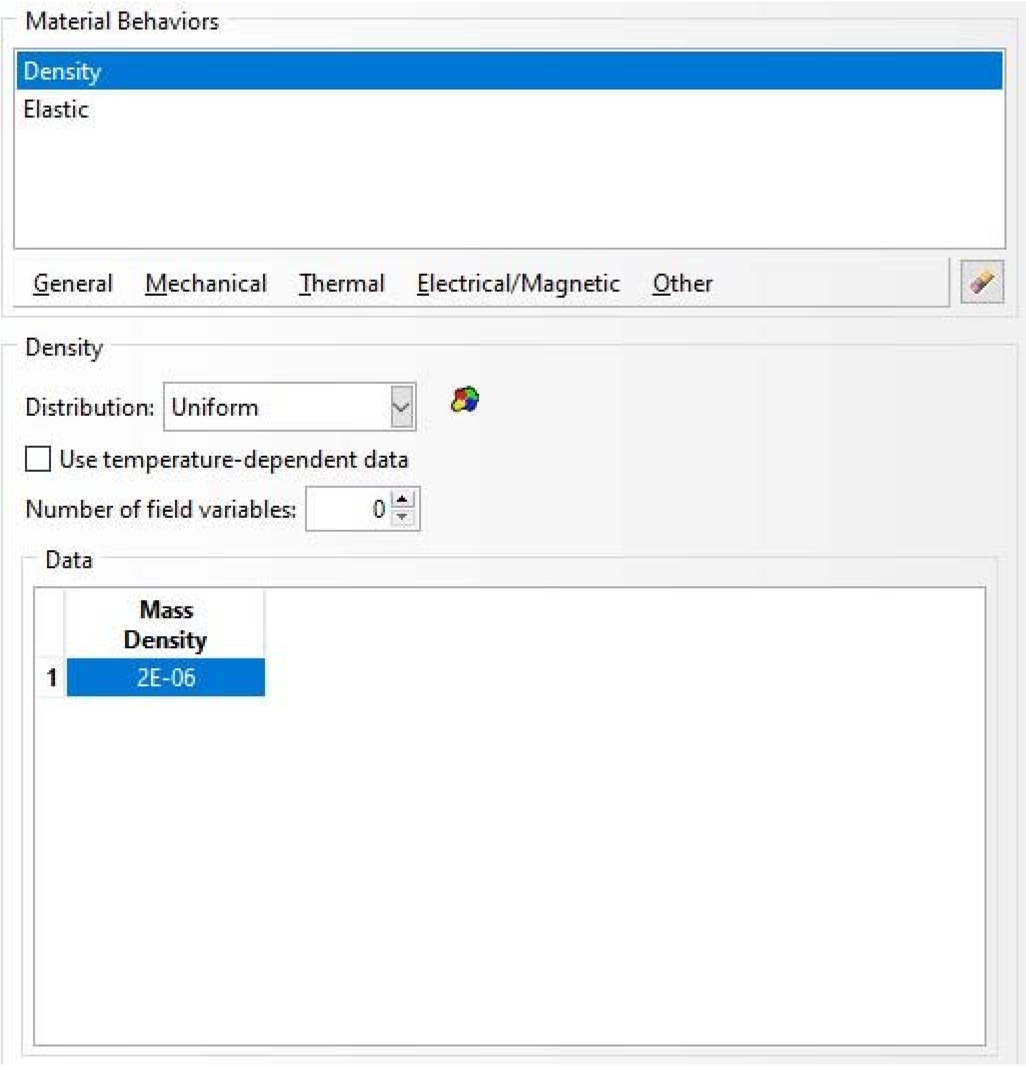

Figure 3.6. Density

3.4.5. Damage behavior property

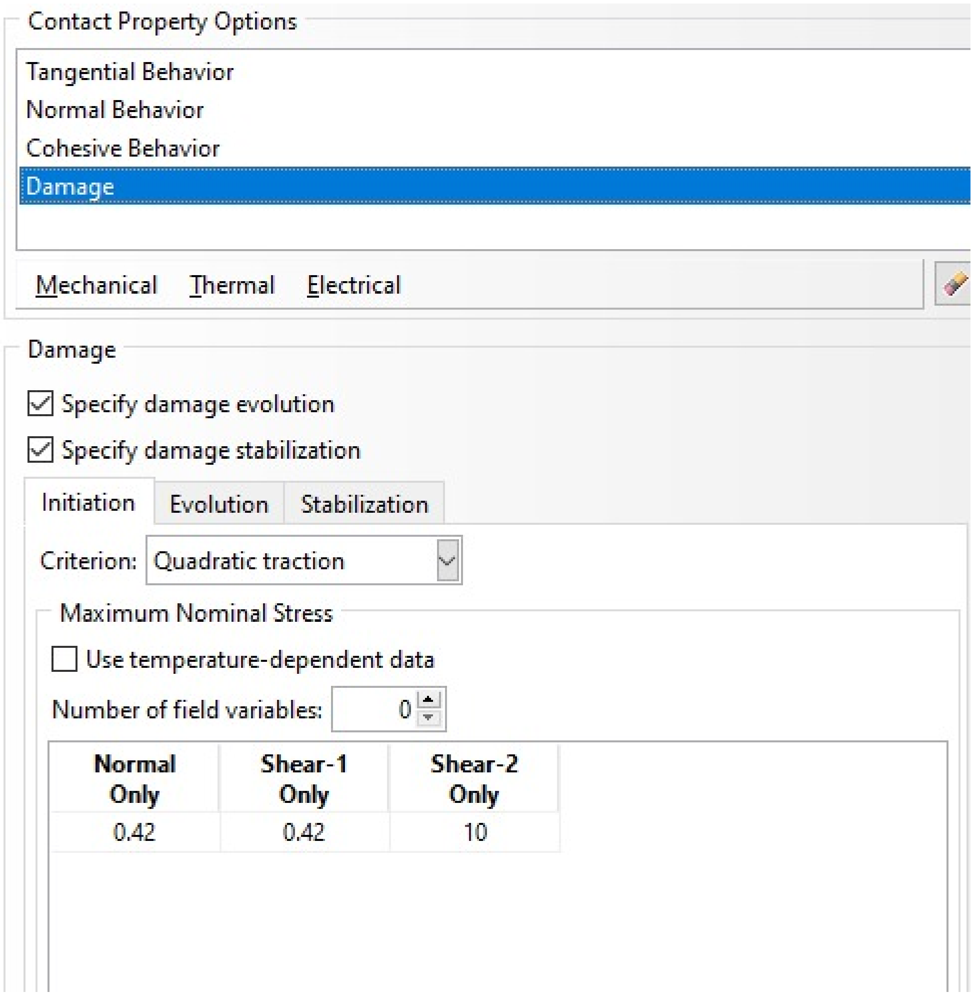

Figure 3.7. Normal and Shear stress

3.4.6. Contact property

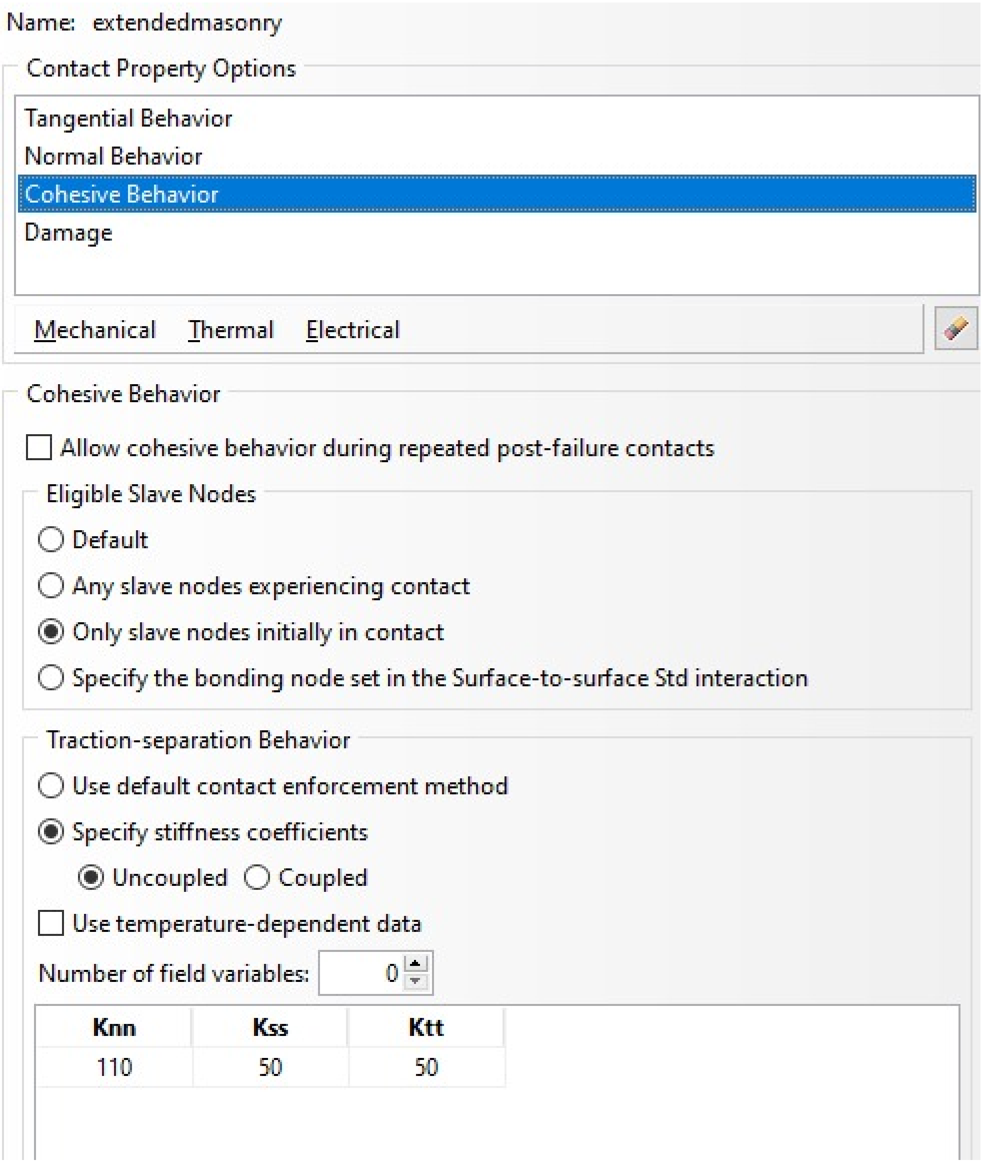

Figure 3.8. Stiffness 'K'

3.4.7. Plastic displacement

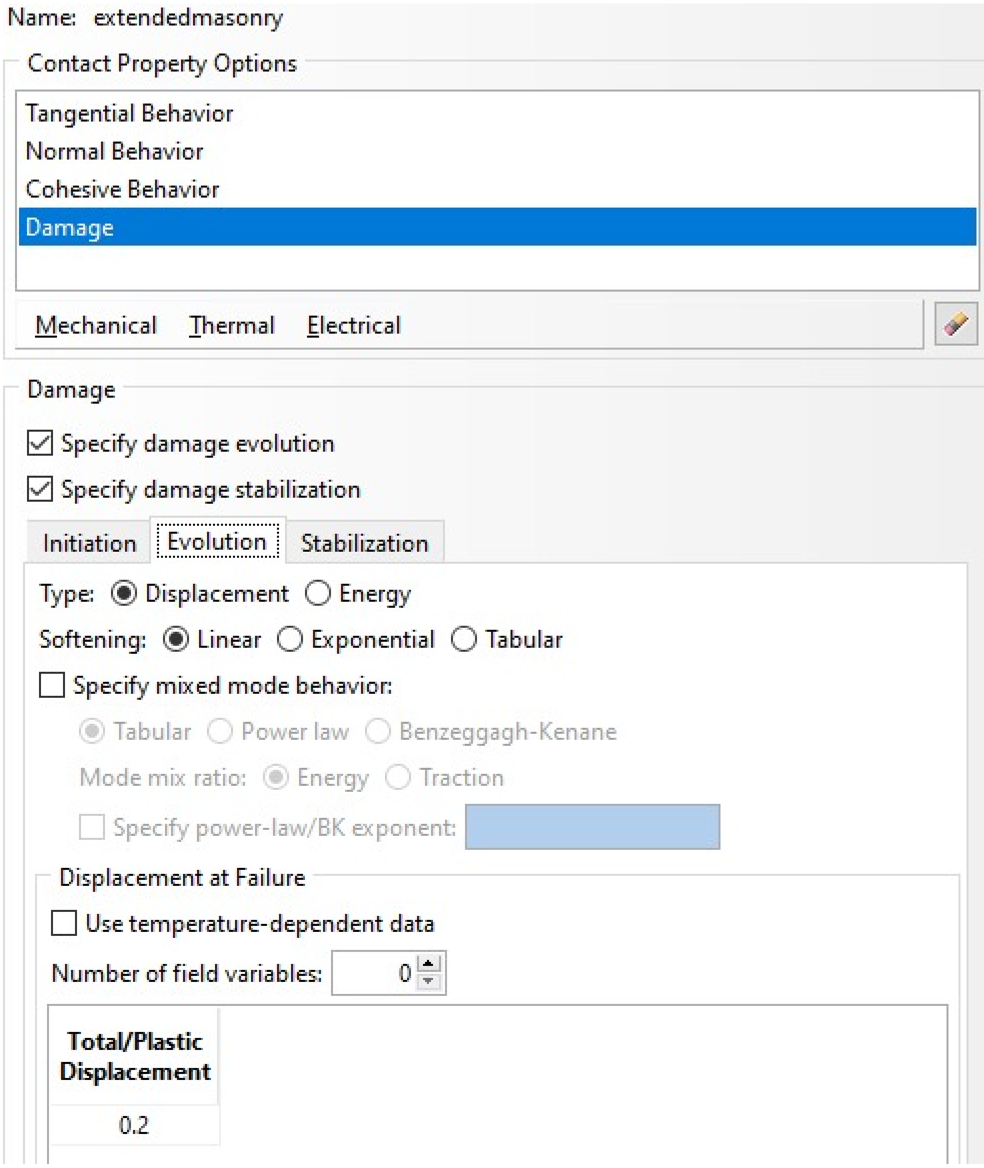

Figure 3.9. Plastic displacement

3.4.8. Normal behavior property

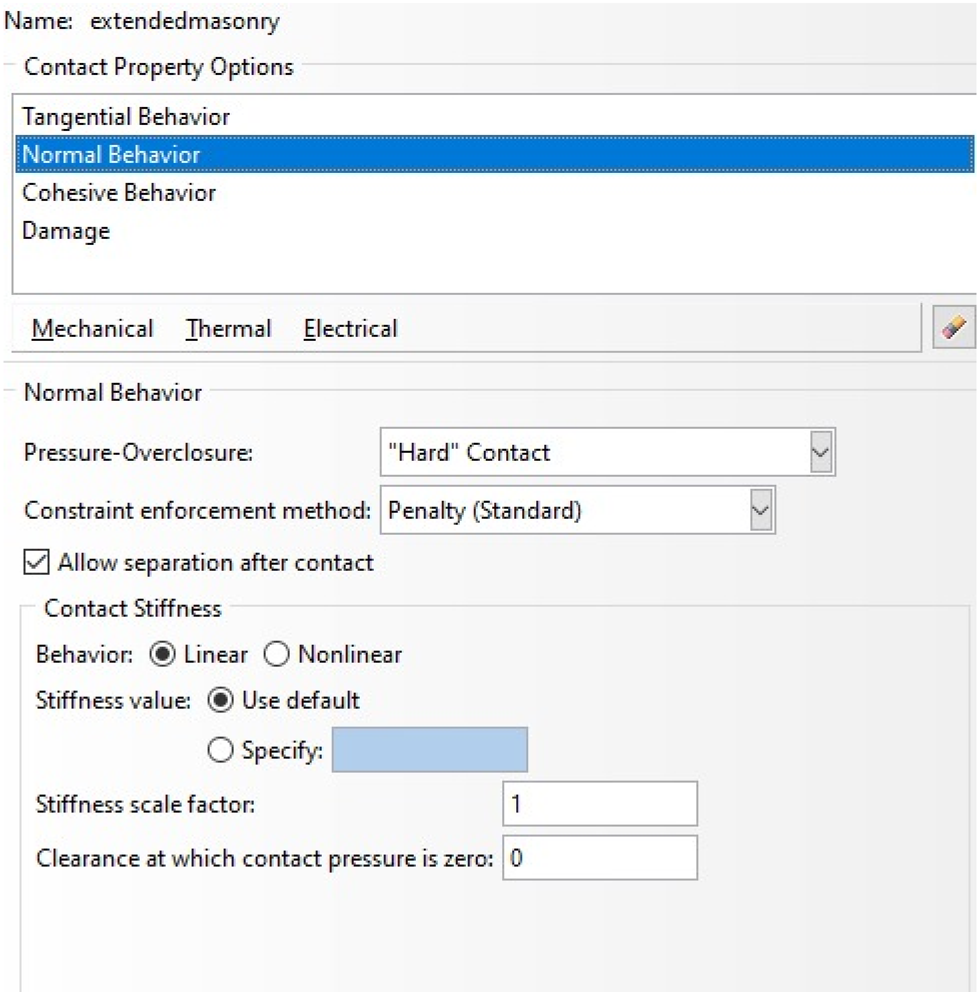

Figure 3.10. Hard contact

3.4.9. Summary tables

Wall Size	480 mm × 288 mm
Brick Length	24 mm
Brick Height	12 mm
Brick Width	12 mm
Brick Material	Fire burnt clay
Elasticity	2500 N/mm2
Poisson ratio	0.24
Density	2000 kg/m3

Mesh type	CSP4
Element shape	Solid 3D Rectangle
Interaction between bricks	Mohr Columb mortar parameters

Table 3.1. Material properties

Friction formulation	PENALTY
Directionality	ISOTROPIC
Shear stress limit	1
Friction coefficient	0.49

Table 3.2. Friction Interaction properties

Normal Stiffness, *Knn*	110 N/m
Shear Stiffness, *Kss*	50 N/m
Tangential Stiffness, *Ktt*	50 N/m

Table 3.3. Cohesive Interaction properties

Initial criteria	Quadratic Traction
Maximum Nominal Stress – Normal	0.3 N/m2
Maximum Nominal Stress – Shear 1	0.42 N/m2
Maximum Nominal Stress – Shear 2	0.42 N/m2
Damage Evolution Type	Plastic deformation
Total/Plastic Displacement	0.2 mm
Viscosity coefficient	0.002

Table 3.4. Damage Interaction properties

Pressure Overclosure	Hard contact

Constraint Enforcement Method	Penalty
Separation after Contact	Allowed

Table 3.5. Normal Interaction properties

CHAPTER 4

ANALYSIS RESULTS

4.1. Analysis of wall with opening

Some of the characteristics related to our model are being discussed in the analysis phase of this research. A unique kind of load pattern is selected to apply on the model and check for its response. As our model is subjected to in plane loading, so for this purpose, we developed this kind of load pattern. The literature we studied related to in plane loading scenario, this type of load pattern was in use, there, in all the papers.

A vertical UDL of 7 Mpa is being applied on the top and lateral displacement on the sides, at the rate of 1 mm per second. The wall panel is constrained with fixed support at the bottom.

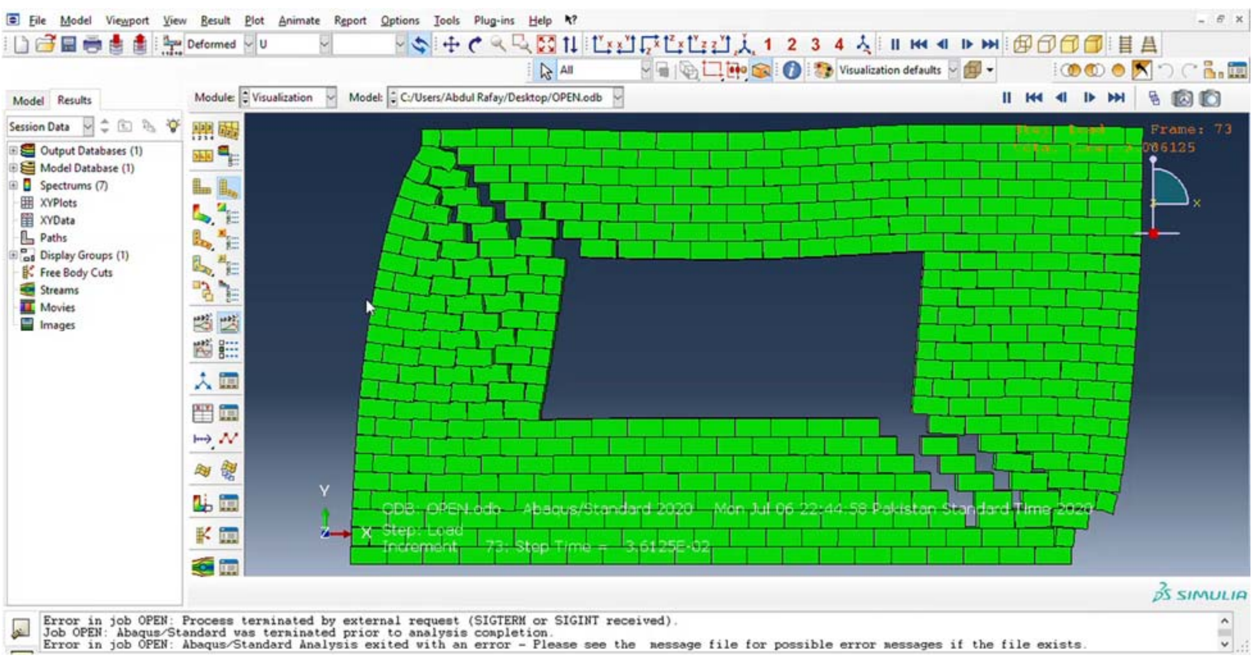

Figure 4.1. Response of wall with opening under loading

The above figure shows the response of the wall with opening under the same loading pattern condition. The cracks which are being propagated diagonally through the walls are depicted in the above figure.

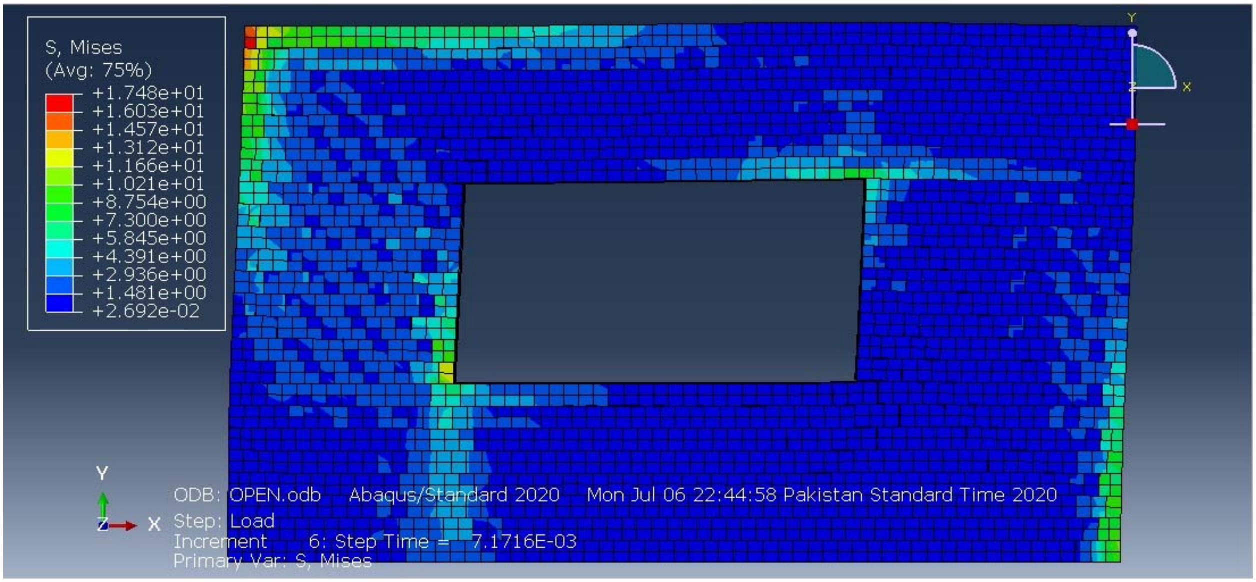

Figure 4.2. Stress contours of wall with opening

Figure 4.2. Shows the representation of stress contours of our model. These are the high zones of stress where the colors are being changed and thus, are weak areas of our model. These are the zones where we can provide the retrofitting.

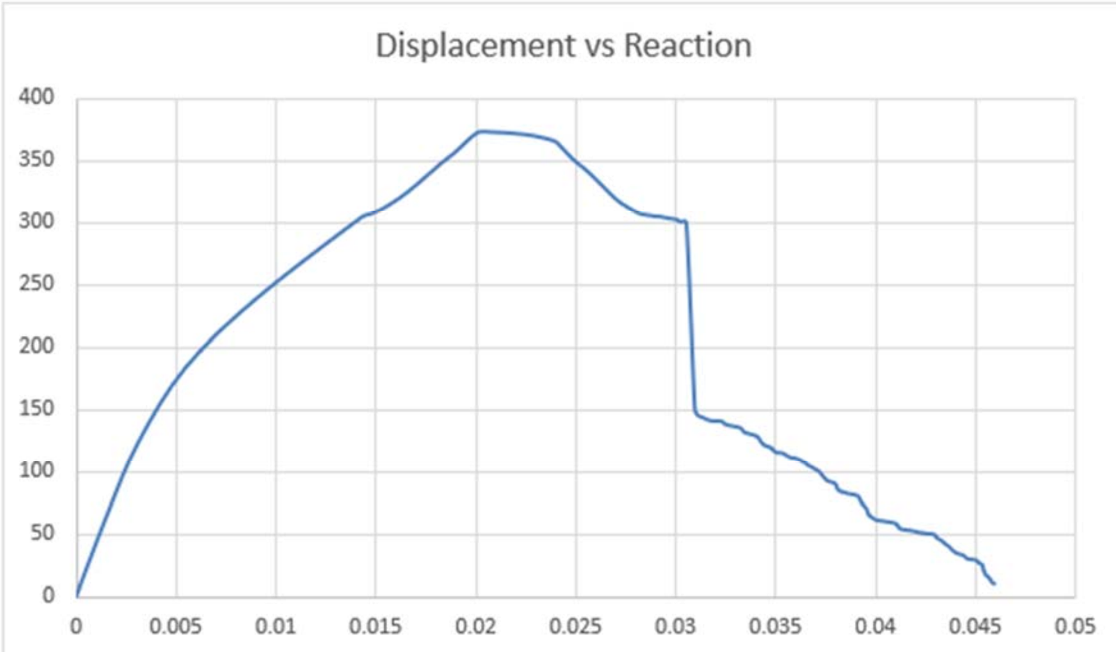

Figure 4.3. Displacement reaction curve of wall with opening

A point to note here is that, at 2 mm displacement, we have the maximum force produced, meaning that after 2 mm deflection, our model will fail. Displacement is given in centimeters and Reaction is given in ksi x10.

4.2. Analysis of solid wall

The same kind of load pattern was applied on the solid wall also. A vertical UDL of 7 Mpa is being applied on the top and lateral displacement on the sides, at the rate of 1 mm per second. The wall panel is constrained with fixed support at the bottom. The following figures shows the analysis results of the solid wall:

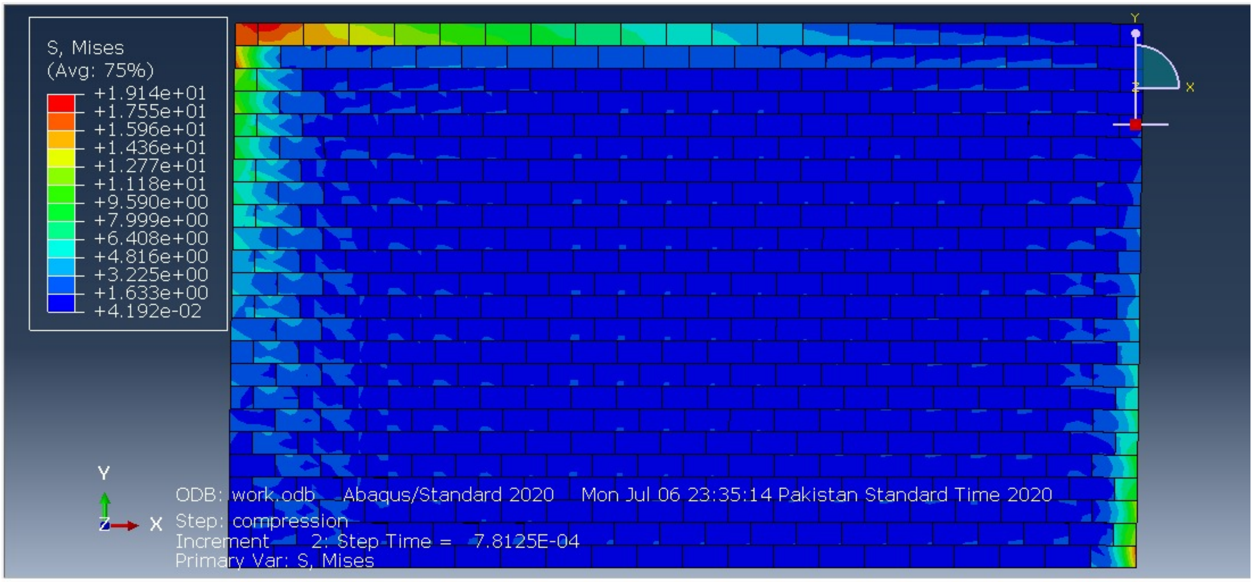

Figure 4.4. Stress contours of solid wall

Figure 4.4. Shows the stress profile of solid wall. The places where the color is changing are the places where the stress is being produced. If we provide retrofitting to these zones, we can increase the strength of the wall substantially.

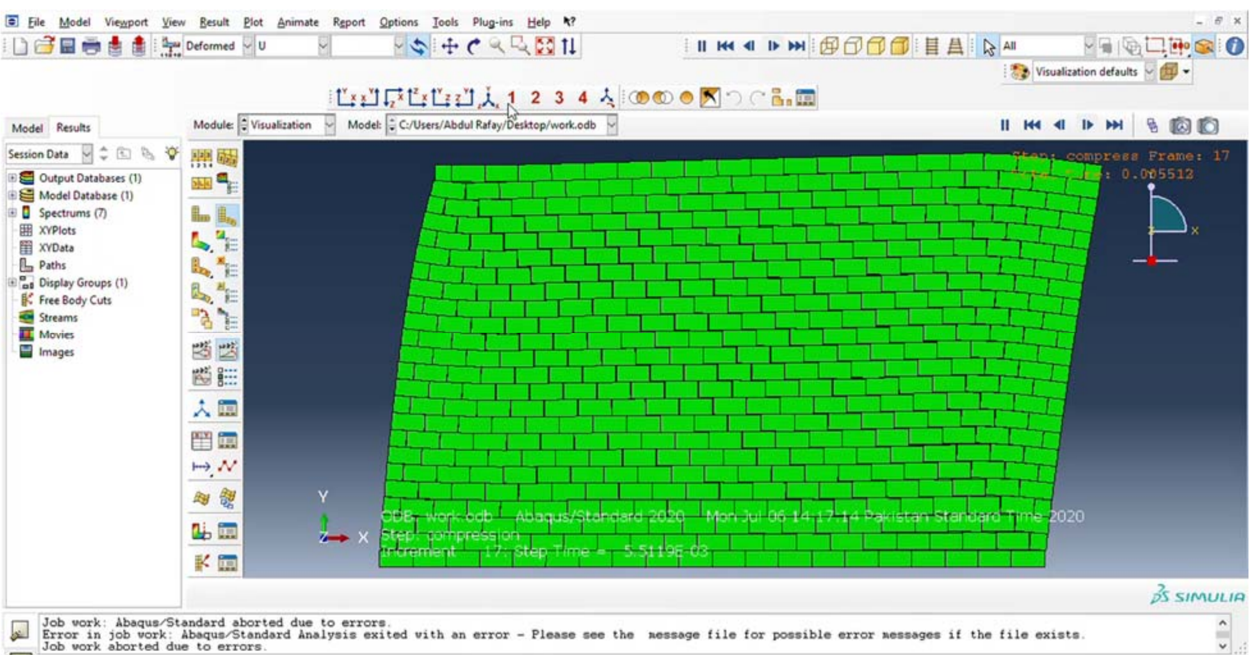

Figure 4.5. Response of solid wall under loading

Figure 4.5. Demonstrate the response of solid wall under loading and its crack pattern.

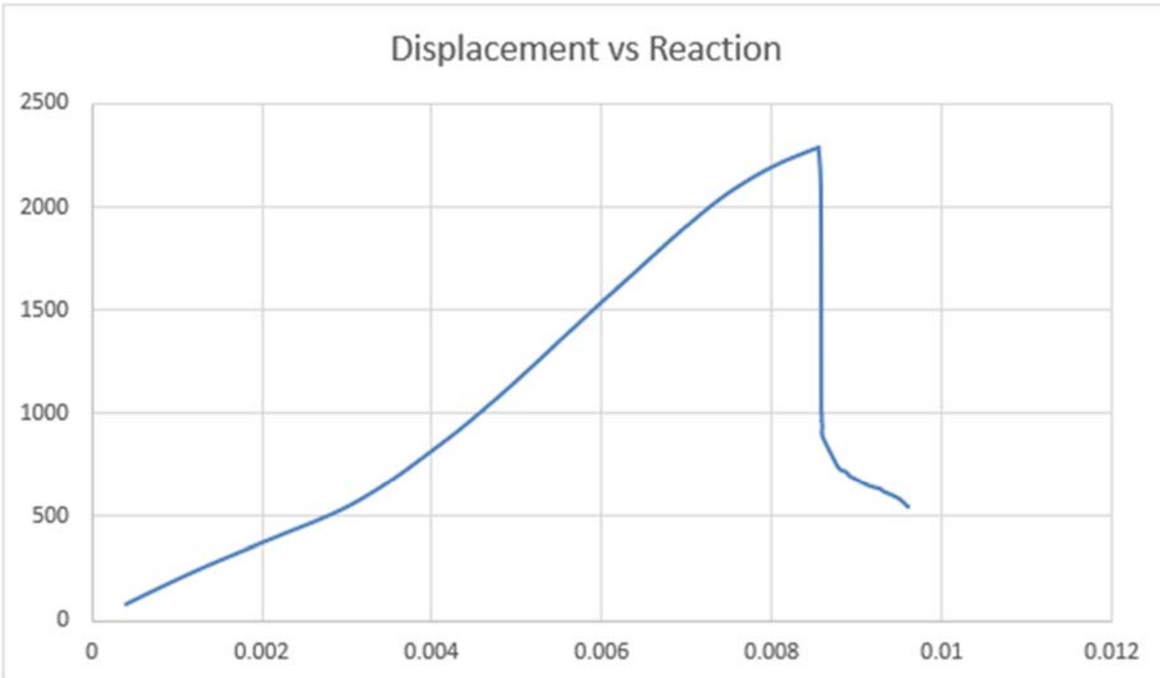

Figure 4.6. Displacement reaction curve of solid wall

As seen in the above figure, the curve goes to the maximum value after 8 mm deflection, marking the start of cracks in the walls, then afterwards, it goes down substantially. Displacement is given in meters and Reaction is given in Nx10^2.

CHAPTER 5
CONCLUSIONS

5.1. Conclusions

- The modelling of both the solid wall and wall with openings was done and analyzed. The solid wall had high peak strength high value of force that it can take before failure but the wall with an opening has more ductility as we can see in its graph. Although it does not take a lot of force because it fails way too early when it is subjected to almost a hundred thousand newton of force but it is more ductile as the graph depicts.
- Even after failure, the hollow wall get some amount of stress while in solid wall when it reaches its peak and when the cracks start to form, the wall drastically loses all of its strength which shows that it is very brittle.
- Another important factor for our analysis is that if we provide retrofitting in diagonal shape then we will get best result from the application of retrofitting which would strengthen our weak zones and make our wall even stronger.

5.2. Future considerations

These are the future consideration that can be considered in future modelling of masonry wall that we didn't do because of time constraints.

- Discrepancies in mortar:
  A mortar wall has different volume and different strength at different points which can be incorporated in our model by special python coding in abaqus and simulate the real geometry and accurate composition of wall.
- FRCP panels:
  FRCP panel can added to masonry wall and modelled and investigated how these panels when retrofitted diagonally through the wall, change the behavior of a masonry wall.
- Material changes
  We can check the novel material in numerical modelling by just checking the density, young modulus, elasticity and have a bond wrench test on them. Further, we can model them numerically in abaqus and investigate how they behave. This will be extremely time

saving and cost saving as there will no need to cure and made huge assembly for this purpose.

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