Comparison of Modal Analysis Results of Data Center Cable Rack Based on Optistruct and Abaqus

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Abstract. As an important infrastructure of the data center, the cable rack provides an important guarantee for the safe and reliable operation of the data center during and after an earthquake. In this paper, the data center cable rack is the research object, the cable rack structural beam unit is modeled, the dynamic characteristics are studied by the modal analysis method, and the frequency and mode shape are combined to initially evaluate its seismic performance, and the difference is made through Optistruct and Abaqus. Comparison of modeling methods, analysis methods, and analysis results between analysis software, compare their mode shape correlation and frequency consistency, ensure accurate modeling and reliable results, and provide data support for subsequent related dynamic analysis.

Keyword: Cable rack, Optistruct, Abaqus, Modal analysis

1. Introduction
Data center is a specialized facility that serves as a place for organizations to place, operate, and maintain back-end IT infrastructure (including computing systems, storage systems, network equipment, and other supporting infrastructure). Driven by the wave of Internet of Everything, it provides a strong infrastructure guarantee for 5G, artificial intelligence, and the internet of things. The cable rack is a facility specially used for cable routing in the data center. It is widely used in data centers in the information and digital industries and is an indispensable auxiliary facility for new infrastructure data center equipment. It can not only beautify the computer room, but more importantly support the weight of all cables, provide wiring and provide a top fixed fulcrum for the equipment [1]. In the 21st century, earthquakes and other natural disasters occur frequently, and the reliability of data center equipment and facilities in the epicenter and after the earthquake has been widely concerned by the society[4]. In this paper, the modal analysis method is used to study the dynamic characteristics of the data center cable rack system, and its seismic performance is preliminarily evaluated through performance indicators such as modal shape and frequency, and compared with mainstream finite element analysis software such as Optistruct and Abaqus in unit selection, structure differences in modeling, analysis methods, and analysis results, and finally use the mode correlation and frequency consistency comparison method to complete the accuracy and reliability comparison of the analysis results, and
provide data support for subsequent related dynamic analysis.

2. Description of cable rack structure

The model selected in this paper is a single-layer C-shaped steel cable rack for data centers (as shown in Fig.1), the length of the cable rack is 5m, the material of the beam and the cross brace is galvanized steel plate with a thickness of 3.0mm, and the section size of the beam is 33mm(Width)×43mm(Height), the section size of the cross brace is 30mm(Width)×34mm(Height), the material of the boom is M16 threaded rod, and the height of the boom is 1.5m, the spacing of the boom 1.5m, the spacing of the cross brace is 0.25m. The mass of the cable rack is 57.8kg, the mass of the cable counterweight is 1008kg, and the total mass of the structure is 1065.8kg.

![Figure 1. Cable rack configuration diagram.](image)

![Figure 2. Cross-section of cable rack.](image)

3. Finite element model establishment

This paper is based on the Optistruct modeling when the cross brace, beam and boom are established using classic beam elements (Beam) [2]. When modeling based on Abaqus, the cross brace, beam and boom are built using linear beam (B31) elements. They are Timoshenko beams that consider shear deformation. They are suitable for simulating the shear deformation of deep beams, and slender beams where shear deformation is not important [3, 4].

Due to the different beam element modeling methods of the two software, the beam-cross brace and beam-boom section positions are different during the model assembly process, which affects the stiffness of the entire structure. In order to ensure the consistency of model modeling, reduce the difference between results error, the node offset of the cross section is required. In this paper, the material model density is 7.9e³t/mm³, poisson's ratio is 0.3, and elastic modulus is 2.1e⁵MPa. The boundary conditions are fully constrained by 6 degrees of freedom at both ends and top. The modal calculation method adopts Lanczos method to solve the eigenvalues.
4. Introduction to modal analysis

Modal analysis, also known as free vibration analysis, is a modern method to study the dynamic characteristics of structures, and is the application of system identification methods in the field of engineering vibration. The mode is the natural vibration characteristic of the mechanical structure, and each mode has a specific natural frequency, damping ratio and mode shape. Modal parameters can be obtained by calculation or experimental analysis. Such a calculation or experimental analysis process is called modal analysis, which is the basis of other dynamic analysis such as harmonic response analysis, transient dynamic analysis and spectrum analysis [5]. The ultimate goal of modal analysis is to identify the modal parameters of the system and provide a basis for the analysis of the vibration characteristics of the structural system, the diagnosis and prediction of vibration faults, and the optimal design of the dynamic characteristics of the structure.

Modal analysis applications can be summarized as:
(1) Evaluate the dynamic characteristics of the existing structural system.
(2) Predict and optimize the structural dynamic characteristics in the design of new products.
(3) Diagnose and forecast structural system failures.
(4) Control the radiated noise of the structure.
(5) Identify the load of the structural system.

The classic definition of modal analysis is to transform the physical coordinates of the vibration differential equations of a linear time-invariable system into modal coordinates. The transformation matrix of coordinate transformation is called the modal matrix, and each column is the modal shape [6].

For modal analysis, the vibration frequency $\omega_i$ and mode $\phi_i$ are calculated by the following equations:

$$\left( [K] - \omega_i^2 [M] \right) \{ \phi_i \} = 0$$

5. Analysis results and comparison

5.1. Analysis results

The first 12-order modal frequencies and error results of the cable rack are shown in Table 1. The first 5 modes and frequency values are shown in Fig.4 to Fig.8. The left side is the Optistruct calculation result, and the right side is the Abaqus calculation result.
Table 1. The first 12-order modal frequencies and error results of the cable rack.

| Order | Optistruct (Hz) | Abaqus (Hz) | Error (%) |
|-------|-----------------|-------------|-----------|
| 1     | 4.90            | 4.92        | -0.41     |
| 2     | 9.94            | 9.96        | -0.20     |
| 3     | 11.45           | 11.41       | 0.35      |
| 4     | 15.36           | 15.26       | 0.65      |
| 5     | 15.43           | 15.47       | -0.26     |
| 6     | 19.09           | 19.05       | 0.21      |
| 7     | 21.41           | 21.46       | -0.23     |
| 8     | 23.85           | 23.80       | 0.21      |
| 9     | 24.28           | 24.11       | 0.007     |
| 10    | 24.34           | 24.24       | 0.004     |
| 11    | 24.58           | 24.44       | 0.006     |
| 12    | 25.13           | 25.14       | 0.001     |

Figure 4. The first-order shape and frequency.

Figure 5. The second-order shape and frequency.

Figure 6. The third-order shape and frequency.
5.2. Comparison

5.2.1. Correlation criterion of mode shape

(1) MAC (Modal Assurance Criterion) is the most widely used tool in model benchmarking.

\[
MAC(r,q) = \frac{\left( \phi_r^T \phi_q \right)}{\left( \phi_r^T \phi_r \right) \left( \phi_q^T \phi_q \right)}
\]

Among them, \( \phi_r \) is the mode shape corresponding to a certain natural frequency. MAC represents the least squares deviation in the correlation graph of the mode shape. For large differences in the mode shape, the MAC value is more obvious, but when there is only a small difference in the mode shape, the MAC value is relatively insensitive. It was originally used in the experiment to compare the mode shapes under different excitation points. MAC can also be used in different test excitation positions, test mode comparison, simulation and test mode comparison, the same source data through different modal parameter recognition algorithms for the comparison of the mode shape, and the mode shape after changing the structure Comparison. This paper uses MAC to compare the modes calculated by different analysis software. When MAC approaches 0, it means that the two vibration modes are linearly independent. If the MAC approaches 1, it means that the two groups of modes are linearly related. Generally, if it exceeds 0.9, the correlation is high. The MAC value is shown in Fig.9.
In this paper, the abscissa axis of Fig. 9 represents the 19th-order mode shape calculated by Abaqus, and the ordinate axis represents the 19th-order mode shape calculated by Optistruct. The diagonal values of the \textit{MAC} matrix are both greater than 0.9 and approaching 1, indicating that the two modes are related. The sex is very high and the consistency is good.

(2) The \textit{COMAC} value represents the correlation of the structural degrees of freedom, that is, the correlation of a certain node in the two groups of mode shapes, and it can be analyzed which nodes cause poor correlation in the \textit{MAC} value calculation.

\[
\text{COMAC}(i) = \frac{\sum_{j=1}^{N} \phi_{ij}^A \phi_{ij}^B}{\sum_{j=1}^{N} (\phi_{ij}^A)^2 \sum_{j=1}^{N} (\phi_{ij}^B)^2} \tag{3}
\]

The cloud diagram of the calculation results of the \textit{COMAC} value in this paper is shown in Fig. 10. The intersection value of the cross brace, boom and beam at both ends is close to 1, and the value of the other parts is about 0.7, indicating that the two model nodes are highly correlated.

5.2.2. Modal frequency consistency criterion

The first 10 frequency results of the modal are shown in Tab. 1, and the error is less than 0.7%. The first 19-order frequency result curve and error of the modal are shown in Fig. 11. The blue curve in the figure represents the calculated frequency result of Optistruct, and the green curve represents the calculated frequency result of Abaqus. The two tend to overlap. The red curve represents the frequency error curve of the two software, the amplitude is between ±2.5%, which means that the error of the first 19 frequency results is less than 2.5%, and the modal frequency is consistent.
6. Conclusion and outlook

In this paper, two softwares, Optistruct and Abaqus, are used to implement cable rack modeling, material properties and boundary condition settings, complete structural modal analysis, and introduce the modal confidence criterion $MAC$ and coordinate mode confidence criterion $COMAC$ to compare the two modes. The correlation is high, and the frequency error analysis shows that the two frequencies are in good agreement. Combining the comparison results of mode shape correlation and frequency consistency verify the accuracy of this article in terms of modeling method, setting of boundary conditions, setting of analysis conditions, and selection of calculation method, for subsequent harmonic response analysis, transient dynamics analysis and Kinetic analysis such as spectrum analysis provides data support [6, 7]. The next step is to continue the dynamic analysis of the cabling frame structure, combining with other evaluation indicators to continue to compare and verify the two software while improving the reliability of structural analysis.

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