Stress Analysis of the Circular Pier Anti-collision Box Made of Sandwich Plate with Stiffening Rib

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Abstract. The pier anti-collision box made of steel-polyurethane sandwich plate with stiffening ribs can withstand greater impact force. In order to ascertain the influence of stiffening ribs to anti-collision box, the static equivalent method is adopted to numerically calculate the stress and impact depth of the anti-collision box in the conditions of no stiffening rib and the different forms and amount of stiffening ribs. The results show that it can reduce the stress and deformation of anti-collision box to set vertical or horizontal stiffening rib separately, and the effect of the former is much better than the latter, but the decrease degree of vertical stress is different from horizontal stress. The stiffening rib in the box should not be too many; especially horizontal rib and vertical rib should be considered mainly. The anti-collision box with horizontal rib and vertical rib is mainly to reduce collision deformation; however, it can reduce little than the box with only vertical rib in the aspect of stress.

1. Introduction
In recent years, the events of ship impacting bridge have occurred, leading to the destruction of the bridge, resulting in greater social impact. In order to solve this problem, more and more new anti-collision devices appear, the purpose of which is to reduce the collision force of the ship and reduce the energy exchange during the collision, so as to achieve the effect that the bridge, ship and anti-collision device are not damaged [1]. The anti-collision device studied in this paper is a kind of sandwich box made of sandwich plate, which is curved, sheathed on piers or anti-collision piles, and can float up and down with the water level, and has strong adaptability to inland waterway with large water level change [2, 3]. The sandwich plate is added a thick layer of polyurethane core layer between the two layers of steel plates, the research on this aspect abroad early. The sandwich structure has good impact resistance and fatigue performance, and is mainly used in military, ship, bridge reinforcement and other fields [4, 5]. There are few studies in anti-collision bridge pier device made of sandwich plate at home and abroad. The paper [6, 7] conducted the finite element analysis of the collision happened to the bridges by cars or ships. The paper [8] studied the static performance of the box in the case of front impact and slanting impact. The paper [3] studied the change of box energy during the collision course, which is that the box can absorb most of the front impact energy; on the contrary, due to the smooth and rotating surface of the box, the ship is easy to move in the slanting impact, so the most kinetic energy is kept in the ship. The paper [9] simulated the ship impact force using the equivalent static load, which analysed the stress performance of no stiffening rib box by changing the thickness of steel plate and polyurethane core layer.

The results show that when the ship tonnage is large, it is necessary to set up the steel stiffening rib inside the box. In this paper, ANSYS software is used to build the anti-collision system model and
calculate numerically repeatedly in the form of equivalent static loads, which was to analyze the influence of different types and different number of stiffening rib on the strength and rigidity of the anti-collision box, so as to properly set up the stiffening rib.

2. Model Building

2.1. Model Size
This paper with a practical project as the background, relying on the waterway level for IV, according to the design specification of highway bridge [10], it is concluded that the corresponding ship collision force is 550 kN. For example, the diameter of the pier is 1.3 m, and the height is 10 m, the anti-collision box is shown in Figure 1. The inner diameter is 1.6 m, the outer diameter is 4.6 m, the vertical section is the ellipse, the long axis is 2.3 m, and the short axis is 1.5 m. The box is the sandwich structure, the thickness of the outer steel plate is 8 mm, the thickness of the inner steel plate is 6 mm, and the intermediate polyurethane thickness is 40 mm, as shown in Figure 2. The box and pier are combined with a circular ring rubber fender, with a thickness of 100 mm and a height of 400 mm.

![Figure 1. Profile of the anti-collision box made of sandwich](image1)

![Figure 2. Meshing box element in the horizontal circle](image2)

2.2. Material Parameters
The panel and stiffening rib of the anti-collision box are made of Q345 steel, whose elastic modulus is 2.05 x 10^5 MPa, the poisson ratio is 0.3 and the heavy was 78.5 kN/m^3. The hardness of polyurethane is not less than 80HRA, the elastic modulus is 750 MPa, the poisson ratio is 0.48, and the weight is 12 kN/m^3 [11]. The pier adopts C30 concrete, whose elastic modulus is 3 x 10^4 MPa, the poisson ratio is 0.2, the heavy is 25 kN/m^3; The fender adopts the styrene butadiene rubber SBR, the hardness of which is 40 degrees, the density is 940 kg/m^3, the elastic modulus is 6.1 MPa, and the tensile strength is 20.5 MPa.

2.3. Division of Units
The steel - polyurethane sandwich plate is simulated by shell99, which can be used to model the layered shell structure, which can define the material properties of each layer and output the stress and displacement in different directions of each layer. Each node has six degrees of freedom. They are the translation of X, Y and Z directions and the rotation along the X, Y, and Z axes. In this paper, the stress performance of the sandwich panel is studied, so it is reasonable to use shell99 sandwich unit to simulate the stress of the sandwich plate. The pier and fender are simulated with solid45 unit, which has eight nodes and each node has 3 degrees of freedom moving along the X, Y and Z direction.

The box unit is divided into 60 equal parts along the vertical ellipse and 80 equal parts along the horizontal circle. The size of the unit grid is 180 mm in width and 95 mm in height, as shown in Figure 3 and Figure 4. The pier division is divided into 40 equal parts of the loop segment, the radial segment is 20, and the vertical segment is 10. The pier division is divided into 40 equal parts of the loop segment, the radial segment is 20, and the vertical segment is 10. In the middle of the pier, the box section is divided by means of the encryption grid, the loop is 40 equal to the segment, the radial...
segment is 20, and the vertical segment is 30. For the convenience of modeling, the fender height is 1500 mm, and the grid division of the fender is the same as the middle part of the pier.

The stiffening rib is divided into two kinds, which are circular horizontal and oval vertical stiffening rib. The horizontal stiffening rib is the same as the direction of the latitude, which is divided into 80 equal parts along the circumference. The vertical stiffening rib is the same as the direction of the longitude, which is divided into 60 equal parts along the ellipse direction. The horizontal stiffening rib is arranged in the central height of the box along the circular direction of the inner steel plate in the box, which is coupled with the inner steel plate joint, evenly arranged along the upper and lower sides of the box, and the spacing is the height of a box unit, which is about 100 mm. The vertical stiffening rib is arranged evenly around the circumference of the casing. The arrangement of stiffening rib is shown in Figure 5.

2.4. Boundary Conditions
Because of the large rigidity of the transverse bridge of the pier and bearing platform, the lower part of pier can be assumed to be consolidated, and the upper part is free, without taking account of the upper structure's favorable restraint to the pier top. The fenders are connected to the pier by means of the GLUE command in the ANSYS without relative displacement. The connection between the fender and the box is a connection between the body element and the shell element, which is simulated in a half-cycle coupling manner, that is, the degree of freedom is defined on each pair of coincidence nodes, a coupling set is generated, and the coupling of the coincidence nodes in the model is realized by the CPINTF command in the ANSYS. The boundary conditions of the model are shown in Figure 6.

![Figure 3. Meshing box element in the horizontal circle direction](image1)

![Figure 4. Meshing box element in the vertical ellipse direction](image2)

![Figure 5. Arrangement of the stiffening ribs](image3)
3. **The Force Analysis of Box in Ship’s Frontal Collision**

The ship’s frontal collision is one of the least unfavorable collisions, which is located in the middle of the box height and pointed to the box radial, as shown in Figure 7 and Figure 8. The ship’s collision force according to the corresponding technical standard is taken as the local uniformly distributed load acting on the one unit of the collision point. In order to study the influence of stiffening rib on the mechanical properties of this type of anti-collision box, there are two kinds of settings, one is setting circular horizontal stiffeners and elliptical vertical stiffeners, another one is not setting. The sandwich plate’s stress and deformation of the impact point a range of up and down, right and left are calculated to reflect the mechanical performance of the anti-collision sleeve.

Due to the symmetry of the force and structure, the force of the impact point is symmetrical, so the data of the gathering point on one side of the collision point is taken. According to the test, the stress of the sandwich the outer steel plate is the maximum, so in the following analysis, the vertical and lateral stresses and the deformation of the impact direction are only taken from the points of the outer steel plate. Figure 7 shows the stress collection point on the vertical side of the impact point. Within the range of 60° above the impact direction, the length of the elliptic arc is divided into 60 equal parts, with a total of 10 collection points. Figure 8 shows the stress collection point on the horizontal side of the impact point. Within the circumference of 40.5° to the right of the impact direction, the arc length is equally divided into 9, which also has 10 collection points. The following diagram shows that the stress of the collection point is positive, indicating the tensile stress, and the negative value indicates the compressive stress.

**Figure 7.** Distribution of the stress collection points of the box in vertical section

**Figure 8.** Distribution of the stress collection points of the box in horizontal section
3.1. The Influence of Horizontal Stiffening Rib on the Force of Anti-collision Box

There are two situations that one is setting horizontal stiffening ribs and another one is not setting. The Settings are shown in figure 5. One, three, five and seven horizontal stiffening ribs are set respectively. The thickness of steel plate with stiffening rib is 10 mm and the width is 100 mm. The spacing of the stiffening rib is the height of a box unit, which is about 100 mm. One of the horizontal stiffening rib is located at the impact point, and the vertical stiffening rib is not set.

From Figure 9 to Figure 12, it can be seen that the transverse and vertical stress of the outer plate of the anti-collision box are mainly compressive stress, which sharply decreases after leaving the collision center, then gently, and the stress concentration is prominent. Compared with no stiffening ribs, for the setting, the initial compressive stress of the outer steel plate decreases a lot, but the decrease of the vertical compressive stress is greater than that of the transverse stress. For the same collision position, it is not helpful to reduce the initial compressive stress of the outer layer steel plate by setting multiple or more horizontal stiffening ribs. The horizontal stiffener changes rapidly from the transverse tensile stress to the compressive stress at the impact point, and the less stiffening ribs there are, the larger the undulation is. The depth of impact at the impact point decreases with the increase of the quantity of horizontal stiffeners, but the more stiffening ribs there are, the smaller the reduction is.
3.2. The Influence of Vertical Stiffening Rib on the Force of Anti-collision Box

There are also two situations that one is setting vertical stiffening ribs and another one is not setting. The Settings are shown in Figure 5. 10, 20 and 40 vertical stiffening ribs are set respectively, so the interval is 36°, 18° and 9° along the circumference of the box respectively, the thickness of the stiffening rib steel plate is 10 mm, the width is 100 mm, and the stiffening rib is coupled with the corresponding nodes of the inner steel plate. While one of the vertical stiffening ribs is just at the impact point, the horizontal stiffening rib is not set.

From Figure 15 to Figure 18, the transverse and vertical stress of the outer steel plate of the anti-collision box are mainly compressive stress, which sharply decreases after leaving the collision center, then gently, and the stress concentration is prominent. Compared with no stiffening ribs, for the setting, the initial compressive stress of the outer steel plate decreases a lot, the maximum can be decreased by 43.9%. The degree of reduction is much greater than that of setting the horizontal stiffening rib, and the degree of stress reduction in the horizontal direction is greater than that in the vertical direction. It shows that the effect of setting the vertical stiffening rib is better than that of the horizontal stiffening rib. For the same collision position, it is not helpful to reduce the initial compressive stress of the outer layer steel plate by setting multiple or more vertical stiffening ribs. The transverse tensile stress of the vertical stiffening rib at the impact point is rapidly transformed into compressive stress, and the transverse tensile stress of the vertical stiffening rib is slightly larger than that of the horizontal stiffening rib, as shown in Figure 19. The depth of impact at the impact point decreases with the increase of the number of the vertical stiffening rib. However, the decrement becomes smaller when the number is more than one, as shown in Figure 20.
In the above collision calculation, the collision points are equipped with stiffening rib and the stiffening rib of other positions is not obvious to reduce the force effect of the steel plate. However, the position of the collision point of the ship is random within a certain range of the anti-collision box, and the box is also rotatable, so when the impact force is large, the stiffening rib with a certain density must be installed. Therefore, it is necessary to study the force in the middle of the two vertical stiffening ribs, while other conditions are invariable, and the results of Figure 21 ~ Figure 26 are obtained by calculation. In contrast to the previous case, it can be found that the stress of the outer steel plate increases by more than 90% when the load is between the stiffeners, but there's not much difference in the number of stiffening ribs, which indicates that the encryption of the stiffening rib does not effectively reduce the force of the outer plate. But the force of the stiffening rib is much smaller than that of the previous one, as shown in Figure 25. The impact depth increases slightly and decreases linearly with the increase of the stiffener number, as shown in Figure 26.
Figure 21. Lateral stress of the collection points on surface of outer steel plate in horizontal direction

Figure 22. Lateral stress of the collection points on surface of outer steel plate in vertical direction

Figure 23. Vertical stress of the collection points on surface of outer steel plate in horizontal direction

Figure 24. Vertical stress of the collection points on surface of outer steel plate in vertical direction

Figure 25. Vertical stress of the collection points on vertical stiffening ribs

Figure 26. Displacement of the impact point

3.3. The Influence of Horizontal and Vertical Stiffening Rib on the Force of Anti-collision Box

The above is the situation of setting the horizontal stiffening rib and the vertical stiffening rib separately. When setting the horizontal stiffening rib and vertical stiffening rib at the same time in the box, then the influence on the force of the box is analyzed. At the same time, the number of the 5 horizontal stiffening rib remains unchanged, and the size of the stiffened steel plate also remains unchanged. In this case, the stress analysis is done by changing the spacing between the vertical stiffening ribs. The vertical and horizontal stiffeners are installed at the impact point.

From Figure 27 to Figure 30, it can be seen that the transverse and vertical stresses of the outer steel plate of Anti-collision box are mainly compressive stress, which sharply decreases after leaving the collision zone, and the stress concentration is prominent. For the same impact position, setting 20 or more vertical stiffeners is of little help to reduce the initial compressive stress of the outer layer.
steel plate. When the horizontal and vertical stiffening ribs are set at the same time, the effect is relatively ideal, which can greatly reduce the stress level of the inner and outer steel plate, but the distance between stiffening ribs is not as dense as possible, because of an optimal combination problem of horizontal and vertical stiffening ribs. The vertical stiffening ribs changes rapidly from the transverse tensile stress to the compressive stress at the impact point. The displacement at the impact point decreases with the increase of the stiffening rib number, but not linearly.

Figure 27. Lateral stress of the collection points on surface of outer steel plate in horizontal direction

Figure 28. Lateral stress of the collection points on surface of outer steel plate in vertical direction

Figure 29. Vertical stress of the collection points on surface of outer steel plate in horizontal direction

Figure 30. Vertical stress of the collection points on surface of outer steel plate in vertical direction

Figure 31. Vertical stress of the collection points on vertical stiffening ribs

Figure 32. Displacement of the impact point
3.4. Force Condition of the Pier

Figure 33 shows that the stress nephogram of the collision surface of pier and the maximum tensile stress at the bottom of pier is 10.6 MPa, when 5 horizontal stiffening ribs and 40 vertical stiffening ribs are installed in the box. In fact, in the static calculation, the number of stiffening ribs in the anti-collision box changes, the stiffening ribs and strength of the collision box also change, which only affects the force of the box itself, and does not affect the force of the pier. Only in the dynamic calculation, the stiffness change or rotation of the anti-collision box will prolong the impact time and change the direction of impact, so as to reflect the impact force change on the bridge pier.

![Stress cloud of the pier](image)

Figure 33. Stress cloud of the pier

4. Conclusion

(1) The horizontal stiffening rib can reduce the stress of the sandwich plate, and the stress reduction in the vertical direction is greater than that in the horizontal direction. The numbers of horizontal stiffening rib have little difference in reducing the initial stress of the sandwich plate.

(2) The vertical stiffener can greatly reduce the stress of the sandwich plate, and the stress reduction in the horizontal direction is greater than that in the vertical direction. The effect is better than that of the horizontal stiffening rib, but the stress of the stiffening rib itself will increase. The numbers of vertical stiffening rib have little difference in reducing the initial stress of the sandwich plate.

(3) The stiffening rib should be mainly considered in the installation of stiffening box, and the density should be maintained. When the horizontal and vertical stiffeners are set up at the same time, compared with only the vertical stiffening rib, the stress of the sandwich plate decreases less, but the impact depth decreases slightly.

(4) From the analysis, it can be seen that the number of stiffening rib is too much to improve the force of anti-collision box, on the contrary, which will increase the cost and weight. But considering the randomness of the collision location, it must also set a certain density stiffening rib. Therefore, the horizontal stiffening rib should be set according to odd symmetry in the middle of the box, the number of 5 is appropriate, the spacing is determined by the size of the box. The vertical stiffening rib should be set along the circumference of the box, the number depends on the spacing of about 350 mm, in order to form the best combination of optimization.

5. References

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