Finite Element Analysis and optimization of a three-storey Parking Garage

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Abstract—Finite element analysis is one crucial means to evaluate and optimize the stability and safety of a three-storey parking garage. The geometric model of a three-storey parking garage was built with CATIA. A finite element model was set up by HyperMesh for static strength analysis in Abaqus. It is essential to consider some key factors such as simplification of mesh model, boundary conditions, weight and loads. The strength of the parking garage under full-load was analyzed. Finally, the frame structure of the parking garage was improved based on the result of simulation.

1. INTRODUCTION
With the continuous improvement of people's living standards, more and more people buy private cars, and the large use of private cars has a significant impact on urban traffic and environment. In order to solve the problem of difficult parking for family cars in urban areas, this paper proposes a new type of three-storey parking garage, as shown in Fig.1.

![Figure 1 Schematic drawing of the three-storey parking garage](image_url)

The three-storey parking garage mainly consists of Q345 steel tubes with size of 80*80*8 (mm) and Q235 sheets with thickness of 10-20mm. And it can be divided into six stationary parking space and
one lifting parking space. The lifting parking space act as the medium to transport the car to the stationary parking space. The operation principle of the parking garage is as follows: first, the traction motor placed on the top of the garage, drives the rotating shaft and wire rope to operate; then, the lifting parking space lifts the vehicle to the corresponding height of the target parking space by the wire rope; and then, the translation motor selectively drives the gear set and transmits the car to the target parking space. The three-storey parking garage has the advantages of energy saving, high space utilization, convenient operation and high cost-saving [1-3]. However, the three-floor parking garage must have highly structural stability to ensure the safety. This is because the frame structure of the garage bears the overall weight of the structure and bears complex loads. In this paper, the geometry and mesh model of the parking garage are established, and the full-load capacity of the frame structure is analyzed by finite element software Abaqus. Then, the optimal design of the three-storey parking garage is given.

2. SIMULATION ANALYSIS

2.1. Model description
According to the operation principle of the parking garage, the worst working condition occurs when all the six parking space (regions in green color, Fig. 2) are filled up and the lifting parking space (regions in blue color, Fig. 2) keeps going up with a car inside. The full-load case under the gravitational field is carried out to simulate this working condition. By wire rope, the lifting parking space is connected to the rotating shaft at the top of parking garage.

A three-dimensional three-storey parking garage with a total size of 8060(length)*6440(width)*7150(height, mm) was built up in CATIA. Due to the symmetry, only half of the parking garage was used in this work, as shown in Fig. 2. The main frame structure and supporting plate of the parking garage were modeled by the S4R shell element in HyperMesh. The total number of elements and nodes were 477450 and 516041, respectively. The parking car (each one), traction motor, translation motor were simplified as point mass, and the corresponding mass is 2000kg, 1000kg and 250 kg, respectively.

2.2. Material data
The physical properties of steel are as follows: The density is 7.8 g/cm³. The Yong’s modulus is 210GPa. The Poisson’s ratio is 0.28. The gravitational acceleration is 9.8m/s². The empty weight of the parking garage is 51.65t.

Figure 2 Computational domain of the three-storey parking garage
2.3. **Boundary conditions**

Linear elastic material model was used in the FEM analysis. Two loading points which connected to the rotating shaft are set to bear the weight of the lifting parking space. Accordingly, two loading points which connected to the top of lifting parking space are set as ENCASTRE (U1=U2=U3=UR1=UR2=UR3=0) to hang the lifting parking space. The bottom of parking space at the ground floor is set as ENCASTRE (U1=U2=U3=UR1=UR2=UR3=0). The symmetry plane is set as XSYMM (U1=UR2=UR3=0). Considering the dynamic condition, the dynamic load coefficient of the lifting parking space is set to 1.1 [4]. Abaqus was used to solve the stress result of parking garage under full-load condition.

2.4. **Simulation result**

Fig.3 shows the stress distribution of the stationary parking space under full-load condition. It can be seen that most of the stress concentrates at the supporting frame just below the roof of the parking garage, with the frame’s maximum stress of 1123.0MPa. The maximum stress exceeds the allowable stress of 230MPa and could not meets strength requirement [5]. Deflections are significant at the end of the upper steel tube of stationary parking space. The excessively high deflections will reduce the safety and stability of the frame. Therefore, the frame structure of the stationary parking space needs to be modified and optimized.

![Figure 3 Stress distribution of stationary parking space](image)

Fig.4 shows the stress distribution of lifting parking space under full-load condition. It can be seen that the maximum stress occurs just below the roof steel tube of the lifting parking space, with the frame’s maximum stress of 427.2MPa. The working stress at the region of maximum stress and its...
adjacent areas are higher than the allowable stress and could not meet the strength requirement. Therefore, the frame structure of the lifting parking garage needs to be modified and optimized.

![Stress distribution of (a) lifting parking space; (b) local enlarged image of the maximum stress in Fig.4a](image)

3. **Optimization and Improvement**

As the working strength of the original parking garage could not meet the requirement of allowable stress. The parking garage needs to be redesigned and optimized. According to the stress distribution in the parking garage, the thickness of the supporting floors can be reduced. For example, the thickness of the roof plate of the stationary parking garage was reduced from 20mm to 10mm. As shown in Fig.5, the steel tubes’ thickness were adjusted from 8mm to 4mm except for several key bearing position (red color in figure.4b). In addition, several reinforced steel tubes were used at the roof frame of stationary parking space and lifting parking space, as shown in Fig.5b. The empty weight of the optimized parking garage is 34.65t, with the weight reduction ratio of 32.9%.
Fig. 6 shows the stress distribution of the optimized stationary parking garage under full-load condition. The high stress distributed areas of initial parking garage are significantly strengthened. The maximum stress is decreased to 218.6 MPa at the end of the supporting steel tube of third storey, which is less than the allowable stress of 230 MPa and meets the strength requirement of the frame structure.

Fig. 7 shows the stress distribution of the optimized lifting parking garage under full-load condition. It can be seen that the maximum stress occurs at the end of the steel tube of roof frame. The maximum stress is decreased 224.3 MPa, which is less than the allowable stress of 230 MPa and meets the strength requirement of the frame structure.
4. CONCLUSION
This paper calculates the stress distribution of the three-storey parking garage under full-load condition by the finite element analysis software Abaqus. The calculation results show that the frame structure of the parking garage in full-load condition could not meet the strength requirement of Q345 material. After the optimized design, the optimized frame structure meets to the strength requirement and achieves the goal of lightweight design. The finite element analysis in this paper provides a reference basis for the structural optimal design of parking garage.

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