



Stability Analysis of Large-Scale Display Terminals in Marine Applications

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Abstract. This paper focuses on marine large display terminals and systematically investigates their vibration response characteristics using the finite element analysis method. First, through modal analysis technology, we extracted the first six natural frequencies of the display terminal: 86.47 Hz, 87.42 Hz, 100.68 Hz, 215.66 Hz, 253.73 Hz, and 292.94 Hz. These natural frequencies reveal their dynamic characteristics under free vibration states. Second, we analyzed the deformation and stress distribution of the display terminal under static loads. Results show a maximum vertical deformation of 0.034 mm and a maximum equivalent stress of 19.284 MPa, verifying structural stability under static conditions. Additionally, random vibration analysis was employed to evaluate the terminal's response under dynamic loads. The analysis revealed a maximum random vibration displacement of 13.8353 mm (99.73% confidence interval) at the damping device and 4.3471 mm (99.73% confidence interval) at the centroid, confirming the effectiveness of the damping system. Finally, to simulate the vibration behavior of terminals in real navigation environments, we specifically considered the impact of external excitation under extreme weather conditions. Results indicate that the terminal's maximum resonant frequency is approximately 88 Hz, with the largest external excitation displacement below 0.1 mm, demonstrating robust stability in complex vibration environments.

Keywords: Display Terminals; Vibration analysis; Modal analysis

1 Introduction

With the continuous improvement of electronic device integration density, large-scale display terminals have become increasingly vital as core human-machine interaction equipment [1-2]. In marine applications, large display terminals are responsible for the real-time visualization of radar information, equipment operating status, navigation data, and other critical information [3-4]. The operational stability and reliability of large display terminals are directly related to the safety of ship navigation. However, ships face complex vibration environments during navigation, including wave impacts, engine vibrations, and external loads from various excitation sources. These factors

severely affect the structural integrity and functional stability of large display terminals. Therefore, studying how to enhance the stability of large display terminals in marine vibration environments holds significant engineering and academic value.

The unique vibration environment of ships makes the design of large display terminals significantly different from other application scenarios. Traditional design methods are often insufficient to meet the stringent vibration requirements of ships. Therefore, it is necessary to optimize the design based on the vibration characteristics of ships. Simulation analysis, as an efficient simulation tool, can accurately model the vibration loads experienced by ships under actual navigation conditions and predict and optimize structural designs [5-6]. Through finite element analysis and modal analysis, key parameters such as natural frequencies, vibration modes, and stress distributions of large display terminals under vibrational conditions can be extracted. Furthermore, potential resonance risks or structural weaknesses can be identified. This simulation-based optimization design approach has become a mainstream research direction in current engineering practice[7-8].

This study employs simulation analysis to investigate vibration scenarios for large display terminals in maritime applications. By establishing finite element models, structural responses under different vibrational excitations are simulated, and optimization design schemes are proposed based on the simulation results. The research aims to effectively improve the stability and reliability of large display terminals in ship vibration environments through structural optimization, material selection, and the introduction of vibration reduction measures [9-10]. This study not only provides theoretical support for the design of marine electronic equipment but also offers practical references for related research in the field of vibration engineering.

2 Methods and Models

Figure 1(a) shows the three-dimensional rectangular model of the large display terminal (1400 mm × 900 mm × 272.5 mm). The model is divided into three parts. The first part is the base plate, which is used to secure the large display terminal to the ship's hull. Its center is positioned 1.5 meters above the hull surface and is tightly connected to the hull via M8 screws distributed around its perimeter. The second part consists of stainless steel wire rope vibration dampers which are crucial for ensuring the normal operation of the large display terminal. Made from 316L stainless steel, these dampers possess excellent vibration damping, deformation resistance, impact resistance, and anti-corrosion properties. One end of the damper is fixed to the base plate while the other end connects to the large display terminal, ensuring both equipment stability and reducing the impact of hull vibrations and external excitation on the terminal. The third part is the core section of the large display terminal. It integrates essential components such as power supplies, display screens, chips, memory, and other internal devices.

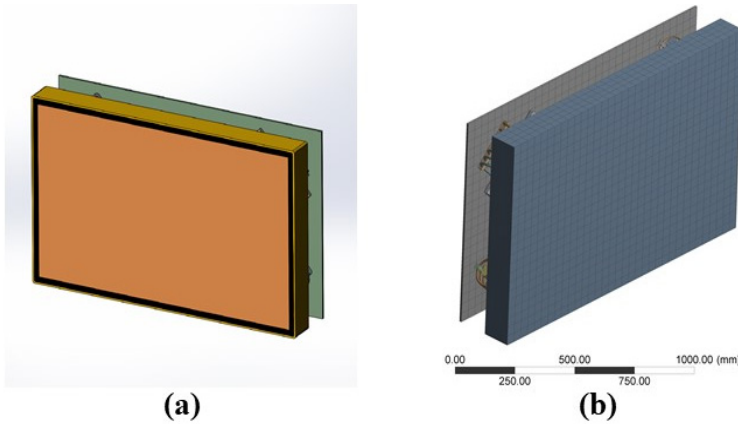


Fig. 1. (a) The three-dimensional model of the large display terminal. (b) The finite element mesh division model of the large display terminal.

The vibration sources of the large display terminal are mainly divided into two parts. The first is the basic vibration of the large display terminal itself, and modal analysis is an important parameter to describe the free vibration of a system [5-6]. Therefore, to investigate the natural frequencies of the large display terminal itself, finite element analysis tools are first used to analyze the modalities of this device. The first-order mode corresponds to the lowest natural frequency of the system, representing the most basic shape change that can be formed when the structure vibrates. As the modal order increases, the corresponding modal frequencies also gradually increase, representing increasingly complex vibration shapes. In practical applications, only a portion of the lower-order modes can significantly affect the dynamic response of the system. Therefore, this paper analyzes the first six vibration modes of the large display terminal. The second part is the vibration caused by external excitation when the large display terminal is in a navigational state. Therefore, we analyze the vibration impact of external excitation on the large display terminal in actual navigation conditions. Through the vibration analysis of these two parts, the vibration situation of the large display terminal in actual use can be simulated more completely. The finite element mesh model of the large display terminal is shown in Figure 1(b), where the finite element analysis units use tetrahedral and hexahedral meshes, with a total of 8,303,622 nodes and 421,563 elements.

3 Results and Discussions

First, we discuss the directional deformation of the large display terminal when mounted on the ship's sidewall. This device is mounted at a position 1.5 meters from the ship's surface. Through simulation analysis, the vertical directional deformation of the large display terminal is shown in Figure 2, where Figure 2(a) represents the overall deformation of the large display terminal, and Figure 2(b) shows the deformation after

removing the display terminal, leaving only the base plate and vibration dampers. According to the simulation results, the minimum deformation of the base plate is 6.6558×10^{-5} mm, while the maximum deformation of the vibration dampers and display screen is 3.3755×10^{-2} mm.

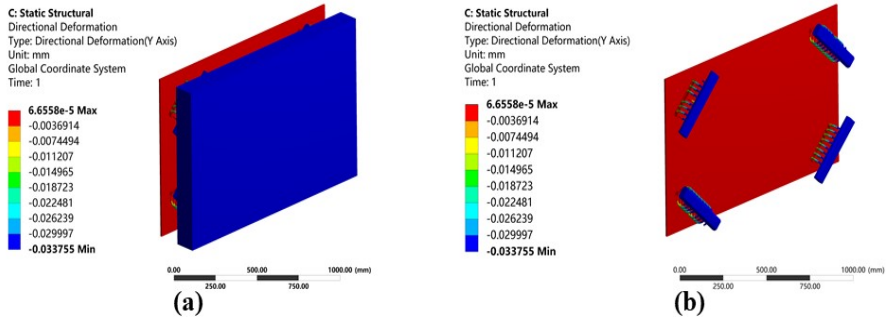


Fig. 2. Vertical directional deformation of the large display terminal: (a) Overall deformation (b) Base plate deformation.

Equivalent stress is also one of the key parameters for measuring material performance. Through simulation analysis, the equivalent stress distribution of the large display terminal is shown in Figure 3, where Figure 3(a) shows the overall equivalent stress distribution of the large display terminal, and Figure 3(b) shows the equivalent stress distribution of the base plate and vibration dampers after removing the display terminal. The minimum equivalent stress of the base plate and display terminal is 5.2875×10^{-9} MPa, and the maximum equivalent stress of the vibration dampers is 19.284×10^{-9} MPa.

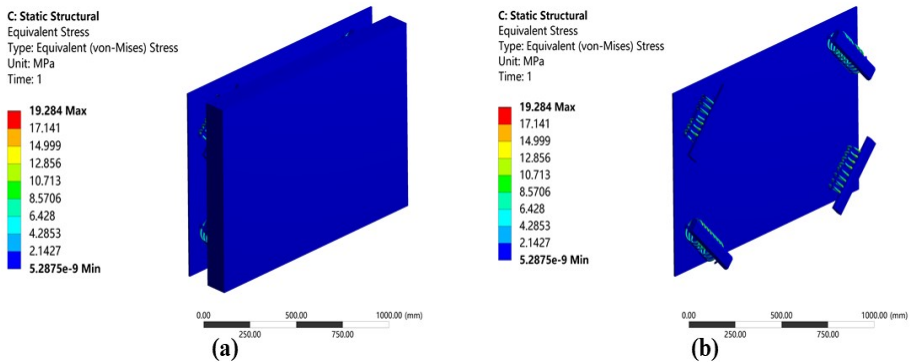


Fig. 3. Equivalent stress distribution: (a) Overall equivalent stress distribution. (b) equivalent stress distribution.

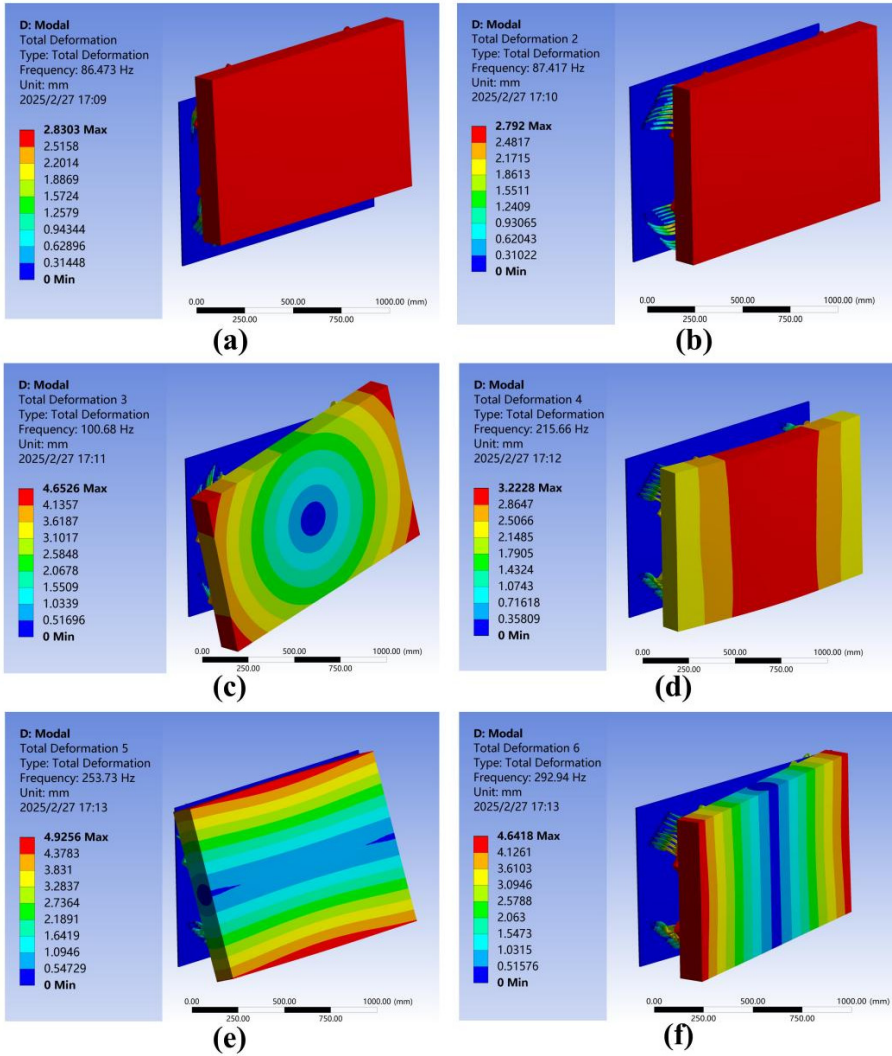


Fig. 4. The first six modal vibration modes of the large display terminal.

Modal analysis is a common method used to study the dynamic characteristics of structures. This method can effectively analyze parameters such as the natural frequencies and vibration modes of structures. This paper investigates the first six modes of the large display terminal, and the modal analysis results are shown in Figure 4. The first six natural frequencies of the large display terminal are shown in Table 1. From the analysis results in Figure 4(a), it can be seen that the natural frequency of the first mode of this display terminal is 86.473 Hz. The main vibration part is the vibration damper, causing the vibration mode of the display terminal to translate along the Y-axis, showing a vibration pattern of the overall movement of the display terminal, with a maximum displacement offset of 2.83 mm. From the analysis results in Figure 4(b), it can

be seen that the natural frequency of the second mode of this display terminal is 87.417 Hz, with the main vibration part being the vibration damper, causing the vibration mode of the display terminal to translate along the X-axis, showing a vibration pattern of the overall movement of the display terminal, with a maximum displacement offset of 2.79 mm. The resonance frequency of the third mode is 100.68 Hz, with the main vibration manifesting as torsional oscillation of the display terminal around the Z-axis. The maximum displacement offset of the four corners of the display terminal is 4.6526 mm, and the minimum displacement offset at the center is 0.51696 mm, as shown in detail in Figure 4(c). The resonance frequency of the fourth mode is 215.66 Hz, with the main vibration manifesting as the bending of the display terminal along the Z-axis direction. The maximum displacement offset at the X-axis midline position of the display terminal is 3.2228 mm, and the minimum displacement offset at the two side edges in the X-axis direction is 0.35809 mm, as shown in detail in Figure 4(d). Finally, the natural frequencies of the fifth and sixth modes are 253.73 Hz and 292.94 Hz, respectively. The vibration mode of the fifth mode mainly presents as tilting around the X-axis, with the maximum displacement offset of 4.9256 mm at the Y-axis edge positions of the display terminal, as shown in Figure 4(e). The vibration mode of the sixth mode mainly presents as tilting around the Y-axis, with the maximum displacement offset of 4.6418 mm at the X-axis edge positions of the display terminal, as shown in Figure 4(f).

Table 1. The first six natural frequencies of the large display terminal.

Order	Frequency/Hz	Vibration mode description	Maximum displacement/mm
1	86.473	Translation along Y-axis	2.83
2	87.417	Translation along X-axis	2.79
3	100.68	Torsion around Z-axis	4.6526
4	215.66	Bending along Z-axis	3.2228
5	253.73	Tilting around X-axis	4.9256
6	292.94	Tilting around Y-axis	4.6418

In addition to the vibration modes of the large display terminal itself, external excitation vibrations during its operation are also one of the important factors affecting the equipment's operational state. Therefore, this paper further analyzes the vibration state of the large display terminal during ship navigation. Considering the sea surface vibration velocity PSD data under Category 4/5 typhoon conditions as the excitation source [9-10], we simulated the vibration response of the large display terminal in extreme environments. The simulation analysis results are shown in Figs. 5 and 6. Figure 5 shows the vibration response of the display terminal's damping device section, where Figure 5 (a), Figure 5 (b), and Figure 5 (c) represent the deformation situations for confidence intervals of 1-sigma, 2-sigma, and 3-sigma respectively, with the 3-sigma confidence interval being 99.73%, corresponding to a maximum deformation of 13.875 mm. Figure 6 shows the vibration response at the center of mass position of the display terminal, where Figure 6 (a), Figure 6 (b), and Figure 6 (c) represent the deformation situations for confidence intervals of 1-sigma, 2-sigma, and 3-sigma respectively, with the 3-sigma confidence interval being 99.73%, corresponding to a maximum deformation of 4.3471mm.

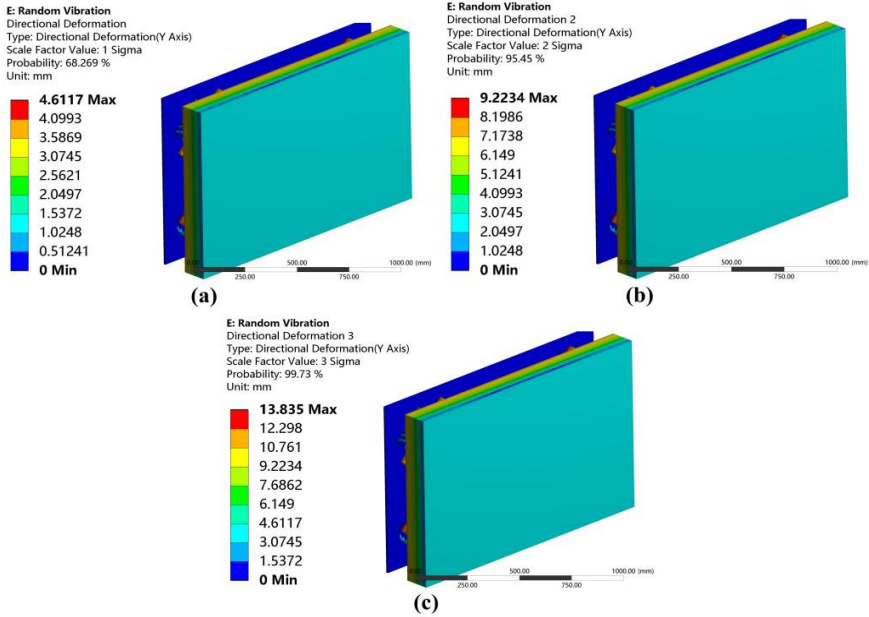


Fig. 5. Vibration response situation of the display terminal's damping device section: (a) 1-sigma confidence interval, (b) 2-sigma confidence interval, (c) 3-sigma confidence interval

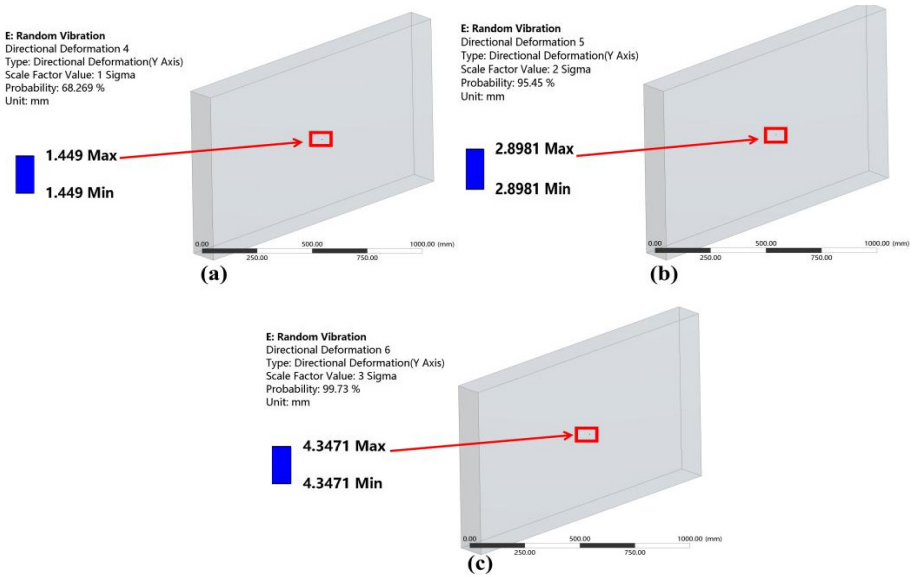


Fig. 6. Vibration response characteristics at the centroid position of the display terminal: (a) 1-sigma confidence interval, (b) 2-sigma confidence interval, (c) 3-sigma confidence interval

Based on the response of the large display terminal to external input vibrations, the corresponding displacement response spectrum is shown in Figure 7 as a function of frequency distribution. Analysis reveals that when the large display terminal is in operation, it exhibits a significant displacement response to low-frequency vibrations. However, as the frequency increases, the response gradually decreases. A noticeable resonance response occurs around 88 Hz, with the vibration displacement in the resonance region remaining below 0.1 mm. This indicates that the large display terminal maintains stable operation even under extreme environmental conditions, meeting the required vibration-damping performance of the design.

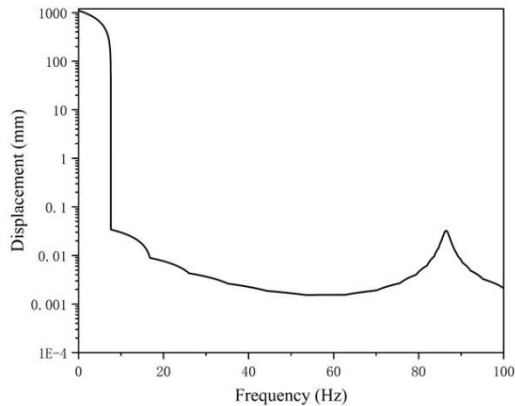


Fig. 7. Displacement response spectrum

4 Conclusion

This paper conducted vibration simulation analysis on large display terminals used in ships using finite element tools, including static analysis of the first six natural vibration frequencies, directional deformation, equivalent stress, etc. The analysis results show that the first six natural frequencies of the large display terminal are 86.47 Hz, 87.42 Hz, 100.68 Hz, 215.66 Hz, 253.73 Hz, and 292.94 Hz, respectively, and the higher natural frequencies can effectively improve the anti-vibration effect of the equipment. The maximum vertical deformation of this device is 0.034mm, and the maximum equivalent stress is 19.284 Mpa, both of which meet the design requirements. The maximum deformation corresponding to the 3-sigma confidence interval of the damping device is 13.875 mm, and the maximum deformation corresponding to the 3-sigma confidence interval of the centroid part is 4.3471 mm, which confirms that the damping device can effectively reduce the vibration deformation of the large display terminal. In addition, we also simulated the response to external input vibrations under extreme typhoon weather conditions. The results show that there will be a more obvious resonance response near 88 Hz for the large display terminal, but the vibration displacement is still less than 0.1 mm. This proves that the large display terminal maintains good

working conditions even in extreme environments. Furthermore, this study provides a scientific theoretical basis for the structural optimization of large display terminals.

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