The seismic analysis of the safety evacuation device

Yongyan Wang, Yong Wang*, Lizhuang Cui, Xuezhi Feng, Gengyu Sun and Xiumin Jing
Qingdao University of Science and Technology, Qingdao 266061, China

*Corresponding author e-mail: 1164147393@qq.com

Abstract. The seismic resistance of the safety evacuation device is mainly dependent on the structural design of the cabin, and it requires that the bulk structure must have sufficient strength and stiffness to resist the impact of the seismic load applied to the cabin. In this paper, the structure model of the similar triangular cabin structure is established, and then the seismic analysis of the structure of the similar triangular structure is carried out. The first twelve modes and the natural frequencies of the similar triangular structure are obtained by modal analysis in ANSYS Workbench, and the cabin structure deformation position and the most serious dangerous frequency are obtained to avoid resonance. Finally, the seismic acceleration load is applied to the triangular cabin, and the transient dynamic analysis is carried out to simulate a certain earthquake condition. The equivalent stress cloud image and the total deformation cloud analysis show that the acceleration, deformation and stress of the cabin structure are not large, and indicating that the triangular cabin structure satisfies the seismic requirements.

1. Introduction
The safety evacuation device is used as an emergency evacuation device for high-rise residential buildings, mainly for emergency disasters, such as earthquakes and fires [1]. In the face of earthquake disasters, the safety refuge device must not only avoid the occurrence of resonance, but also meet the requirements of intensity and rigidity under dynamic load response. Otherwise, local deformation and damage of the cabin may occur. Abroad, Patel SN, Datta PK et al. used finite element analysis method to analyze the dynamic and static of the internal stiffener ribs cabin construction [2]; Sheikh et al. studied the structure of the hull with ribs. The linear transient response and nonlinear transient response of the cabin structure are analyzed by the spline collocation method [3]. Domestically, Wang Yuanbin and Xu Dehua from Southwest Jiaotong University proposed the design of a seismic safety evacuation device, and proposed a preliminary design for the seismic performance design of the safety evacuation device, and made theoretical analysis and experimental research on the reliability of the seismic safety evacuation device [4]; Wenzhou Nanjiang Enterprise Group has successfully developed a mine rescue capsule and conducted a live-action test, which was a great success and filled the domestic research gap in this field [5,6].

In this paper, the advantages and disadvantages of the existing safe evacuation devices are analyzed, and a new type of triangular cabin structure is proposed. The modal and transient dynamics analysis methods are used to analyze the seismic mitigation of the safety refuge. By studying the natural frequency and vibration mode of the safety refuge device, the safety refuge device structure is prevented...
from resonance occurring under external load excitation conditions. At the same time, the safety refuge device is simulated under the action of seismic load of a certain working condition, and the rationality of the structure of the cabin is verified under the dynamic response and force characteristics of the safety refuge device structure.

2. Cabin design of safety refuge
Refer to the existing cabin structure of the safety refuge device, which has a circular shape, a square shape, etc. According to the design requirements of the pressure resistance, the circular tank has the best pressure resistance, but for the position of the placement and the utilization of the space, etc. The square cabin has the worst pressure resistance, but the position is flexible, suitable for placement in a small space such as a corner, and the space utilization is the highest. Based on this, combined with both a circle and a square its own characteristics, a new design scheme - the triangular-like cabin structure is proposed. Under the premise of ensuring high space utilization, the pressure resistance performance, the deformation amount and the stress concentration are reduced as much as possible. Figure 1 is a model diagram of a triangular-like cabin structure.

Figure 1. The structural model of triangular-like cabin

3. Modal analysis
The so-called modality is an inherent characteristic of the structure, that is an inherent vibration characteristic, and it is independent of the loading mode of the input, only related to the shape of the structure, the constraint mode and the characteristics of the added material [7]. The ultimate goal of modal analysis of the structure is to determine the natural frequency and the mode shape of the structure, so that the structure avoids the frequency of the external excitation force and the natural frequency of the structure, avoiding the resonance phenomenon [8].

3.1. Modal analysis of the triangle-like cabin
Adding Modal modal analysis module to the main interface of Workbench, constructing analysis options, and referring to the general technical requirements of mine safety refuge, it is necessary to apply 0.3MPa stress to the outer surface of the entire cabin [9,10]. Considering the size of the space of the high-rise residential buildings, the safe refuge device is generally placed, and the fixed constraint is applied to the bottom surface of the entire cabin structure. The specific loads and constraints are shown in Figure 2.

Figure 2. The applied load and the constraint graph of similar triangle cabin
For the post-processing part of the result, the Modal is solved. The default modal order of the modal calculation in Workbench is 6th order, so under the “Analysis Settings” option Analysis in the Analysis Tree Outline, under the Details of “Analysis Settings” The number of modals is modified under the “Max Modes to Find” option in Options.

3.2. Modal analysis results for a triangular cavity

After the parameters required for the analysis are set in the Modal module, the corresponding modal analysis and solution are performed on the overall structure of the triangle-like safe refuge device. The first twelve natural frequencies of the overall structure of the safety refuge device are taken. The twelve-order modal pattern and the corresponding natural frequencies of each order are shown in Fig. 3 and Fig. 4.
(e) Fifth-order mode

(f) Sixth-order mode

(g) Seventh-order mode

(h) Eighth-order mode

(i) Ninth-order mode

(j) Tenth-order mode
The modal analysis of the first twelve steps of the overall structure of the safe refuge device is obtained, and the total deformation nephogram of the first twelve orders is obtained. On this basis, the modal analysis of the whole structure of the safety refuge device based on X, Y and Z directions is obtained, and the first 12 modes of the X, Y and Z directions are obtained. However, due to the limitation of space, no detailed explanation will be made here. Instead, the data in the three directions of X, Y, and Z and the obtained natural frequencies and total deformation of the first twelve orders are summarized. In order to more clearly and intuitively obtain the deformation data of the safe evacuation device after modal analysis, as shown in Table 1.

| Order (frequency) | X Axis (mm) | Y Axis (mm) | Z Axis (mm) | Total deformation (mm) |
|-------------------|-------------|-------------|-------------|------------------------|
| First-order (198.51) | 0.85094     | 2.0804      | 0.1668      | 2.2463                 |
| Second-order (200.98) | 0.13934     | 1.39496     | 1.3848      | 1.3854                 |
| Third-order (216.68) | 1.0385      | 2.3319      | 0.31737     | 2.5407                 |
| Fourth-order (264.14) | 0.42002     | 0.89472     | 2.4291      | 2.4292                 |
| Fifth-order (297.65) | 1.4104      | 2.9481      | 1.4471      | 3.329                  |
| Sixth-order (304.85) | 1.7941      | 2.1229      | 0.36259     | 2.7722                 |
| Seventh-order (307.59) | 1.8094      | 2.7594      | 1.0457      | 3.2969                 |
| Eighth-order (343.23) | 0.53249     | 0.79685     | 2.4423      | 2.4424                 |
| Ninth-order (345.97) | 1.5231      | 2.0643      | 0.55253     | 2.3323                 |
| Tenth-order (393.52) | 0.46505     | 0.66258     | 1.9106      | 1.9119                 |
| Eleventh-order (411.5) | 0.13777     | 1.8771      | 0.73861     | 2.1751                 |
| Twelveth-order (425.83) | 0.63982     | 1.2029      | 2.1846      | 2.1914                 |
From the first twelve-order modal pattern of the overall structure of the safety refuge device in Figure 3, it can be found that the second, eighth and tenth modal patterns mainly show vibration deformation in one direction, and the deformation is mainly concentrated in the position of the hatch, and the maximum deformation is 2.4424 mm. It can be seen from Table 1 that vibration distortion occurs mainly in the two directions on the first, third, fourth, sixth, ninth, eleventh and twelfth mode shapes, among which the first, third and sixth, The ninth order is mainly caused by vibration deformation in the X and Y directions. The most deformed places are mainly concentrated on the two sides of the cabin. The maximum deformation is 2.7722mm, while the fourth, eleventh and twelfth steps are mainly Vibration deformation occurs in both directions of Y and Z. The most deformation is concentrated in the position of the hatch, and the maximum deformation is 2.4292mm. For the remaining fifth and seventh steps, it mainly undergoes vibration deformation in three directions and more complicated.

From the first twelve natural frequencies of the overall structure of the safe refuge device in Figure 4, it can be observed that the natural frequency of the first order in the first twelve natural frequencies is the smallest (198.51 Hz), and the natural frequency of the twelfth order is the largest (425.83 Hz). The two-order natural frequency difference is large; and can also be obtained in the third, fourth, fifth, sixth, seventh, eighth, ninth, tenth, and eleventh natural frequencies of the twelve orders, the difference between the natural frequencies between the two or two orders is small, and the difference between the natural frequencies of the fifth and sixth orders is the smallest, only 7.2 Hz. While others like the third, the fourth, seventh, eighth, ninth, tenth, and eleventh and thirteenth orders, the difference between the two or two orders is 47.46 Hz, 35.64 Hz, 47.55 Hz, and 14.33 Hz, respectively. When the frequency of the external excitation force is the same as the natural frequency of the overall structure analyzed in this paper, resonance phenomenon will occur. At this time, energy will be absorbed from the outside to the maximum extent, resulting in excessive vibration deformation and even fatigue damage. Therefore, in practical applications, avoid dangerous frequencies and avoid resonance.

According to Fig. 3 and Fig. 4, at the frequencies of natural frequencies of 200.98 Hz, 264.14 Hz, 343.23 Hz, 393.52 Hz and 425.83 Hz, the deformation of the cabin door position is large, indicating that at these various frequencies, the structure of the hatch is prone to damage. Therefore, in practical applications, the number of ribs should be increased and the wall thickness of the hatch should be changed to improve the rigidity of the structure.

4. Transient Dynamics Analysis of the triangle-like cabin

In this section, the seismic acceleration spectrum is used to analyze the seismic structure of the triangle-like cabin structure, and the dynamic strength and dynamic stiffness of the whole triangle-like structure in a given seismic acceleration load are simulated by transient dynamics analysis.

4.1. Triangular cabin transient dynamics analysis setup

Transient dynamics analysis of the triangular-like chambers was performed using the Transient Structural in Workbench to calculate the stress, strain and total deformation of the triangular-like chambers over time based on seismic acceleration spectra.

In Creo, the overall structure of the triangle-like cabin is simplified, especially at the joints of the hatch. The purpose is to improve the computational efficiency in the calculation of transient dynamics. Import it into the Workbench and the settings of material properties, the contact form, meshing, and constraint application are the same as those in the previous section modal analysis. I will not go into details here. Enter the Transient Structural module and set the total time step, sub time step and other parameters in the Detail of Analysis Setting. Select "Acceleration" under "Inertial" in the Workbench toolbar, and enter the seismic acceleration spectrum values in the Details of "Acceleration" to obtain the curve as shown in Figure 5. The red curve represents the vertical acceleration curve, and the green curve represents the horizontal acceleration curve. The seismic acceleration load spectrum curve simulates the case where the seismic load is loaded on the triangle-like cabin.
Because the factors affecting the seismic response spectrum include magnitude, epicentral distance and site conditions etc. That is to say, each earthquake is sudden, and the response spectrum of the earthquake is not the same. Therefore, it is difficult to simulate the real situation of each seismic response spectrum. In this paper, when studying the seismic performance of the safety refuge, only one of the many cases of seismic response spectrum is selected for research, and the selected seismic acceleration spectrum is loaded on the triangle-like cabin structure, which for more complex situations, more data on seismic spectra is needed for research.

4.2. Triangular transient dynamics analysis results
Acceleration, total deformation and stress options are added to obtain the acceleration response curve, total deformation response curve and stress response curve of the triangle-like cabin under the applied seismic acceleration spectrum, as shown in Figure 6, Figure 7, Figure 8. Through these response curves, the dynamic response of the triangle-like cabin under the action of seismic acceleration spectrum can be well simulated.

Figure 5. The earthquake acceleration load spectrum

Figure 6. The acceleration curve of the cabin
Analysing Figure 6, Figure 7 and Figure 8, it can be clearly seen that compared to the seismic acceleration curve, the acceleration response curve of the resulting triangular-like cabin has a larger fluctuation range, and the peak of the fluctuation occurs at 3.92 s; the total deformation response curve and stress response curve of the resulting triangular-like cabin are basically similar, and the peak and valley of the fluctuation appear at the same time node, respectively, the peak appears at 3.9s and the valley appears at 3.1s.
Figure 9, Figure 10 and Figure 11 are respectively the total acceleration cloud map of the cabin at 3.92 s, the total deformation cloud map of the cabin at 3.9 s, and the equivalent stress cloud diagram of the cabin at 3.9 s. It can be seen from Figure 9, Figure 10 and Figure 11 that the maximum acceleration is 63.256 mm/s², the maximum total deformation is 0.022744 mm, and the maximum equivalent stress is 3.4179 MPa; the maximum acceleration and the maximum total deformation occur on the side plates. The maximum equivalent stress occurs at the maximum corner; the stiffness of these parts such as the side plates and the largest corners of the triangle-like cabin is smaller than other positions of the cabin, which is a weak link that is prone to damage during the earthquake. However, since the total deformation and equivalent stress in the weak link are not very large, the structure of the safe evacuation device can reach a relatively stable state and the structure is not unstable under the action of the seismic spectrum.

5. Conclusion
In this paper, a new type of triangular-like safety evacuation device is proposed on the structure of the original safety evacuation device. Based on this, the model is modeled by Creo. Through the modal analysis in ANSYS Workbench, the first twelve modes and natural frequencies of the triangle-like cabin structure are obtained, and the most severe position and dangerous frequency of the cabin structure deformation are found to avoid resonance. Applying seismic acceleration spectrum load to the triangle-like cabin, simulating a seismic condition, performing transient dynamic analysis, and obtaining the acceleration of the cabin structure through the total acceleration nephogram, the equivalent stress nephogram and the total deformation nephogram. The deformation and stress are not large, indicating that the triangular-like cabin structure meets the seismic requirements.

Acknowledgments
This work was supported by the Natural Science Foundation of Shandong Province (ZR2019MEE082).

References
[1]  Zhang Haixin, Yang Yousong. Study on a New Type of High-rise Rescue Escape Device [D]. Technology and Innovation, 2016.
[2]  Patel S N, Datta P K, Sheikh A H. Buckling and dynamic instability analysis of stiffened shell panels[J]. Thin-walled structures, 2006, 44(3): 321-333.
[3]  Cammarot F, Benedetto A Di, Disarli V, et al. Combined effects of initial pressure and turbulence on explosions of hydrogen-enriched methane/air mixtures[J]. Journal of Loss Prevention in
the Process Industries, 2009, 22(5): 607-613.

[4] Wang Yuanbin, Teng Zijian, Liu Yiyu. Study on reliability of earthquake rescue cabin [J]. Enterprise Journal, 2012, 1(23): 253-254.

[5] Ai Changbo, Mine rescue generation at home and abroad [J]. Ship defense, 2010, (6): 5-8.

[6] Wang Sheng, Jin Longzhe, Li Jing. Status quo of emergency rescue generation technology in foreign mines [J]. Journal of Safety Science and Technology, 2010, 6(4): 199-123.

[7] Li Long. Transition dynamics and structural optimization of moving members of five-axis EDM [J]. Journal of Suzhou University, 2011.

[8] Li Qinhua, Hao Xiaofeng. Study on vibration response of intake manifold based on transient dynamics analysis [J]. China Science and Technology Expo, 2013, (30): 112-114.

[9] Li Guoxing, Design and research of a new type of mobile life saving tank [D]. Qingdao University of Science and Technology, 2014.

[10] ZD Guo, Structure Design and Mechanics Checking of Survival Space of Mine Rescue Capsule [J]. Shanxi Coking Coal Science & Technology, 2013.