A new approach to numerical modeling of the masonry structures using explicit dynamic finite elements method

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ABSTRACT :

Since the masonry structures are the most common type of building in some country such as Iran, India and Latin America, evaluation on the behavior of the masonry elements shall be taken place regard to the brittle, crushable and hybrid materials with large deformation. Discrete models of masonry structures cannot be done for the whole building due to large amount of nodes and DOF which may cause excessive CPU and memory usage. Hence a continuum numerical analysis must be performed with respect to the discrete specimens and same behavior under cyclic lateral forces.
This research contains a discrete wall model which has been analyzed by FEM software and compared by the assumed real experimental model with the same material properties such as brick and mortar materials as the existing building. After calibrating the FE discrete model, a continuum wall model of the experimental test specimen has been made as well, and then compared with the discrete FE model. Since the continuum model behavior is pretty much the same as discrete one, it is reliable for a well simulation of the assumed masonry building (it can be expended to any masonry building type). By knowing the parameters of the wall continuum FE model, the whole building can be modeled in continuum form with very simple conditions regarding to the time of analyzing and also HDD and memory requirement.

KEYWORDS: Masonry structures, Numerical analysis, Explicit dynamic, Discrete finite element method

1. INTRODUCTION

First step of the research is making the numerical discrete models for the main structure containing masonry bricks and mortar in FEM software and verify them by the existing experimental/laboratory specimens which have the same properties as the main structure. The material properties can be defined by physical and chemical essays. The second step is to change the numerical model into the continuum one instead of discrete one. The continuum model shall have the same behavior as the discrete one. The third step is to build the main structure or a part of the structure using the proper boundary conditions and load pattern.
Since this research is an approach to numerical modeling, it was assumed that the experimental specimens are already evaluated. The below flowchart (Figure 1) shows the procedure of modeling the masonry structures.

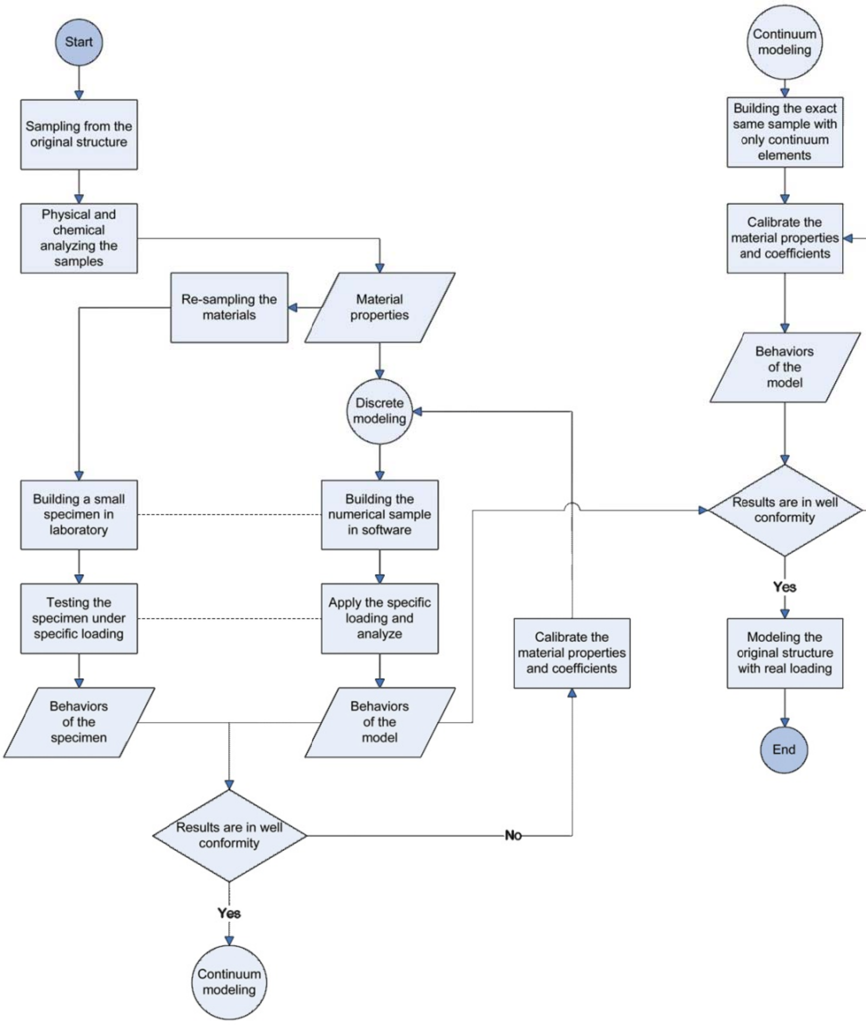

Figure 1- Progress flowchart

2. DISCRETE MODELING

By assuming a simple concrete frame with masonry block infill for the laboratory experimental specimen, a discrete finite element numerical model has been built as showed in Figure 2.

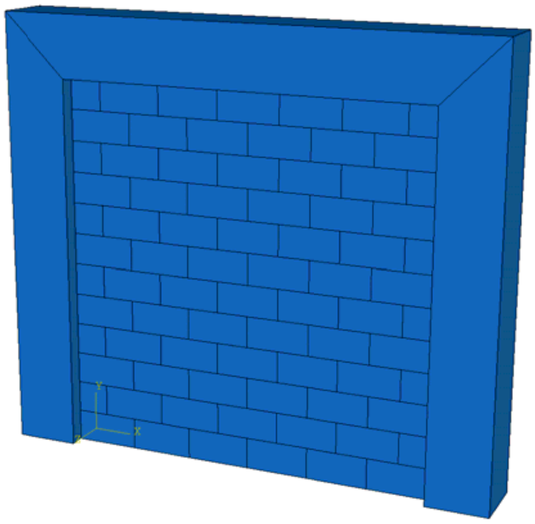

Figure 2- Concrete frame with masonry block infill

The bottom face has been restraint for all translating DOF's; and a displacement has been applied for the upper face; the mortar has been simulated with slip rate frictional contact. The plasticity of the material has been simulated using extended drucker-prager plasticity considering compression hardening. The main advantages of this plasticity formula are summarized as follows (ABAQUS/CAE documentation, Sec. 18.3.1):

1- The extended Drucker-Prager models are used to model frictional materials, which are typically granular-like soils and rock, and exhibit pressure-dependent yield;
2- The extended Drucker-Prager models are used to model materials in which the compressive yield strength is greater than the tensile yield strength, such as those commonly found in composite and polymeric materials
3- The extended Drucker-Prager models allow a material to harden and/or soften isotropically;
4- The extended Drucker-Prager models generally allow for volume change with inelastic behavior: the flow rule, defining the inelastic straining, allows simultaneous inelastic dilation (volume increase) and inelastic shearing;
5- The extended Drucker-Prager models are intended to simulate material response under essentially monotonic loading.

Figure 3 shows the yield/flow surfaces in Drucker-Prager hyperbolic and linear model.

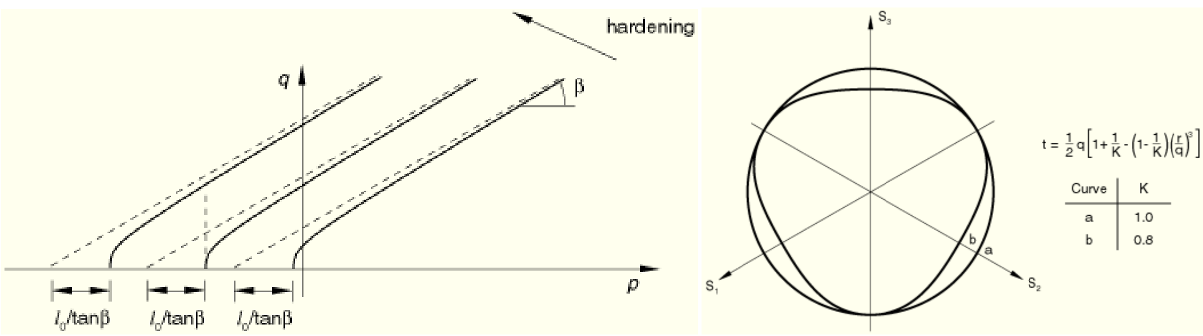

Figure 3- Left: Hyperbolic model: yield surface and hardening; Right: Typical flow surfaces of the linear model where K is the ratio of the yield stress in triaxial tension to the yield stress in triaxial compression

Figure 4 shows the specimens behavior during analyzing.

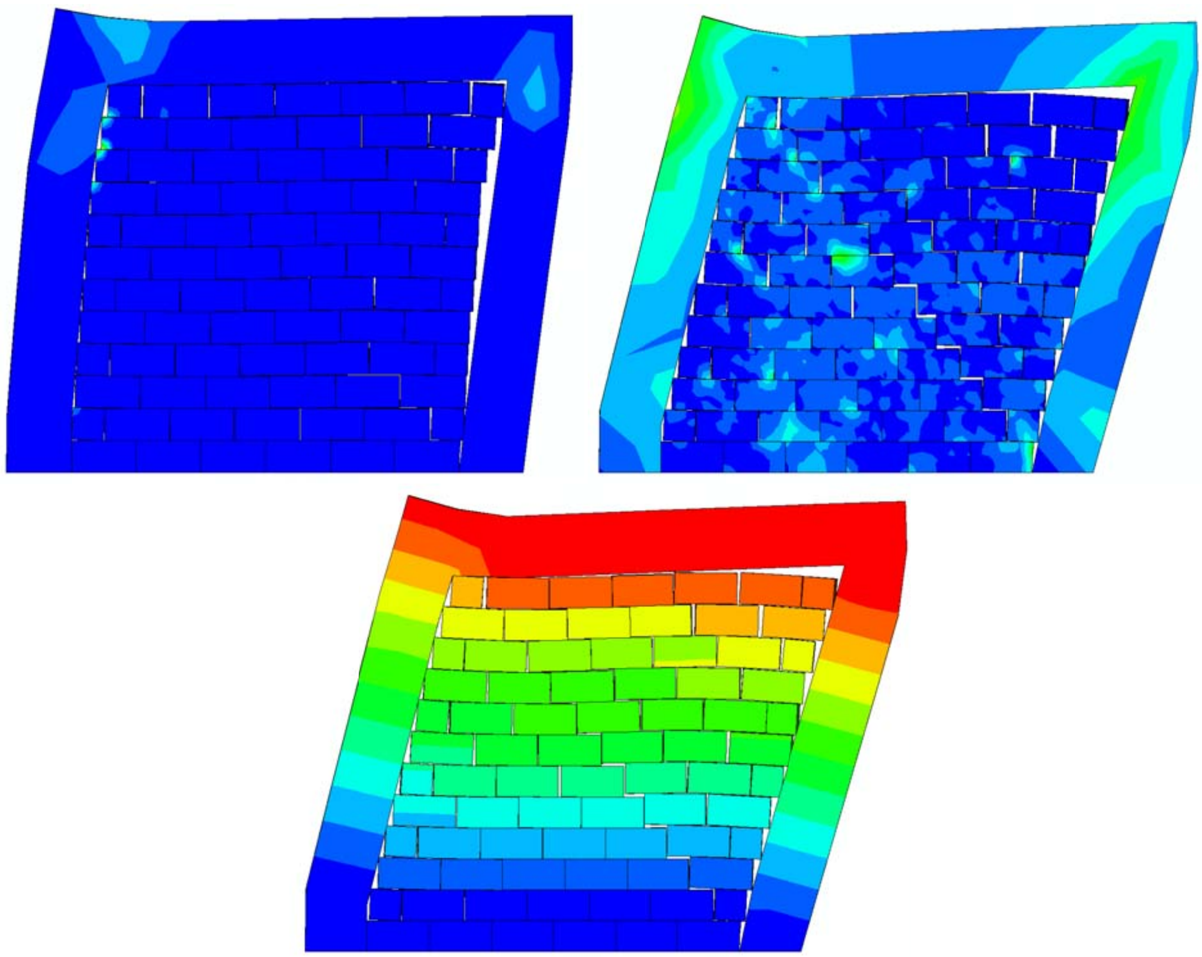

Figure 4- Top/Left: Specimen at the beginning of the analysis (Tresca stress), Top/Right: Specimen at the end of the analysis (Tresca stress), Bottom: Specimen at the end of the analysis (Displacement)

It has to be noticed that the tension behavior of the mortar (Tensile strength) is assumed to be zero in this analyses. However it could be defined based on the test results as one of the contact parameters.
Sometimes experimental data are not directly available. Instead, the analyst is provided with the friction angle and cohesion values for the Mohr-Coulomb model. The Mohr-Coulomb failure model is based on plotting Mohr's circle for states of stress at failure in the plane of the maximum and minimum principal stresses. The failure line is the best straight line that touches these Mohr's circles. Figure 5 shows the Mohr-Coulomb failure model. (Equations 2.1, 2.2 and 2.3 and Figure 5)

$$s = \frac{1}{2}(\sigma_1 - \sigma_3)\ ;\ and\ \sigma_m = \frac{1}{2}(\sigma_1 + \sigma_3) \tag{2.1}$$

$$\tau = c - \sigma\ tan\varphi\ ;\ and\ \tau = s\ cos\varphi\ ;\ and\ \sigma = \sigma_m + s\ sin\varphi \tag{2.2}$$

Hence;

$$s + \sigma_m\ sin\varphi - c\ cos\varphi = 0 \tag{2.3}$$

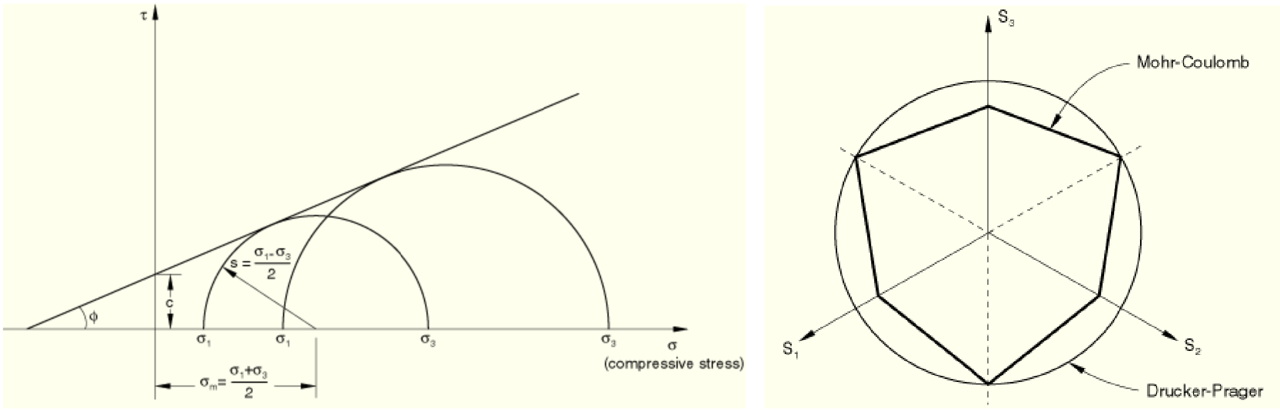

Figure 5- Mohr-Coulomb failure model. (ABAQUS/CAE documentation, Sec. 18.3.3)

3. CONTINUUM MODELING

Finite element discrete model uses many contact elements and therefore solve many equations which may be impossible for many structures to be analyzed due to computer limitations. Therefore preparing a continuum model is mandatory.

Since the material parameters are different it is recommended that the material parameters to be exited from the discrete model for better results.

The process begins with results calibrations between the new continuum numerical model and the previous discrete model which had been verified by existing structure or laboratory test results.

Material properties contain Concrete damaged plasticity as inelastic behavior. Concrete damaged plasticity contains more parameters than the Drucker-Prager plasticity which makes the modeling more flexible and reliable. Hardening can be defined both in compression and tension with different stress-strain table; also the damage property can be defined in compression and tension. Other advantages of concrete damaged plasticity are that concrete damaged plasticity model assumes nonassociated potential plastic flow. The flow potential G used for this model is the Drucker-Prager hyperbolic function; it provides a general capability for modeling concrete and other quasi-brittle materials in all types of structures (beams, trusses, shells, and solids); it can be used for plain concrete, even though it is intended primarily for the analysis of reinforced concrete structures; it is designed for applications in which concrete is subjected to monotonic, cyclic, and/or dynamic loading under low confining pressures; it consists of the combination of nonassociated multi-hardening plasticity and scalar (isotropic) damaged elasticity to describe the irreversible damage that occurs during the fracturing process; it allows user control of stiffness recovery effects during cyclic load reversals; and finally can be defined to be sensitive to the rate of straining (ABAQUS/CAE documentation, Sec. 18.5.3). Figure 6 shows the numerical results from continuum model.

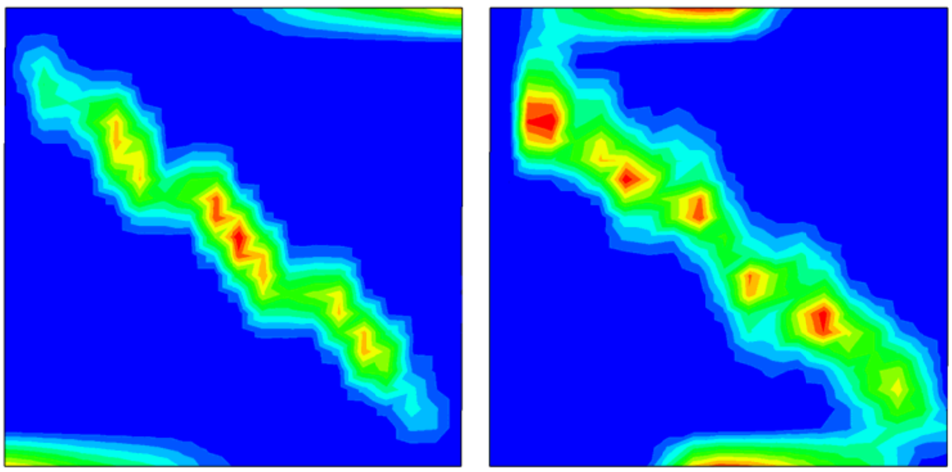

Figure 6- Left: tension cracks in structure (time=2), Right: Compression-Tension cracks in structure (time=3)

Figure 7 shows the experimental specimen of masonry infill behavior under cyclic loading. The damage pattern has been marked by another color.

Figure 7- Experimental study of masonry infill (H.Farshchi and A.S.Moghaddam)

By reaching the best collation, material data can be used for full structural numerical continuum model. Figure 8 shows damage patterns on the assumed masonry dome structure as the main structure under cyclic loading using concrete damaged plasticity and explicit dynamic finite element method.

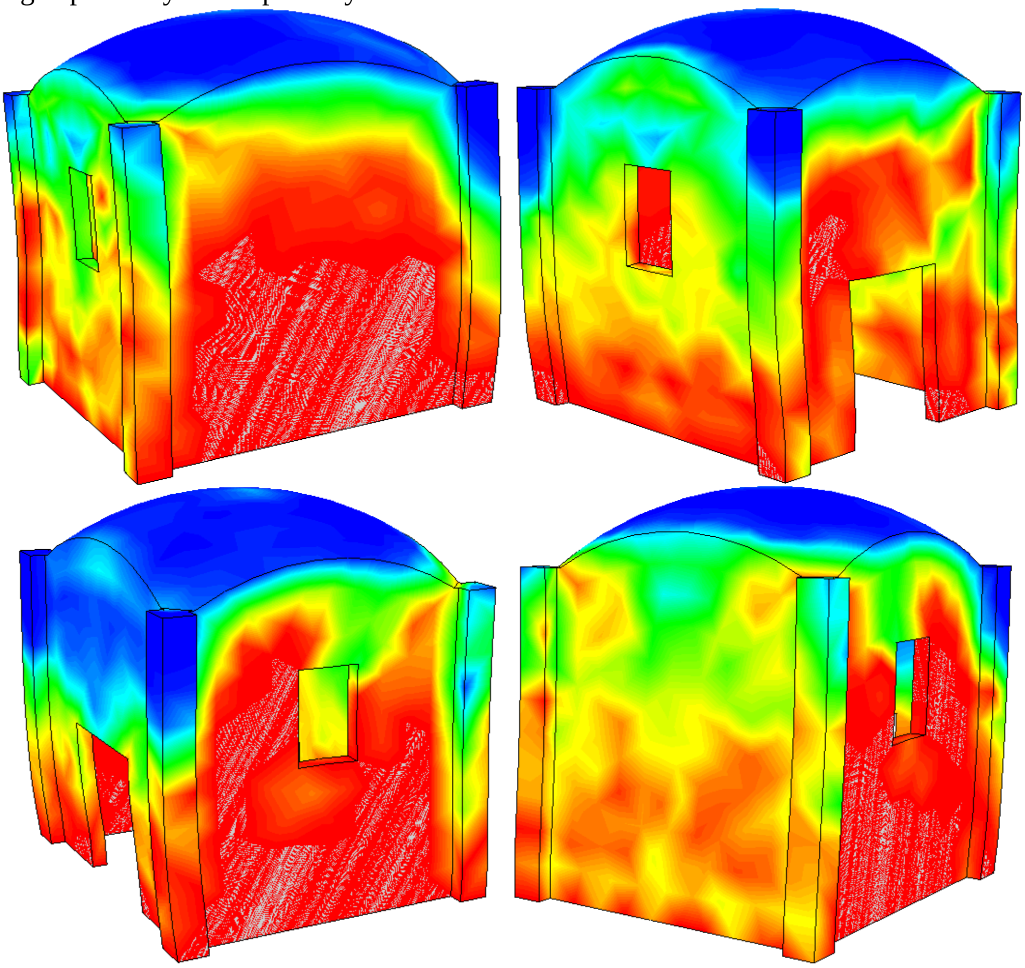

Figure 8-Masonry dome structure damage patterns under cyclic loading: Top: in axis 1; Bottom: in axis 3

As it was expected damage concentrate in the corners and also in the openings. The main purpose of the numerical examinations are to guide the structural engineers to realize the behavior of the structure fast, reliable and easy without having experimental investigations that might be expensive and time consuming, and also to decide the proper retrofitting program.

4. CONCLUSION

Since the analyses are time consuming and need lots of memory, it's important to carefully build the model and choose the right elements and material properties such as shell or solid elements either quad or tri elements. It has to be noticed that tri elements are much more time consuming than quad elements.

In continuum modeling the material property for concrete damaged plasticity especially the hardening or softening shall be chosen very carefully as it may cause the instability in finite elements model and the program would stop running eventually.

REFERENCES

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