Analysis of Stress Distribution of Double-layer Shoulder Beam of Concrete-filled Steel Tubular

Yang Wang¹, Baofeng Qi² and Yao Peng²
¹China Shipbuilding Industry Corporation International Engineering Co. Ltd, Beijing 100121, China
²Unit 91053 of Navy, Beijing 100071, China
Email: wangyang@csic602.com.cn

Abstract: At present, single-layer shoulder beam can not meet the operation of large-tonnage bridge cranes with different elevations. However, due to the complexity of the bearing forms of double-layer shoulder beam, there is no corresponding design formula in the code. In order to study the one-way pushing force performance of concrete filled steel tubular (CFST) double-layer shoulder beam with mid-column, combined with the prototype of the shoulder beams in a shipbuilding building, the scale of the beam was analyzed by ABAQUS software, and the P-Δ curve was calculated, the failure process and the stress mechanism were described, and the stress distribution law of lower shoulder beams in elastic stage was emphatically analyzed.

1. Introduction
Shoulder Beam is a transfer member that transmits the internal force form the upper column to the lower column and acts as a crane beam support, which is widely used in heavy factory. Because the shoulder Beam is an important part of the design of industrial plants, it has the characteristics of high bearing capacity and large lateral stiffness, which can effectively ensure the safe operation of the bridge crane [1]. As shown in Figure 1, the traditional double-story shoulder beam adopts a variable-section column to place the crane beam of the upper crane, its calculation model is also based on the calculation model of the single-layer shoulder beam. However, due to the complexity of the bearing forms of double-layer shoulder beam [2], it cannot be applied to existing design methods.
Domestic scholar Jin Tiande, Rao Zhiying [3] made a finite element analysis of the single-layer shoulder beam of the concrete filled steel tubular in 1997. The experiment shows that the distribution of the normal stress of the web of the shoulder beam is not in accordance with the flat section assumption. In the form of failure, the shear failure of the shoulder web causes damage to the overall failure of the member. In this year, Shen Zuyan and Zheng Yi [4, 5] of Tongji University studied the ultimate bearing capacity and stiffness of concrete-filled steel tubular single-slab shoulder beam, and obtained the theoretical formula for calculating the ultimate bearing capacity of shoulder beam. In 2017, Lan Tao, Hu Weizhong, Men Jinjie [1, 6] and others established the finite element model of column shoulder beam of concrete filled steel tubular double-layer double-limb, and gave the calculation model and formula of double-layer shoulder beam.

2. Establishment of Finite Element Model

2.1. Model Design
The lower column of the double-layer shoulder beam studied in this paper adopts a circular steel tubular concrete column and it is inserted into the shoulder beam web range. In addition, adds a long stiffener at the shoulder beam concentration. As shown in picture 2. The upper column and the inner column are made of steel columns with a section of H 220×140×4×8 and a height of 300 mm on the upper column. Two stiffeners are added to the inner pillar height, and the inner limb column is separated from the right concrete tubular column. The upper shoulder beam is H 230×180×4×6, the lower shoulder beam is H 260×180×4×6, the height of the lower column is 600 mm, the web is Φ50×4 and the tilt angle is 450.
2.2. Unit type Selection and Meshing
C3D8R (8-node linear reduction integral solid element) is used for Steel pipe, diagonal bracing, concrete use, and this unit is not sensitive to the shape of the unit. Compared with the complete integral unit it can effectively reduce the calculation cost [7]. And C3D20R (20-node secondary reduction integral physical unit) is used for the upper column, the upper shoulder beam, the inner column, and the lower shoulder beam. At the opening of the shoulder beam the mesh is reasonably refined [6], as shown in Figure 3.

2.3. The Constitutive Relationship of Materials
Selection of steel Q235B, Elastic modulus $E=210$ GPa, Poisson's ratio $\gamma=0.3$, yield stress $F_y=230$ Mpa.
Selection of Concrete C40. The Elastic modulus $E=32.5$ GPa, Poisson's ratio $\gamma=0.2$. The uniaxial stress-strain relationship of concrete is recommended by GB50010-2002 "Concrete Structure Design Code" [8].
2.4. Boundary Conditions and Interactions
The coupling point of the bottom of the concrete-filled steel tubular column is consolidated by simulation. The upper surface of the upper column and the horizontal load point of the lower layer are constrained by the out-of-plane displacement (Uy) and the in-plane rotation (URz).

2.5. Loading Method
The load is loaded in three steps, first applies the vertical load once and keeps invariant. The second step applies the lower horizontal load once and keeps invariant. The third step applies the horizontal load of the upper crane and uses displacement control until the component is destroyed.

![Figure 4. Location and direction of load action](image)

3. Finite Element Analysis and Force Performance of Shoulder Beam Failure Process
After the vertical load is applied, most of it is transmitted to the lower shoulder beam. Due to the structural asymmetry, the left shoulder stress of the lower shoulder beam increases faster. As shown in Figure 5, the load is transmitted through the baroclinic belt of the left zone web. After the application of the lower horizontal load, the strain of the baroclinic belt of the left shoulder of the lower shoulder beam continues to develop. As the upper horizontal load is applied and gradually increases, the yield range expands rapidly until the full section of the left zone web yields. As shown in Figure 6. As the displacement of the top of the column continues to increase, the bearing capacity of the member reaches a maximum value. After that, the bearing capacity of the member decreases slowly. When the displacement of the top of the column reaches about 60 mm, the surface of the web is buckling and the bearing capacity drops rapidly. Then the lateral buckling pattern is shown in Figure 7 (the black line specifically indicates the out-of-plane buckling), the overall stiffness of the component is seriously degraded and cannot be carried. The overall failure mode of the member and the top load-displacement curve are shown in Figure 8 and Figure 9, respectively.

![Figure 5. Baroclinic Belt of Lower Shoulder Beam](image)  ![Figure 6. Full Section Yield of Lower Shoulder Beam](image)
Figure 7. Outside buckling of web of lower shoulder beam

Figure 8. Overall failure mode of the component

Figure 9. Load-displacement curve of column top

4. Finite Element Analysis of the Stress of the Lower Shoulder Beam

Stress analysis of the lower shoulder web at x=178 mm. As shown in Figure 10a, after the vertical load is applied, the compressive stress is small on both sides. When the horizontal displacement reaches 4 mm, the stress in the middle of the web suddenly drops below 5 MPa, and the distribution is irregular. As shown in Fig. 10b, after the vertical load is applied, the shear stress of the web is compressive stress, and most of the high-level stress is large. When the horizontal displacement reaches 4 mm, the shear yield stress is 135 MPa in the middle part of the web. In this time, the shear stress tends to be the same at all points of the web height. As shown in Fig. 10c, the general rule of the bending normal stress is that the upper portion of the upper portion is pulled. The pre-loading stress conforms to the flat section assumption, and the tensile stress value demarcation point is approximately at the center. After that, the upper compressive stress increases and the compression zone expands downward, which is seriously inconsistent with the flat section assumption.
5. Conclusion
(1) When the working conditions described in this paper are used, the lower shoulder beam is the main force-bearing part, and the lower shoulder beam web transmits the load through the diagonal pressure belt. The failure of the component is due to the shear failure of the lower shoulder web, the buckling occurs outside the surface, the member loses rigidity, and the bearing capacity decreases rapidly.

(2) The shoulder beam web is in a plane stress state, and the bending stress and the compressive stress value are low. In the late loading stage the bending stress does not conform to the flat section assumption; the shear stress distribution law is large in the middle part, and the stress on the two sides away from the oblique pressing belt is small.

6. References
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Figure 10. Stress Distribution of Lattice Web in Left Zone of Lower Shoulder Beam