

PAPER • OPEN ACCESS

Structural elastoplastic time-history analysis using solid element

To cite this article: Xiaoming Chen *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **330** 022077

View the [article online](#) for updates and enhancements.

You may also like

- [The effect of temperature and pressure on nitrogen adsorption in amorphous silica](#)
J. F. Fatriansyah, D. Dhaneswara, F. R. Kuskendrianto et al.
- [Efficient absorption of laser light by nanoporous materials with well-controlled structure](#)
Reza Fazeli
- [The effect of electro-mechanical coupling stiffness on the through-the-thickness electric potential distribution of piezoelectric actuators](#)
Yanti Rachmadini, Sangki Lee, Hoon Cheol Park et al.



ECS
The
Electrochemical
Society
Advancing solid state &
electrochemical science & technology

DISCOVER
how sustainability
intersects with
electrochemistry & solid
state science research

Structural elastoplastic time-history analysis using solid element

Xiaoming Chen^{1*}, Jianyun Sun¹ and Yungui Li¹

¹ China state construction technical center, Beijing, 101300, China

*Corresponding author's e-mail: haneec@126.com

Abstract. Beam element is often used for simulation of frames, and the two-dimensional element is used for simulation of shear walls and slabs in structural analysis. This kind of method can be used for most of the conventional structures, but for the super-large section of super-tall buildings or the complex geometry structural members, this simplified may produce significant numerical error. In this paper, three-dimensional solid element is used to simulate the special shape members in a framework, and the embedding of model processing, multi-point constraints and other special constraint forms are introduced, which provides a new idea for engineers to use three-dimensional solid element to simulate the building structures. The results of the example show that the simplification of the special members in the structure will not only have a significant impact on the local results of the structure, but also may cause analysis bias on the overall results of the structure.

1. Introduction

According to the structural design method of "three levels and two stages" in China codes, to ensure that the structure will not collapse when it is even seriously damaged under the action of rare earthquake, it is necessary to check the floor displacement angle under the action of rare earthquake. Especially for those high-rise buildings that are more than 150m high; or under high intensity; or the site conditions are not ideal and the isolation bearings and energy dissipation is adopted [1].

According to the code for design of concrete structures [2], the model of finite element analysis of structures can be assumed as follows:

1) Beam, column, brace can be simplified with one-dimensional element, it is appropriate to use fiber bundle model or plastic hinge model;

2) Walls, slabs and other components can be simplified with two-dimensional elements. Membrane elements, plate elements or shell elements should be adopted;

3) For complex concrete structures, bulk concrete structures, joints of structures or local areas requiring detailed analysis, three-dimensional solid elements should be used.

According to the plate and shell theory [3], when the scale of one direction of the structure is much smaller than that of the other two directions, the shell element model can be used to simplify the calculation. In the actual calculation, the membrane element will be used as required, or the stiffness in the plane is assumed to be infinite while the stiffness outside the plane is assumed to be elastic. The one-dimensional element is a further simplification of the computational model.

Due to the characteristics of the building structure, the calculation model combining two-dimensional element and one-dimensional element is usually adopted in the practical analysis. The shear wall and floor of the structure are formulated with shell element, and the frameworks are



formulated with one-dimensional element. Compared with the three-dimensional solid element, this model can greatly reduce the degree of freedom of calculation, but still can present enough precision.

In recent years, the super high-rise building structure is increasing day by day, the structure form is also becoming more and more complex. For super high-rise buildings, with the increase in height, in order to ensure the bearing capacity of the structure and control the ductility of concrete, for both shear wall and column, the section of the members is getting larger and larger; In addition, beam or shell elements cannot simulate accurately for some special geometric shapes in the structure. In this case, the three-dimensional stress effect of the members is more prominent, therefore, engineers have to use multi-scale finite element method for accurate results[4,5].

In this paper, ABAQUS is used to analyze a frameworks containing a swimming pool, and the method of solid element in the elastoplastic analysis of building structure is studied, and the results are compared with those of general beam and shell element models, so as to provide a new idea for structural engineers to conduct more detailed structural analysis.

2. Structural model

The frame structure, including with a swimming pool in the upper floors is shown in Fig.1:

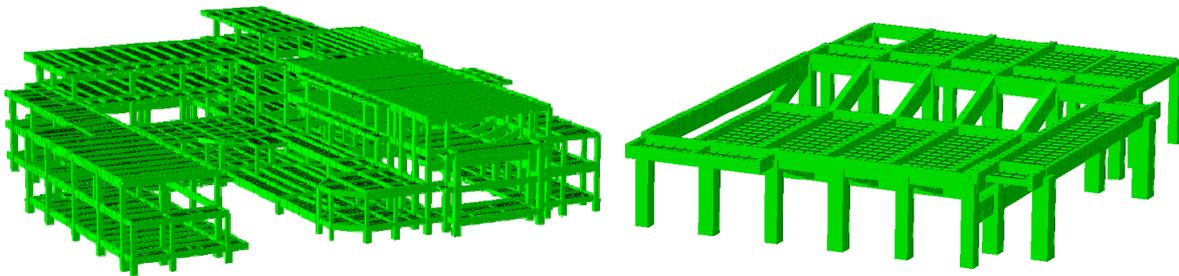


Fig.1 Model(MBeam) with simplified beam element

Due to the load of the swimming pool shown in Fig.1 and the complex geometric shape, it is difficult to simulate the main members by beam elements accurately, and more accurate simulation can be achieved by using three-dimensional solid elements (MSolid), as shown in Fig.2.

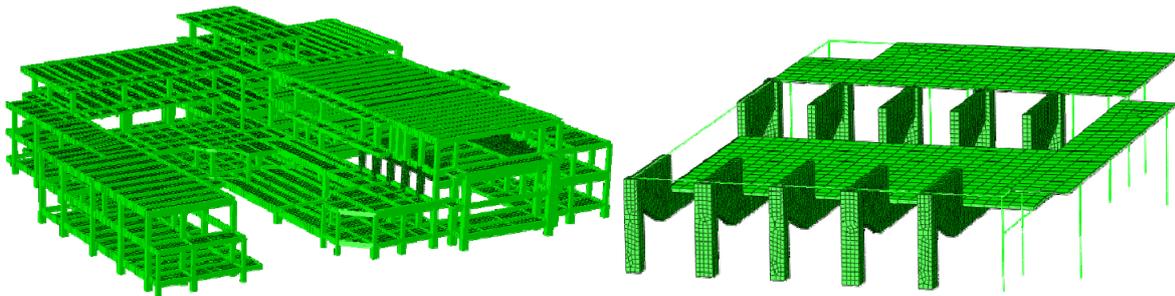


Fig. 2 Model (MSolid) with three-dimensional solid element

Under the rare earthquakes, the seismic waves loaded at the structural bottom are shown in Fig.3:

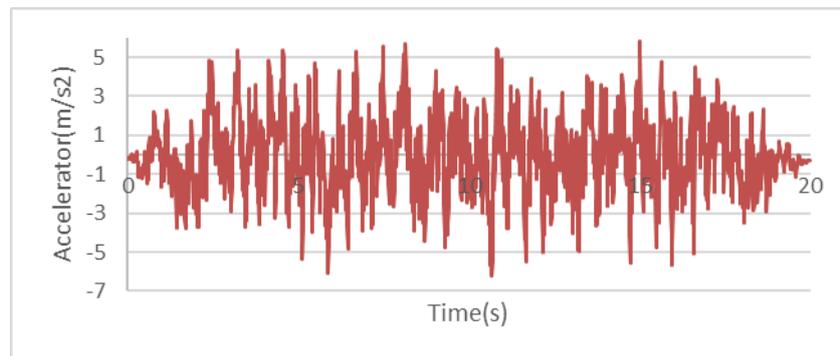


Fig.3 Time-history of seismic wave acceleration

3. Constraints of three-dimensional solid elements

In the original model, beam and column sections are all designed with shape steel, in which the frame column is designed with cross I-beam steel, and the frame beam is embedded with I-beam steel. In the three-dimensional entity, the definition of shape steel is consistent with the original model, and embedded into the concrete. In ABAQUS[6], EMBED command is adopted to achieve embedding (Fig.4). The software automatically realizes the binding of shape steel and related concrete elements, and ignores the bond and friction between each other.

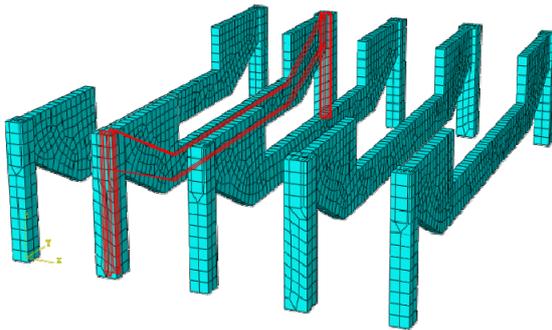


Figure 4 embedded section steel in concrete

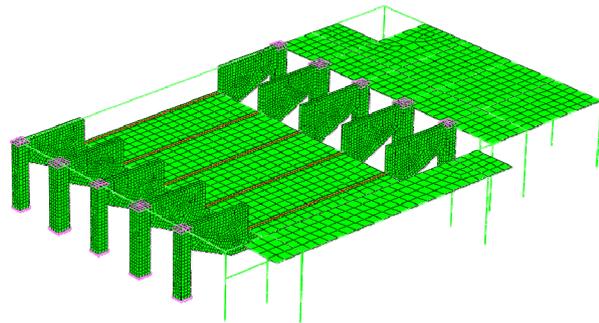


Fig.5 Constraints for solid elements

In addition, the three-dimensional entity part needs to be connected with the original structure through constraints, as shown in Fig.5.

The upper and lower sections of the three-dimensional solid column are compatible with the deformation of the frame column simulated with beam element by defining the upper and lower surfaces of the three-dimensional solid column. The cross-section of the frame beam of those overlapped with the three-dimensional entity in the original structure is reduced and the ABAQUS/EMBED method is adopted. The load on the slab is transferred to the surrounding beam element at first, since the beam element is embedded into the 3D solid element, so the load is transferred to the beams simulated with the 3D solid element. In ABAQUS, although the coupling constraint between shell element and 3D solid element can be realized, and the deformation compatibility between slabs and 3D solid beams can be realized, it is obviously easier to embed frame beam directly into 3D solid element.

4. Constitutive relationship of concrete

According to the code for design of concrete structures, the tensile skeleton curve of concrete is defined as follows:

$$\sigma = (1-d_t) E_c \varepsilon \quad (1)$$

$$d_t = \begin{cases} 1 - \rho_t [1.2 - 0.2x^5] & x \leq 1 \\ 1 - \frac{\rho_t}{\alpha_t(x-1)^{1.7} + x} & x > 1 \end{cases} \quad (2)$$

The compressed skeleton curve is:

$$\sigma = (1 - d_c) E_c \varepsilon \quad (3)$$

$$d_c = \begin{cases} 1 - \frac{\rho_c n}{n - 1 + x^n} & x \leq 1 \\ 1 - \frac{\rho_c}{\alpha_c(x-1)^2 + x} & x > 1 \end{cases} \quad (4)$$

Unloading path under compression is:

$$\sigma = E_r (\varepsilon - \varepsilon_z) \quad (5)$$

The skeleton curves under compression and tension are shown as shown in Fig.6:

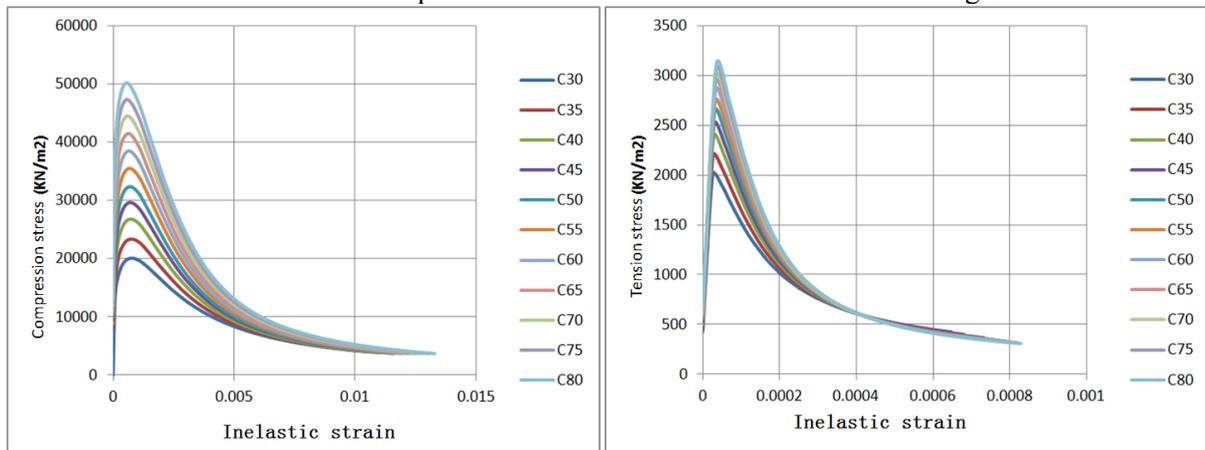


Fig.6 Skeleton curves under compression and tension

The damage curve is shown as Fig.7:

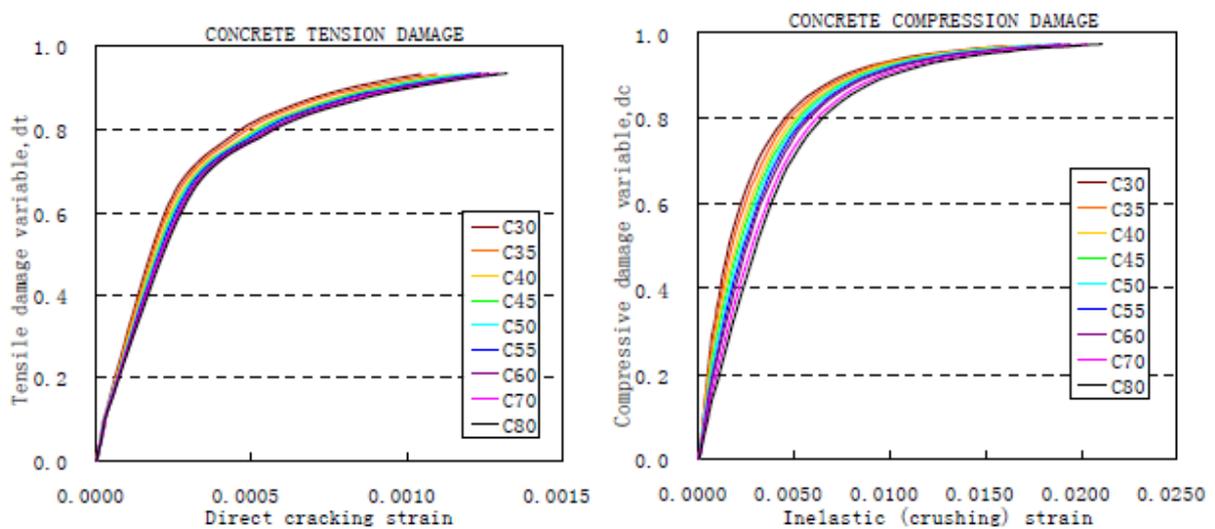


Fig.7 Damage curves of compression and tension

For shell elements, the skeleton curve defined in equation (1-5) is adopted with the plastic damage constitutive method of ABAQUS, as shown in Fig.8[6] :

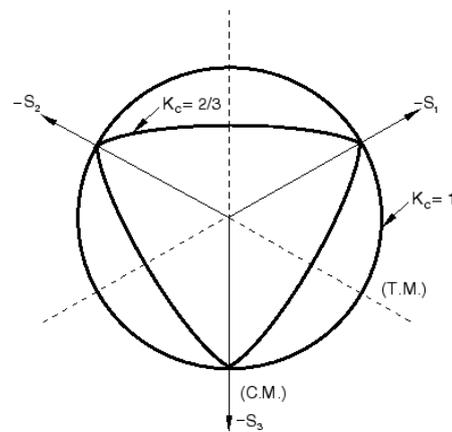
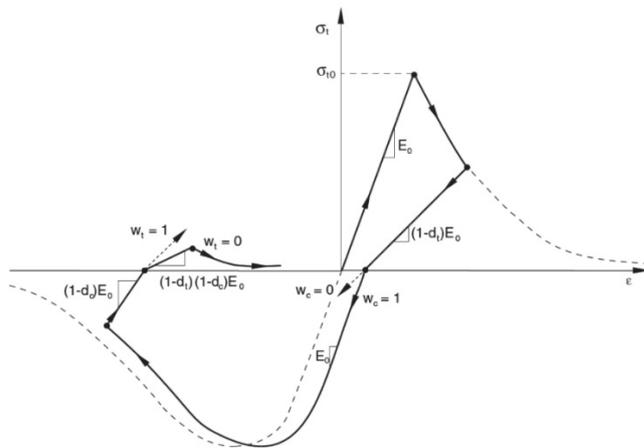


Fig.8 Plastic damage constitutive of ABAQUS Fig.9 Yield surfaces in the deviatoric plane

For 3D solid elements, skeleton curves defined by equation (1-5) were still used[6], where $K_c = 0.667$ in the yield surface definition in the deviatoric plane, as shown in Fig.9.

5. Comparison of analysis results

The structural masses of different models and the main periods are listed in Tab.1. The results show that the period and mass errors of two models are very small.

Tab.1 Structure mass and periods

	Mass (Ton)	T1(s)	T2(s)	T3(s)	T4(s)	T5(s)	T6(s)
MBeam	55706	1.5012	1.5750	1.8151	1.9477	2.3582	2.4304
MSolid	55914	1.4786	1.5250	1.7769	1.9072	2.3579	2.3981

The displacement angle envelope of each floor is shown in Fig.10. The results show that the displacement angle at the top of the structure is greatly different with two models in both x and y directions.

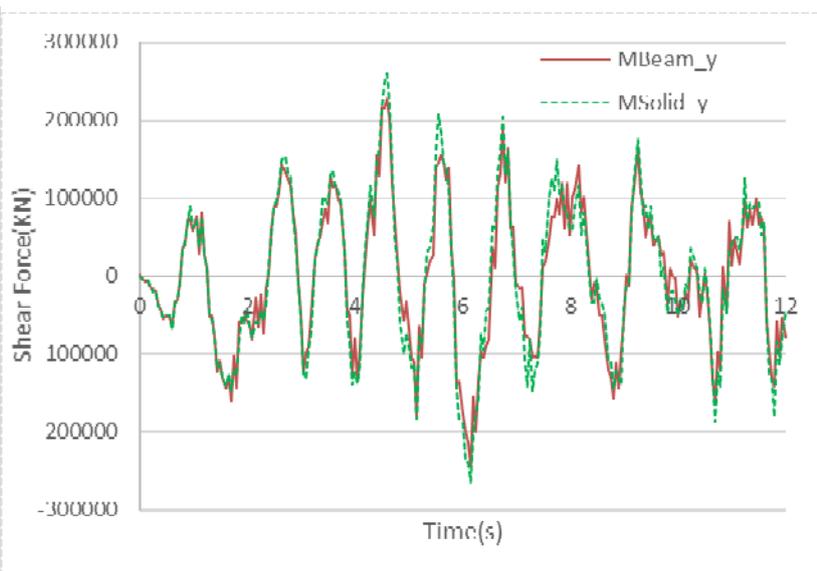
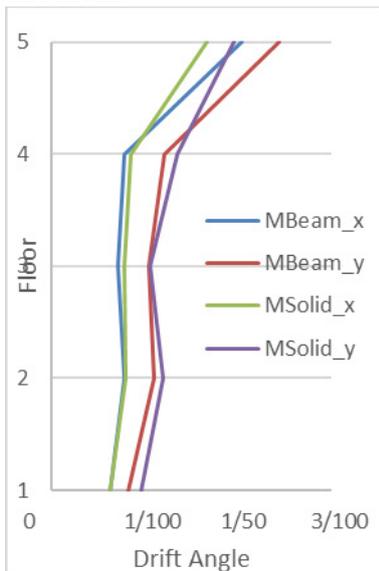
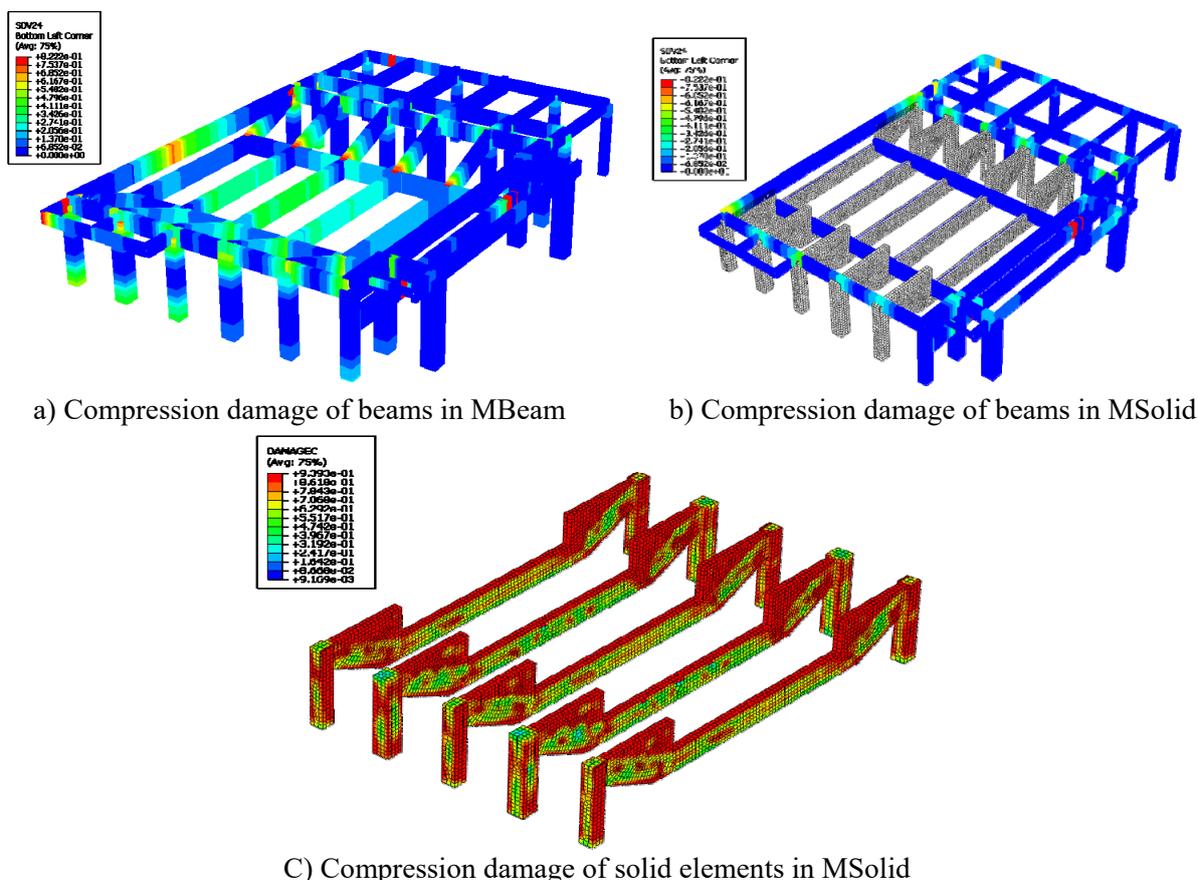


Fig.10 Envelope of drift angle Fig.11 Time-history of bottom shear force in y -direction structure

Fig.11 shows the time-history comparison of bottom shear force in y direction. The results show that the shear force at the structural bottom with 3D solid element model is larger.

To compare the influence of different element on the local structure, the compressive damage of concrete in key parts is analyzed as shown in Fig.12.



C) Compression damage of solid elements in MSolid
 Fig.12 Comparison of concrete damage under compression

Damage results show that the concrete column is damaged by compression at the periphery, but the core area still keep enough ductility. The upper of the beam is obviously damaged by compression, while the bottom of the beam is relatively intact. The details of these damages are difficult to be reflected in the beam element model in Fig.12(a). On the other hand, in the model with solid elements, the failure of the remaining beam elements is more minor than the beams shown in figure 12(a).

6. Summary

In order to improve the calculation efficiency, the finite element calculation model combining beam element and shell element is usually adopted for the building structure, but this simplification may produce large analysis error for those members with large section and complex geometry. In this paper, the special members in 3D solid elements are used to simulate the structure, and the application of special constraints such as embedded and multi-point constraints in the actual calculation is introduced, which provides a new idea for engineers to use 3D solid elements to analyze the building structure. The results of the example analysis also show that the simplification of the special members in the structure will not only affect the local results of the structure, but also bring analysis deviation to the overall results of the structure.

References

- [1] China architecture & building press(2010). *Code for seismic design of buildings*. Beijing, China.
- [2] China architecture & building press(2010). *Code for design of concrete structures*, Beijing, China.
- [3] EL. Wilson (1998). *Three-Dimensional Static and Dynamic Analysis of Structures: a Physical Approach with Emphasis on Earthquake Engineering*. Computers and Structures.

- [4] LI Hongnan, Wang Dadong(2014). Multi-scale finite element modeling and numerical analysis reinforced concrete structure. *Journal of Architecture and Civil Engineering*. 31(2): 20-25.
- [5] JIANG Shaofei, WU Minghao, TANG Weijie, LIU Xiaoming(2016). Multi-scale modeling method and seismic behavior analysis for ancient timber structures. *Journal of Building Structures*, 37(10): 44-53.
- [6] ABAQUS Inc(2016). ABAQUS User Manual, V2016.