Journal of Precision Instrument and Machinery (2023)
Clausius Scientific Press, Canada
DOI: 10.23977/jpim.2023.030101
ISSN 2616-1990 Vol. 3 Num. 1

Structural Design and Finite Element Analysis of a Heavy Equipment Shelter

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Keywords: Shelter; strength; stiffness; finite element analysis; structural design

Abstract: A heavy equipment shelter has a large number of installed equipment, heavy equipment weight, multiple cooling pipelines, and multiple doors and windows around it. The structural stiffness and strength requirements for the shelter were high under the lifting and transportation conditions. The finite element analysis technology was introduced into the design process, the rationality of the structural design was verified, meanwhile, the quality of structural design has been improved. In response to the installation and layout characteristics of large equipment in this type of shelter, key analysis and local reinforcement were carried out on the bearing area, and a finite element model of the shelter structure was established. A static analysis was conducted on the stiffness and strength of the shelter structure under adverse working conditions, and the corresponding stress and strain states were obtained, so that the design requirements could be met. The analysis results indicated that the structural design of a heavy equipment shelter was reasonable, the equipment installation layout was feasible, and the finite element method can effectively improve the design efficiency and quality, providing favorable reference for the design and verification of similar products.

1. Introduction

Vehicle shelters were originated from combat requirements. Since the 1960s, they have been widely applied by armies of various countries, represented by the United States and Britain due to their excellent maneuverability, rapid reactivity, and good protection, as well as providing a good environment for operators and electronic equipment [1]. China began conducting research on the shelter in the late 1970s and developed the first skeletal F4 shelter in 1982 [2]. With the advancement of China's shelter development concept and production technology, the shelter structure had gradually developed from a skeleton-based structure to a sandwich panel-based structure [3]. Currently, China’s shelter products are not only widely applied on military operations, but also play a crucial role in civilian fields such as medical, communication, meteorology, emergency response, and camping [4]. In recent years, the usage functions of vehicle shelters have been continuously concretized and normalized, meeting the urgent needs of various fields for the motorization and vehicular transportation [5]. The design concept and implementation methods of shelters had also been constantly improving, which was driven by the design requirements of large-scale equipment shelters [4, 6].

2. Structural Characteristics of the Heavy Equipment Shelter

The overall size of the heavy equipment shelter was 8058mm × 2438mm × 2355mm (L×W×H). The shelter was divided into four parts from front to back: front cabin, middle cabin, rear cabin, and water-cooled cabin. Figure 1 shows the layout of the shelter.

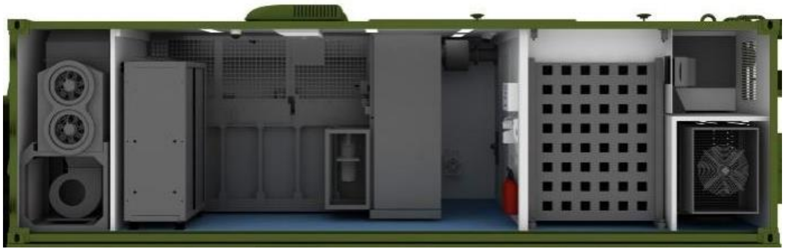

Figure 1: Layout of the shelter

3. Structural Design of the Shelter

There was a heat exchanger, a monitoring cabinet, a signal transmission equipment, two equipment cabinets, two phase-shifting transformers, and a wind-water exchanger installed in the shelter. The overall weight of the equipment reaches 6 tons, with the largest being the signal transmission equipment, which was about 2 tons, followed by the phase-shifting transformer, which was about 1.2 tons, and fixed on the bottom plate and side plate of the shelter respectively. The monitoring cabinet and equipment cabinet were installed on the bottom plate and side plate respectively through resonance free vibration dampers.

During the design process of this heavy equipment shelter, two harsh working conditions need to be considered: one was the shelter lifting condition, and the other was the shelter transportation condition. When lifting the shelter, there will be overload at the moment of lifting, and the shelter will bear the maximum static load, which has a serious impact on the working conditions [7]. When transporting in the shelter, it was also necessary to overcome the large inertia forces generated during starting, braking, and turning [8]. In the specific design, consideration should be given to analyzing the stress conditions of the shelter under two different working conditions, and strengthening the main transmission paths and weak links should be carried out to enhance the structural stiffness and strength of the shelter.

The lifting of the shelter was generally divided into two forms: one was the lifting of the top corner piece, and the other was the lifting of the bottom corner piece. Due to the fact that the internal equipment was mainly installed on the bottom plate, if the bottom corner lifting method had been used, the load transfer path was short, and the structural strength requirements for the top plate, side plate, and end plate were relatively low. Therefore, the bottom corner lifting method was chosen.

This type of shelter adopted the form of a large plate skeleton, and each large plate was assembled by riveting and bonding through corner wrapping and corner pieces. Each plate was welded into an integral frame with steel or aluminum tubular sections, and several longitudinal beams and cross beams were welded in the integral frame. The internal and external layers of aluminum plates and the frame, rigid polyurethane foam, and thermal insulation plate were bonded into a composite sandwich board during the bonding process. The bottom plate was made of steel profiles, which can increase the cross-sectional modulus of the longitudinal beams on the left and right sides. For the bottom plate and side plate framework at the installation of signal transmission equipment and phase-shifting transformers, diagonal profiles were added to improve stiffness and strength. Figure 2 shows the three-dimensional model of the shelter.

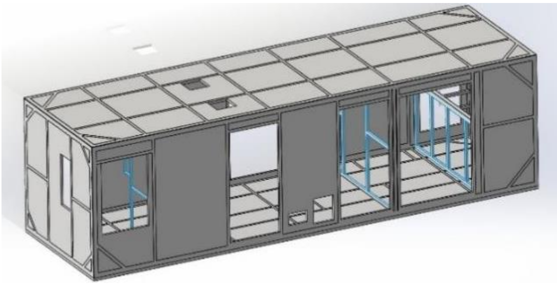

Figure 2: Three-dimensional model of the shelter

4. Finite Element Analysis

Whether the stiffness and strength of the shelter structure could meet the requirements need to be verified and analyzed. Due to the complexity of the system structure and the difficulty of traditional theoretical calculations of stress and strain, finite element analysis was applied to quickly verify the calculation and eliminate design defects.

4.1. Basic Assumptions of the Finite Element Model

In order to improve the efficiency of analysis and calculation, the model was appropriately simplified in the process of establishing the finite element model of the shelter. The main simplification measures and assumptions were as follows [9,10]: 1) The characteristics of the welding material of the large plate skeleton profile and the material of the profile itself were not considered; 2) The plastic deformation or failure mode of the skeleton profile was not considered; 3) The impact of local process details such as screw and riveting on the shelter structure was not considered; 4) The impact of edge wrapping, insulation layer, etc. in the shelter on the overall structural analysis was not considered; 5) The impact of local holes (wiring holes) in the shelter on the overall structure was not considered; 6) The reinforcement effect of the inner and outer skin of the large plate on the shelter structure was not considered.

4.2. Material Parameters

Table 1 shows the material properties used in the shelter structure.

Table 1: Material Properties

Material	Elastic modulus / MPa	Poisson's ratio	Density /kg m^{-3}
Steel Q345	210000	0.288	7.8×10^3
Aluminum 5053	71000	0.3	2.7×10^3
Polyurethane foam	13	0.17	60

4.3. Boundary Conditions and Load Arrangement

This article analyzed the strength and stiffness of the shelter structure under lifting and transportation conditions, with a focus on the analysis of turning condition during transportation. Under the lifting condition, a load of 1.5 times the equipment mass was applied to simulate the bottom overload lifting condition; under the turning condition, a load of 0.6 times side and 1 time the equipment mass was applied to simulate the shelter turning condition.

4.4. Analysis Results

4.4.1. Lifting Condition

Figure 3 shows the stress cloud diagram of the shelter under lifting condition. The maximum stress of the shelter was 101.2 MPa, located on the partition framework.

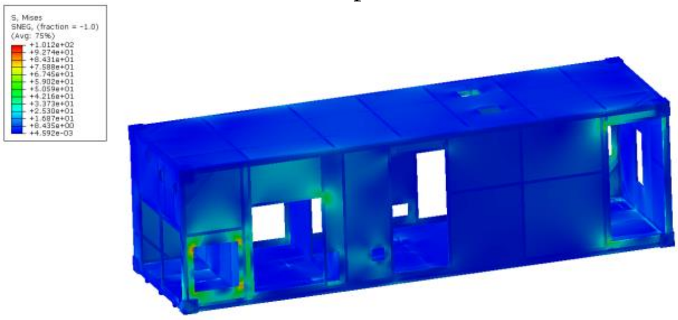

Figure 3: Cloud diagram of shelter stress under lifting condition

Figure 4 shows the cloud diagram of shelter displacement under lifting conditions, with a maximum displacement of 4.76mm, located in the middle of the shelter roof.

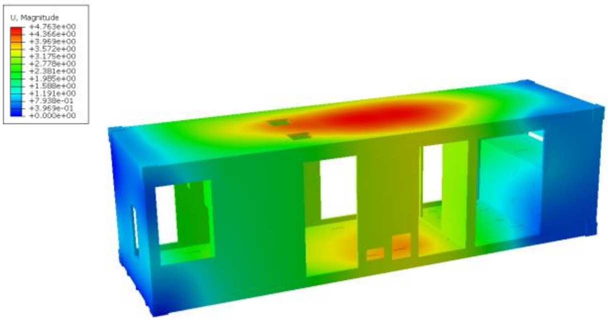

Figure 4: Cloud diagram of shelter displacement under lifting condition

4.4.2. Turning condition

Figure 5 shows the stress cloud diagram of the shelter under turning condition. The maximum stress of the shelter was 104.7 MPa, located on the bottom plate framework.

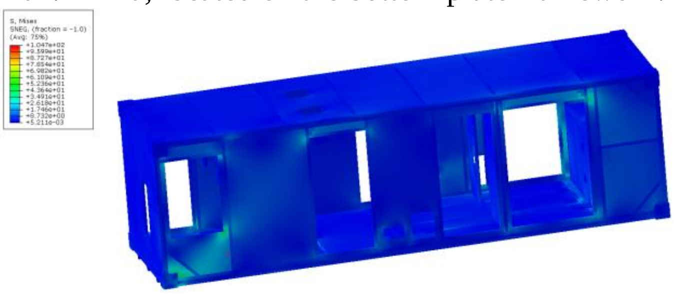

Figure 5: Cloud Chart of Shelter Stress under Turning Condition

Figure 6 shows the distribution cloud map of shelter displacement, with maximum displacement values of 2.93mm, located in the middle of the shelter roof.

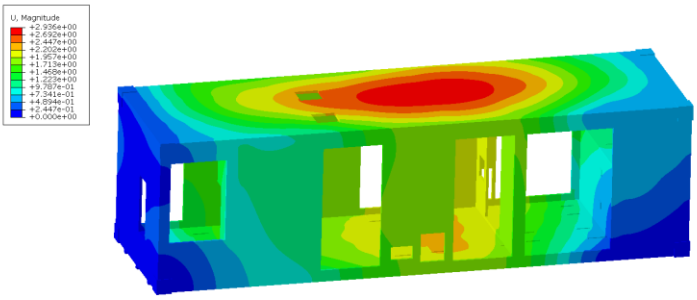

Figure 6: Cloud diagram of shelter displacement under turning condition

5. Conclusion

According to the stress distribution results, there was a phenomenon of stress concentration in the framework of the shelter under all working conditions. The maximum stress was 104.7MPa under the turning condition, but it was lower than the yield strength of steel Q345. According to the displacement cloud map, the maximum displacement under each working condition occurred near the middle of the top plate, while the maximum displacement was 4.76 mm under the lifting condition, which met the requirement of the top plate deformation not exceeding 10mm. The local stress level of the bottom plate skeleton was relatively high, and the stress level was reduced by adding diagonal support locally. The analysis and calculation results showed that although the reinforcement effect of some structures on the cabin was ignored in the finite element analysis process of this article, the design strength and stiffness of the cabin structure could still meet the requirements of harsh working conditions such as lifting and transportation. Meanwhile, the structural design of the heavy equipment shelter was reasonable, the equipment installation layout was feasible, and the finite element method can effectively improve the design quality and efficiency, providing important references for the design and verification of similar products.

References

[1] Mao Q. J. (2012) Design Manual of Shelter. Nanjing: Hohai University Press
[2] Wang Z. (2016) Development Trends of Military Shelters. Modern Military, 5, 70-72
[3] Wang X. L. (2017) Overview of the Development of Military Shelter Technology in China. Special Purpose Vehicle, 3, 68-72
[4] Liu R., Shen J., Wang F. (2019) Design of LRM Modular Vehicle Electronic Equipment. Command Information System and Technology, 10 (1), 95-100
[5] Shen J. (2020) Simulation of optimized electromagnetic design based on a certain type of shelter vehicle. New Technology & New Process, 10, 47-49
[6] Zhang H. L, Fang J. B. (2002) Design and analysis of rigidity and strength of a vehicle borne radar shelter. Fire-control radar Technology, 31 (12), 33-37
[7] Wan J. L., Ding Y. Y., Zhao D. G. (2016) Finite element analysis of a cooling equipment shelter structure. Special Purpose Vehicle, 1, 90-94
[8] Gao D. H, Zhang Q, Wan J. L. (2019) Design and Analysis of a Large Equipment Shelter Structure. New Technology & New Process, 6, 30-32
[9] Wang C. Z., Wang L. M., Wu C. F. (2008) Finite element analysis of special vehicle shelter structure. Journal of Nanjing University of Science and Technology (Natural Science Edition), 32 (6), 707-709
[10] Wang F. C., Wang K. J., Zhou K. H. (2009) Mechanical analysis of special vehicle shelter structures based on finite element method. Mechanical Design, 26 (4), 54-56