Seismic Analysis on The Frame Structure Reformed by Cutting off Column and Jacking

Zhendong Wang 1, Xinsheng Xu 1*
1 School of Civil Engineering, University of Jinan, Jinan, 250022, China
*Corresponding author’s e-mail: xinsheng_xu@163.com

Abstract. The stiffness of the structure will change after the broken column is jacked up, which directly affects the overall seismic performance of the structure. But up to now, the design method and construction technology of the broken column jacking are not standardized, so it is of great engineering significance to study the seismic performance of the frame structure after the broken column jacking. In this paper, the data before and after jacking and after reinforcement of the whole broken column jacking project of a five-story frame structure in Jinan high tech Zone are simulated and analyzed. Based on the stiffness, El Centro seismic wave, Taft seismic wave and Tianjin artificial wave are selected to analyze the dynamic time history of the structure. Through the study of the change of seismic performance of the structure before and after jacking and after reinforcement, it can provide some guidance for the design and construction of the whole structure jacking.

1. Introduction
The jacking technology has just been introduced into the civil industry and is mainly used in the process of bridge erection. With the improvement of hydraulic jack, the synchronous jacking technology is gradually applied to the Construction Engineering (the overall jacking of the roof); after that, the jacking technology has been rapidly improved in foreign countries and widely used in some large-scale projects, such as the overall translation and jacking of buildings [1]. The jacking technology can keep the original style and structure integrity of the building to meet the requirements of the overall urban planning to the maximum[2], and save the construction period, reduce the cost and protect the environment, so it is widely used in the overall jacking project of buildings and structures. The technical specification for displacement engineering of buildings (structures) (GJ / T 239-2011) [3] also only limits the vertical displacement difference of jacking, and the limits and control measures for horizontal lateral displacement are not mentioned.

2. General situation and scheme analysis of a frame structure jacking project

2.1 Project overview
The project is located in Jinan high tech Zone and built in 2014. The jacking part is a five storey reinforced concrete frame with a storey height of 4.5m, the column size is 650mm \( \times \) 650mm, the main beam size is 650mm \( \times \) 300mm, the floor thickness is 120mm, the encryption area range: 1400mm for the lower part of the bottom column, 800mm for the end of other columns, and 1000mm for both ends. The concrete strength grade is C30, and HRB400 steel bars are used in beams, slabs and columns.
2.2 Analysis of beam reinforcement design

Before construction, PKPM software is used to build the structural model of the jacking part of the five-story frame before and after jacking, and SATWE is used to calculate the reinforcement. By comparing the reinforcement area of each beam before and after jacking, the difference of reinforcement is found out. For the beams with more reinforcement area after jacking than before jacking, carbon fiber is used to supplement the lack of strength and improve the bearing capacity of the beams.

2.3 Analysis of column reinforcement design

The height of the first floor changes due to jacking, and the rigidity changes accordingly. Considering the need to restore the rigidity to the previous state, it is decided to use the method of increasing section to strengthen the column. Through comparison, it is found that the difference of column reinforcement is not large, so according to the structural requirements, the increased section should not be less than 50 mm, considering the restoration of stiffness, the increased section is 60 mm, and the reinforcement is carried out according to the structural reinforcement of concrete structures [4].

3. Finite element analysis results

Through the dynamic time history analysis of the frame structure model before and after the jacking and after the reinforcement, the important data are extracted, and the acceleration time history curve and the shear time history curve are drawn by using origin drawing software, and the curves are grouped for comparative discussion:

1. After the frame structure is lifted at the bottom, the first floor stiffness becomes smaller, top floor acceleration and bottom shear force become larger, the elastic-plastic displacement angle also becomes larger, the seismic performance of the frame structure obviously declines, so the structure needs to be strengthened.

2. The frame structure is strengthened on the basis of jacking, the first floor stiffness increases to the level of the structure before jacking, top floor acceleration and bottom shear force of the structure after reinforcement become smaller, and the elastic-plastic displacement angle is also reduced, which shows that its seismic performance is improved.

3. Comparing the seismic performance of the frame before and after jacking, it is found that the top acceleration and bottom shear force of the two models are basically the same under the condition of basically the same stiffness, which shows that the seismic performance before jacking is basically the same as that after reinforcement, reflecting the proper effect of reinforcement.

![Figure 1](image)

(a) Before jacking up  (b) After jacking up  (c) After reinforcement

Figure 1. Time history curve of top floor acceleration of reinforced concrete frame structure under EI Centro seismic wave
Figure 2. Time history curve of top floor acceleration of reinforced concrete frame structure under Taft seismic wave

(a) Before jacking up  (b) After jacking up  (c) After reinforcement

Figure 3. Time history curve of top floor acceleration of reinforced concrete frame structure under artificial wave in Tianjin

(a) Before jacking up  (b) After jacking up  (c) After reinforcement

Figure 4. Time history curve of bottom shear force of reinforced concrete frame structure under EI Centro seismic wave

(a) Before jacking up  (b) After jacking up  (c) After reinforcement

Figure 5. Bottom shear time history curve of reinforced concrete frame structure under Taft seismic wave
Before jacking up

After jacking up

After reinforcement

Figure 6. Time history curve of bottom shear force of reinforced concrete frame structure under artificial wave in Tianjin

4. Seismic performance evaluation based on displacement

The storey displacement angle of the structure is an extremely important index to measure the seismic performance of reinforced concrete frame, which is of great significance to control the maximum deformation of the frame. Table 1-3 shows the elastic-plastic displacement of reinforced concrete frame structure before and after jacking and after reinforcement under EI Centro seismic wave, Taft seismic wave and Tianjin artificial wave respectively.

Table 1. Elastic plastic displacement angle of frame under EI Centro seismic wave

| Floor | Maximum floor displacement (m) | Maximum displacement between layers (m) | Maximum displacement angle between layers (rad) |
|-------|-------------------------------|----------------------------------------|-----------------------------------------------|
|       | BJU  | AJU  | AR  | BJU  | AJU  | AR  | BJU  | AJU  | AR  |
| 1     | 0.062 | 0.070 | 0.061 | 0.062 | 0.065 | 0.064 | 1/73  | 1/71  | 1/78 |
| 2     | 0.105 | 0.117 | 0.104 | 0.043 | 0.047 | 0.043 | 1/105 | 1/96  | 1/96 |
| 3     | 0.126 | 0.143 | 0.126 | 0.021 | 0.026 | 0.022 | 1/224 | 1/173 | 1/205 |

Table 2. Elastic plastic displacement angle of frame under Taft seismic wave

| Floor | Maximum floor displacement (m) | Maximum displacement between layers (m) | Maximum displacement angle between layers (rad) |
|-------|-------------------------------|----------------------------------------|-----------------------------------------------|
|       | BJU  | AJU  | AR  | BJU  | AJU  | AR  | BJU  | AJU  | AR  |
| 1     | 0.070 | 0.079 | 0.072 | 0.070 | 0.079 | 0.072 | 1/65  | 1/63  | 1/71 |
| 2     | 0.115 | 0.127 | 0.116 | 0.045 | 0.048 | 0.044 | 1/100 | 1/94  | 1/103 |
| 3     | 0.138 | 0.154 | 0.137 | 0.020 | 0.027 | 0.021 | 1/225 | 1/166 | 1/214 |

Table 3. Elastic plastic displacement angle of frame under the action of Tianjin artificial wave

| Floor | Maximum floor displacement (m) | Maximum displacement between layers (m) | Maximum displacement angle between layers (rad) |
|-------|-------------------------------|----------------------------------------|-----------------------------------------------|
|       | BJU  | AJU  | AR  | BJU  | AJU  | AR  | BJU  | AJU  | AR  |
| 1     | 0.046 | 0.051 | 0.048 | 0.046 | 0.051 | 0.048 | 1/95  | 1/95  | 1/96 |
| 2     | 0.093 | 0.098 | 0.094 | 0.047 | 0.047 | 0.046 | 1/96  | 1/96  | 1/97 |
| 3     | 0.115 | 0.121 | 0.115 | 0.022 | 0.023 | 0.021 | 1/205 | 1/196 | 1/214 |

(Notes: BJU: Before jacking up   AJU: After jacking up   AR: After reinforcement)

From the above three tables, it can be seen that under the action of three seismic waves, the elastic-plastic inter story displacement angle of reinforced concrete frame structure before and after jacking and after reinforcement does not exceed 1 / 50 of its limit, which conforms to the specifications.

5. Conclusion

(1) Through theoretical analysis, the stiffness of the structure will change after jacking, which directly
affects the seismic performance of the structure. Using ABAQUS software simulation, the models before and after jacking and after reinforcement are established for simulation. It is found that under the same earthquake condition, the top acceleration, bottom shear force and elastic-plastic displacement angle of the structure after jacking are correspondingly increased, the first floor stiffness is reduced, and the seismic resistance is greatly reduced; and after reinforcement, the first floor stiffness return to the level before jacking. As a result, the top acceleration, bottom shear and elastic-plastic displacement angle are correspondingly reduced, and the seismic performance is improved. The above shows that the seismic performance of the structure after jacking is not as good as that before jacking, so the structure needs to be strengthened to some extent to meet the seismic requirements.

(2) In the design of integral jacking reinforcement, it is necessary to pay attention to the rigidity. Even when the bearing capacity is sufficient, it is also necessary to restore the rigidity of the jacking layer to the extent when it is not jacking, so as to avoid the seismic performance deterioration due to the uneven vertical rigidity of the overall structure.

Acknowledgments
First of all, I would like to thank Professor Xu Xinsheng, my Postgraduate Tutor, for his patient guidance and meticulous care, which made me feel more cordial. Second, I would like to thank senior brother sun Yili, Manager Shang and their construction units for their guidance and help in my project.

References
[1] Li Aiqun, Wu Erjun. Progress in integral translation technology and engineering application of buildings in China [J]. Jiangsu architecture. 2003 (S1): 48-54.
[2] Lamar K, Pan D, Barber S. Photo from southcombe’s collection[J]. The Structure Mover. 1999, 1(17).
[3] Ministry of housing and urban rural development of the people's Republic of China. JGJ / T 239-2011 technical code for building (structure) displacement engineering [S]. Beijing: China Construction Industry Press
[4] China building standard design and Research Institute. Concrete structure reinforcement [M]. China Planning Press, 2013