Seismic analysis of the frame structure reformed by cutting off column and jacking based on stiffness ratio

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Abstract. The cutting off column and jacking technology is a method for increasing story height, which has been widely used and paid much attention in engineering. The stiffness will be changed after the process of cutting off column and jacking, which directly affects the overall seismic performance. It is usually necessary to take seismic strengthening measures to enhance the stiffness. A five story frame structure jacking project in Jinan High-tech Zone was taken as an example, and three finite element models were established which contains the frame model before lifting, after lifting and after strengthening. Based on the stiffness, the dynamic time-history analysis was carried out to research its seismic performance under the EL-Centro seismic wave, the Taft seismic wave and the Tianjin artificial seismic wave. The research can provide some guidance for the design and construction of the entire jack lifting structure.

1. Preface
The frame structure of the building can be seen everywhere in our country, from time to time, many old buildings need to be modified to meet the current need. The cutting off column and jacking technology is an effective method for increasing story height, which has been widely used and paid much attention in engineering. There are some engineering examples that have been used to increase the story height of the building, and take the good effect. But its design method is not mature enough, the design code is far from perfect and the construction technology is not standardized. Engineering practice is more than theoretical research and engineering experience is dominant in the design and construction. However, the informal construction will lead to the combination of the new-old concrete interface cannot be fully bonded together, the seismic performance of the structure will be affected and the stiffness of the structure after the rise will be changed, so reinforcement is very important. In this paper, through the study of the models which are before jacking, after jacking and the reinforced of a five story frame structure in Jinan New and High-tech Zone, and analysis of the seismic performance, which has certain theoretical significance and practical engineering value.

2. Project Overview
The paper takes a five story frame structure jacking project in Jinan High-tech Zone as an example, the original building structure has been unable to meet today's use requirements, and the owners proposed to increase 500mm of the layer. For the requirements of the owners, inspection and identification of the construction site, after discussion decided to remove all the walls of a layer, and cut off all the 16 pillars of the part, and do the good job of the separation and inter-layer support of the jacking and no-jacking part before cut off the pillars[1]. Due to the height increase of the layer of the first floor after the jacking, resulting in the changes of stiffness of the first floor, the increasing of stiffness of the first
floor and the second floor, the declined of the seismic performance, and the structural part of the component is not enough to continue carrying. So strengthening the unloaded beams after jacking by adding two layers of carbon fiber cloth, the bottom pillar is reinforced by increasing the cross-section [2].

3. Selection of Seismic Wave and Establishment of Model
In this paper, the seismic wave is selected and adjusted according to the amplitude, spectral characteristics and duration of the seismic wave. The model is simulated by EL-Centro wave, Taft wave and Tianjin artificial wave, and the project is set up under the condition of 8 degree earthquake Calculation [3]. The simulation is divided into three independent models: the frame structure model before jacking, the frame structure model after jacking and the frame structure model after strengthening. According to the previous experience and the simulation content, the separate modeling method is used to build the concrete, the steel bar and the carbon fiber reinforcement unit separately to model [4]. The frame model is set up as shown in figure 1.

4. Seismic performance analysis of frame structures

4.1. The acceleration versus time data
Figure 2 (a), (b) and (c) are respectively acceleration versus time data of reinforced concrete frame structures before and after jacking and strengthening under the action of EL-Centro seismic waves at the top floor.

It can be seen from the curve in the figure that the acceleration of the top floor of the building changes with the acceleration of the seismic wave. The maximum acceleration of the top floor before jacking is 2.07m/s², the maximum acceleration of the top floor after jacking is 2.31 m/s², the maximum acceleration after strengthening is 2.08m/s². At the same times the lateral stiffness of each column decreased from 58767KN/m to 42842KN/m, and the stiffness ratio between the second layers and the first layer is changed to 1.37. It shows that under the same seismic, the bearing capacity of the reinforced concrete frame is higher than that before jacking, and the seismic performance needs to be improved. Compared with the maximum acceleration of the top layer after jacking, the acceleration of the top layer after strengthening is decreased. At this time, each column of the bottom layer is
strengthened by the cross section method, the lateral stiffness of each column increased from 42842KN/m to 60988KN/m, and the stiffness ratio between the second layers and the first layer is changed to 0.97. It is shown that the seismic performance is strengthened compared with the reinforced concrete frame after jacking under the same earthquake. And compared with the model data after reinforcement, the data are very similar. It shows that the reinforcement played its due role, and the seismic performance of the reinforced structure is basically the same as the performance before jacking.

4.2. Shear time curve
Figure 3 (a), (b) and (c) are respectively bottom shear time course of reinforced concrete frame structures before and after jacking and strengthening under the action of Taft seismic waves at the top floor.

![Figure 3](image)

Figure 3. Bottom shear time course under the action of Taft seismic waves.

It can be seen from the curve in the figure that the bottom shear time course of the building changes with the acceleration of the seismic wave. The maximum value of the bottom shear before jacking is 662.87KN, the maximum value of the bottom shear after jacking is 719.19KN, and the maximum value of the bottom shear after strengthening is 661.91KN. At the same times the lateral stiffness of each column decreased from 58767KN/m to 42842KN/m, and the stiffness ratio between the second layers and the first layer is changed to 1.37. It shows that under the same earthquake, the bearing capacity of the reinforced concrete frame is higher than that before jacking, and the seismic performance needs to be improved. Compared with the bottom shear time course after jacking, the bottom shear time course after strengthening is decreased. At this time, each column of the bottom layer is strengthened by the cross section method, the lateral stiffness of each column increased from 42842KN/m to 60988KN/m, and the stiffness ratio between the second layers and the first layer is changed to 0.97. It is shown that the seismic performance is strengthened compared with the reinforced concrete frame after jacking under the same earthquake. And compared with the model data after reinforcement, the data are very similar. It shows that the reinforcement played its due role, and the seismic performance of the reinforced structure is basically the same as the performance before jacking.

4.3. The displacement time history curves
Figure 4 (a), (b) and (c) are respectively acceleration versus time data of reinforced concrete frame structures before and after jacking and strengthening under the action of EL-Centro seismic waves at the top floor.
It can be seen from the curve in the figure that the acceleration of the top floor of the building changes under the influence of the acceleration of the seismic wave. The maximum displacement of the top floor before jacking is 0.115m, the maximum displacement of the top floor after jacking is 0.121m, and the maximum displacement after strengthening is 0.115m. At the same times the lateral stiffness of each column decreased from 58767KN/m to 42842KN/m, and the stiffness ratio between the second layers and the first layer is changed to 1.37. It shows that under the same earthquake, the bearing capacity of the reinforced concrete frame is decreased after jacking, and the seismic performance needs to be improved. Compared with the maximum displacement of the top layer after jacking, the displacement of the top layer after strengthening is decreased. At this time, each column of the bottom layer is strengthened by the cross section method, the lateral stiffness increased from 42842KN/m to 60988KN/m, and the stiffness ratio between the second layers and the first layer is changed to 0.97. It shows that the seismic performance is strengthened and the bearing capacity of reinforced concrete frame is improved. And compared with the model data after reinforcement, the data are very similar. It shows that the reinforcement played its due role, and the seismic performance of the reinforced structure is basically the same as the performance before jacking.

5. Conclusion
Through the theoretical analysis, the stiffness of the structure after jacking will change, which directly affects the seismic performance of the structure. Using the ABAQUS software simulation [5], it is found that under the same seismic, the top layer displacement, the top layer acceleration and the bottom shear force increase after jacking, the first layer stiffness is reduced and seismic performance is also reduced. And the structure of the reinforcement makes the first layer stiffness back to the level before the rise, the top displacement, the top of the acceleration, the bottom of the shear are reduced, seismic performance is improved. The above shows that the seismic of the structure performance is not as good as the performance before jacking, the need for this structure to a certain degree of reinforcement to meet the earthquake demand.

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