

Inelastic Dynamic Time-history Analysis of a Frame-wall Structure

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Abstract

The teaching building of QiaoTou School is a frame-wall structure, which has 14 storeys. In this paper, the elastoplastic model of the structure is studied. On this basis, the dynamic elastoplastic analysis of the structure is carried out by using YJK software, and the nonlinear dynamic responses of the structure, including structural deformation, component damage, are investigated under the action of rare earthquake. The results show that the buckling meets the target of "no collapse under strong earthquake".

Keywords

Frame-wall Structure; Dynamic Elastoplastic Analysis; YJK; Inelastic Hinge; Fiber Model.

1. Introduction

The teaching building of QiaoTou School(TQ) covers about 1328m² of the total area of land and the total construction area is about 16850m². The building has 14 storeys above the ground and the tower roof is 50.4m. The main floors are mainly taken as class room and office, there are some commercial floors at the bottom.

The seismic fortification intensity is 7 and it belongs to the first group in the seismic grouping[1]. The basic earthquake acceleration value designed is 0.10g. Basic wind pressure 0.75kN/m². This project adopts the frame-wall structure. The thickness of the peripheral shear wall is 300mm~200mm. The concrete frame column is 600x600~400x400mm. The size of frame beam is 300x750mm. The floor thickness is 120mm. The steel bar is HRB400, and concrete is C40~C30.

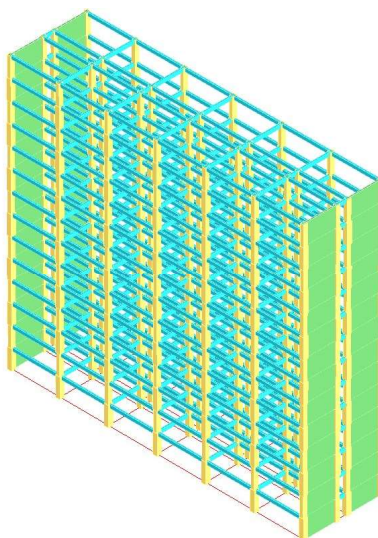


Figure 1. Mode of TQ

The YJK software is adopted to conduct the elastic analysis and inelastic dynamic time-history analysis. The inelastic dynamic time-history analysis is used to evaluate the elastoplastic

behaviors under the major earthquake and confirm whether the structure meets the seismic performance objectives according to the plastic damage and overall deformation of main components. It could judge the weak part of the structure and the corresponding strengthening measures may be proposed to the weak part and components of the structure[2].

2. Inelastic Dynamic Time-history Analysis Method

Inelastic time history analysis is dynamic analysis, which considers material nonlinearity of a structure. Considering the efficiency of the analysis, nonlinear elements are used to represent important parts of the structure, and the remainder is assumed to behave elastically.

2.1. Fiber Model

Fiber Model discretizes and analyzes the section of a beam element into fibers, which only deform axially[4]. When a fiber model is used, the moment-curvature relationship of a section can be rather accurately traced, based on the assumption of the stress-strain relationship of the fiber material and the distribution pattern of sectional deformation. Especially, it has the advantage of considering the movement of neutral axis due to axial force. On the other hand, a skeleton curve based hysteresis model has a limitation of accurately representing the true behavior because some behaviors of a beam element under repeated loads have been idealized. In a fiber model, the status of fibers is assessed by axial deformations corresponding to the axial and bending deformations of the fibers. The properties of nonlinear behavior of a section in a fiber model are defined by the stress-strain relationship of nonlinear fibers.

2.2. Layered Shell Element

The nonlinear behavior of a wall can be analyzed by the layered shell element. For the layered section property, you define how the section is built up in the thickness direction. Layers are located with respect to a reference surface. The thick-plate (Mindlin/Reissner) formulation, which includes the effects of transverse shear deformation, is always used for bending behavior of the layered shell.

The material properties for each layer may be isotropic, uniaxial, or orthotropic. If an anisotropic material is chosen, orthotropic properties will be used. The behavior of the material depends on the material component behavior chosen for the layer.

2.3. Material Properties

2.3.1. Steel Fiber Constitutive Model

Steel fiber constitutive model basically retains the curved shapes approaching the asymptotes defined by the bilinear kinematic hardening rule. It adopts the Clough's stiffness degradation model to simulate the stress-strain relation of the steel under the repetitive load.

2.3.2. Concrete Fiber Constitutive Model

This study uses the equation of envelope curve proposed by Kent and Park (1973) for the concrete fiber constitutive model of concrete under compression. Tension strength of concrete is ignored. This is a well known material model for considering the effect of increased compression strength of concrete due to lateral confinement[4].

The plastic damage model is used to simulate damage of the concrete[5]. The damage of the concrete can be simulated by the damage coefficient based on the reduction of the unloading / reloading stiffness of the concrete. The damage and plastic strain are the main indicators in judging the damage degree of concrete. The damage factor is directly related to the concrete's plastic strain and it could be calculated with the formula below.

3. Analysis Modal

3.1. Simulation and Performance Judgement of the Component's Nonlinear Behavior

3.1.1. Concrete Beam

The distributed plastic model is adopted to simulate the elastic-plastic response of concrete beams subjected to bending in the main axis. The anti-seismic property of the concrete beam may be judged according to the size of plastic hinge.

3.1.2. Concrete Column

The elastoplastic damage material model of concrete columns is input into ABAQUS by a user-defined program. The anti-seismic property of the concrete column may be judged according to the compressive strain of concrete and stretching strain of the steel bar.

3.1.3. Shear Wall

The nonlinear layered shell model is adopted to simulate the nonlinear behaviors of the wall. The reinforcement in the wall is embedded into the concrete section in the form of steel fiber. The normal stress and shear stress of the shear wall shell element reflect the tension, bending and shear of the wall section. The normal stress and shear stress of the shell element are transferred to the principal stress. The principal stress, principal strain and damage coefficient are adopted to judge the stress and strain state of concrete and reinforcement under compression and tension. The damage coefficient corresponds to the plastic strain. The plastic strain is the direct indicator to judge the performance of the shear wall.

3.2. Structural Damping

In general, the damping ratio of the steel structure is 0.02, the concrete structure is 0.05 and the steel-concrete composite structure is 0.03-0.04 based on the quantity and function of the two materials under the small earthquake[6]. Under the large earthquake, the structure's damping ratio is 0.05 under any steel structure and concrete structure. In the non-linear analysis of this structure under the large earthquake, the Rayleigh damping is adopted and the damping ratio is 0.05.

3.3. Structure Model Validation

The period and mode of vibration deformation of the model YJK are compared with other models as follows (Table 1, Figure 2 and Figure 3). It could be observed that the calculation results of two software are quite close and the YJK model is reliable.

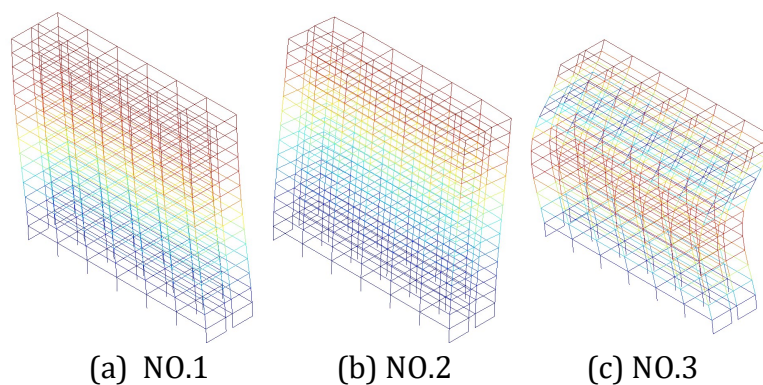
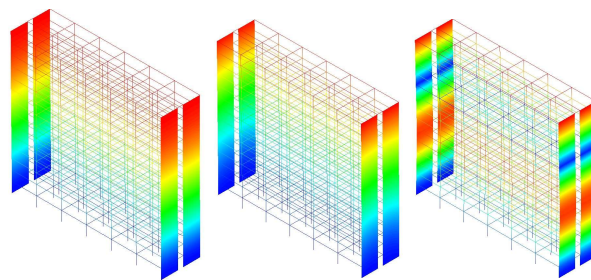


Figure 2. Mode of vibration deformation of the model YJK-A



(a) NO.1 (b) NO.2 (c) NO.3

Figure 3. Mode of vibration deformation of the model YJK-EP

Table 1. Period

Period No.	YJK-A(s)	YJK-EP(s)	error(%)
1	3.6962	3.0401	-17.75
2	1.4235	1.2641	-11.20
3	1.1699	0.9744	-16.71

4. Results

4.1. Base Shear

The Table.2 is the base shear in the direction X and Y. The shear ratio between the basic shearing force of various seismic waves and small-earthquake elastic CQC conforms to the experience value.

Table 2. Base shear

	direction X		direction Y	
	base shear (kN)	ratio	base shear (kN)	ratio
Dynamic	11406.99	4.88	18105.76	4.45
CQC	2339.61	1.00	4068.71	1.00

4.2. Time-history Curve

The elastic-plastic time history curve of the structure is separated from the elastic time history curve(Figure 4 and Figure 5), and the maximum amplitude is not synchronized with the vibration frequency, indicating that the material enters the plastic state under the excitation of seismic waves.

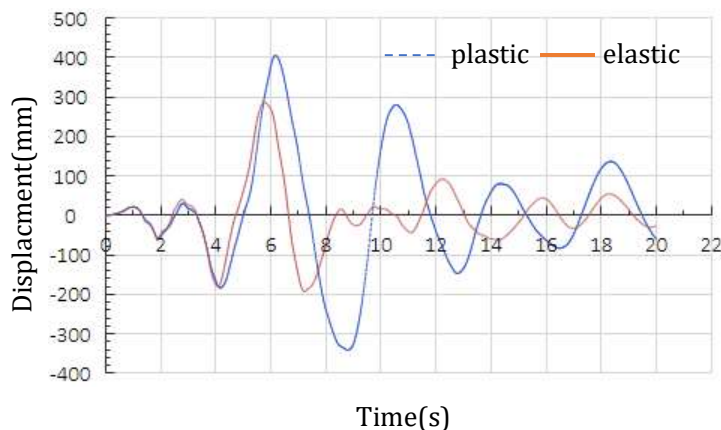


Figure 4. Displacement of top floor

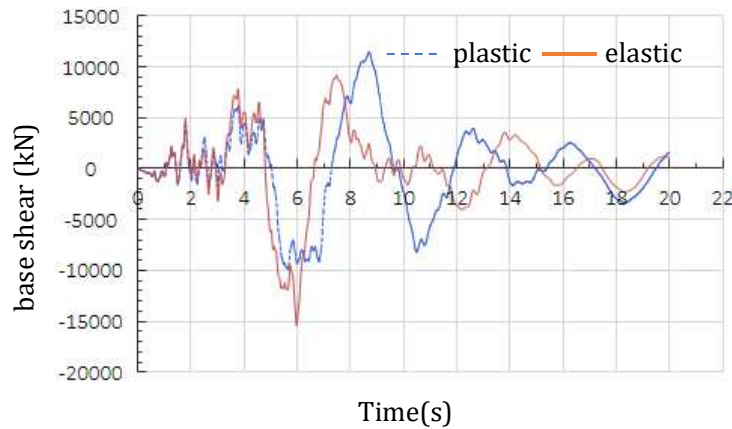


Figure 5. Base shear

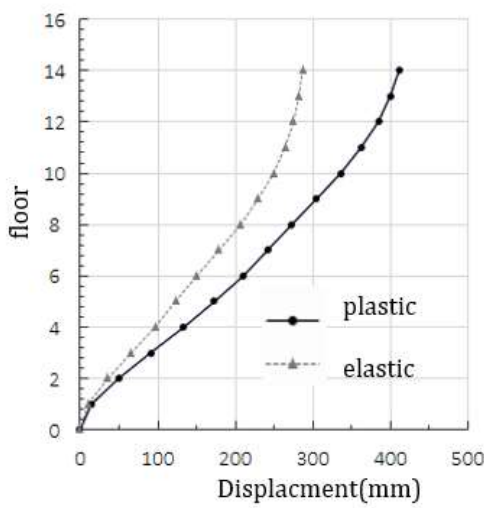
4.3. Maximum Dsplacement

Floor Maximum Response (Figure 6 and Figure 7) shows the maximum response of each floor under the action of seismic waves. It is also often the most important indicator for engineers. The specification clearly stipulates that the elastoplastic displacement angle cannot exceed the displacement angle limit, otherwise the structure cannot reach the fortification level of large earthquakes. The maximum layer displacement, layer displacement angle, and layer shear force curve of each strip wave are shown in the following figure.

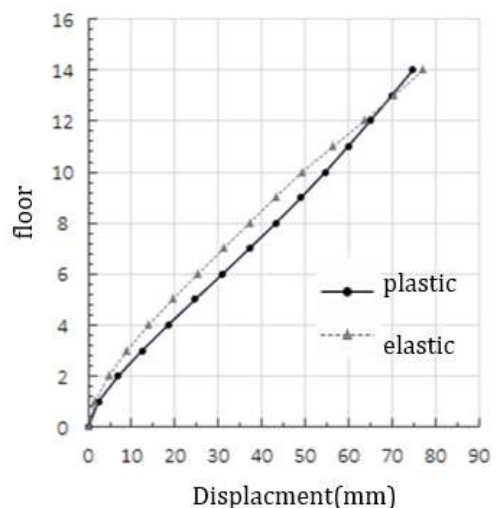
The elastic-plastic displacement is generally greater than the elastic displacement, indicating that the structure may have entered different degrees of nonlinearity, and the maximum displacement is located at the top.

The elastic-plastic base shear is smaller than the elastic one under the large earthquake and it corresponds to the experience value.

It could be observed from the calculation results that the maximum-layer displacement angle of the structure is smaller than 1/100, meeting the specification.



(a) direction X



(b) direction Y

Figure 6. Maximum dsplacement

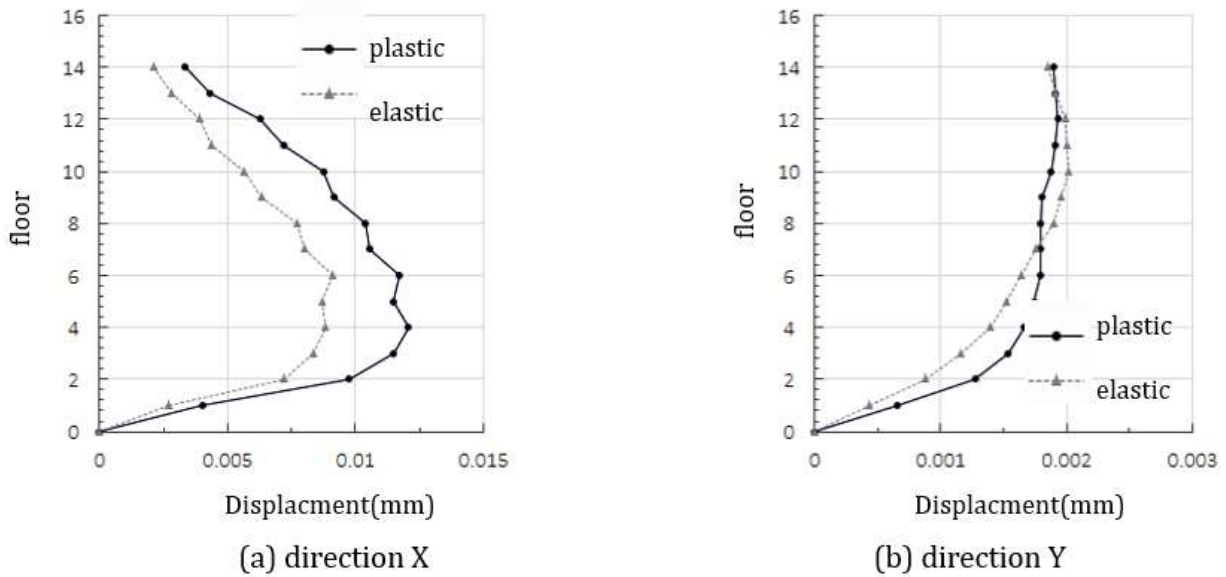


Figure 7. Maximum drift

4.4. Damage

The damage of the building are shown as Figure 8~10. There is a large tensile damage degree between the bottom and upper wall. However, the reinforcement in the wall not yield. There is no compression damage for beams. The steel bar in the beam take on a large tensile damage. The coupling beams are seriously damaged from top to bottom, and many coupling beams are also seriously damaged, while there is an obvious impact of the shear wall on the bottom reinforcement area; The damage of frame beam and column is controllable.

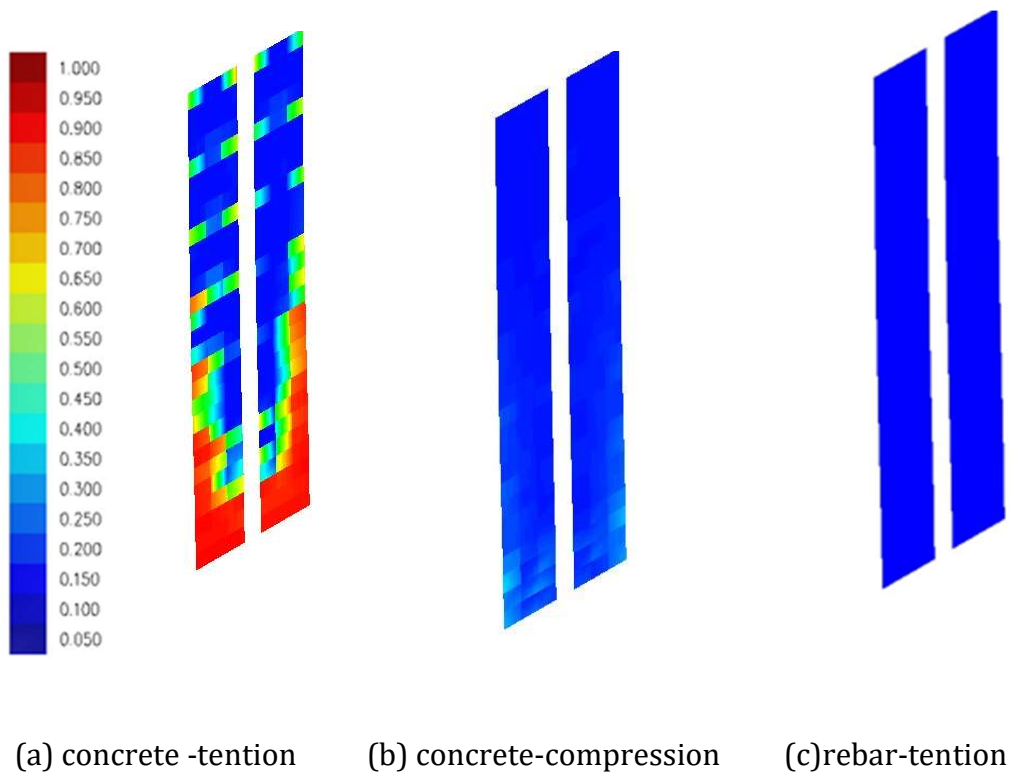


Figure 8. Damage of wall

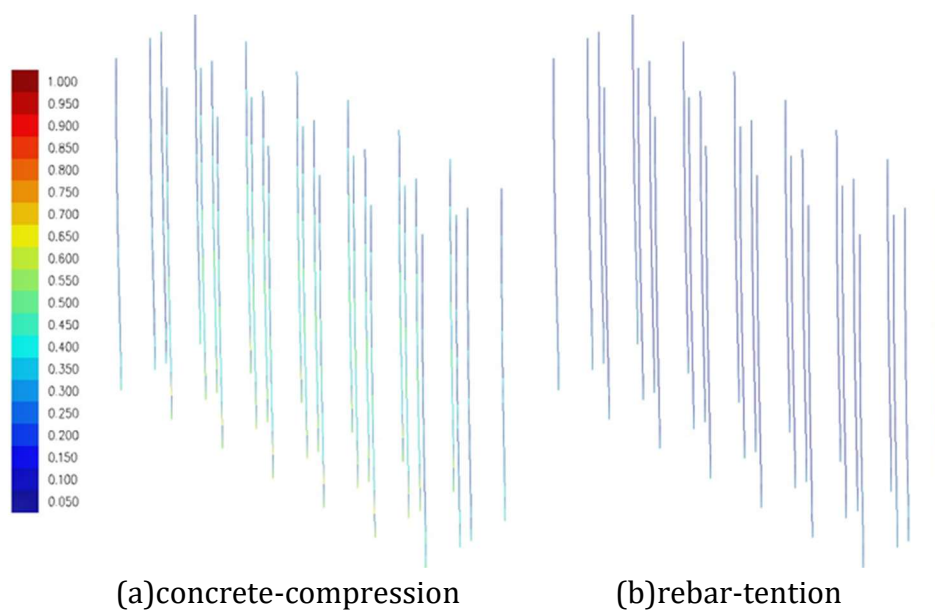


Figure 9. Damage of column

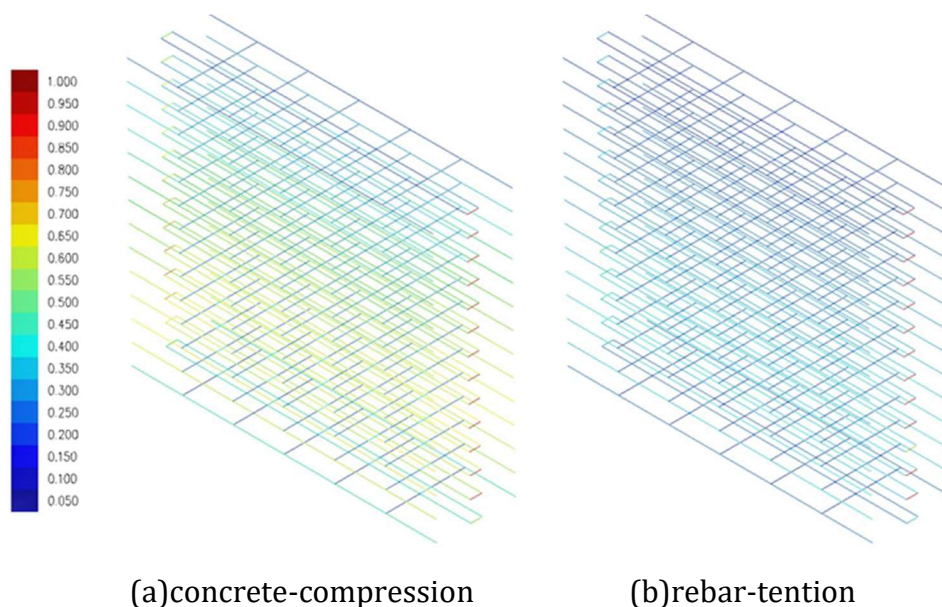


Figure 10. Damage of beam

5. Conclusion

The results of the dynamic elastoplastic analysis shows:

- (1) After the completion of the dynamic elastoplastic analysis, the structure remains upright, the maximum elastoplastic interlayer displacement angle meets the specification requirements.
- (2) The interlayer displacement angle curve of the structure is relatively smooth and unnatural, and the maximum interlayer displacement angle appears on the upper 1/3 height floor.
- (3) Beam yielding generally forms a curved plastic hinge that consumes energy and achieves the design goal.

In summary, the structure of this project can meet the pre-set performance goals and requirements of the use of functions, and meet the seismic design requirements of "small earthquakes are not broken, medium earthquakes can be repaired, and large earthquakes are not overturned".

Acknowledgments

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