Influence of welding deformation on anti-collapse performance of single-layer reticulated shell structures with prestressed cables

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Abstract: In this paper, the ABAQUS finite element software is used to model and analyze the single-layer reticulated shell structure. And the method of removing the constraints of key components is used to analyze the anti-continuous collapse performance of this reticulated shell structure under the action of geometric defects and welding deformation. Welding deformation is mainly caused by welding and prestressed cable tensioning of single-layer reticulated shell. The results show that the removal of the key columns under the reticulated shell will lead to the continuous collapse of the upper part, which leads to the continuous collapse of the whole structure, and the welding deformation can make the continuous collapse of the whole reticulated shell more obvious. Thus determining the influence of geometric defects and temperature shrinkage deformation on the anti-continuous collapse performance.

1. Introduction
Single-layer reticulated shell structure is a kind of space bar system structure. It is a spatial frame based on members, composed of grids according to certain rules and arranged according to shell structure. It has the properties of both bar system and shell [1]. This type of structure has the advantages of large span, small structural deformation, large stiffness and reasonable stress [2]. Due to the large span, the space utilization rate is also relatively sufficient, and it is easy to collapse continuously in the central reticulated shell structure because of the destruction of the supporting column under this reticulated shell structure [3], which leads to the destruction of the whole structure. This kind of failure is very damaging to the reticulated shell structure.

There are many researchers in our country have studied the continuous collapse resistance of different structures [2]. Welding is an important process for the processing and connection of steel stress systems, but the residual deformation caused by cooling and shrinkage after welding will affect the installation accuracy and even the mechanical properties of the structure [4]. Domestic single-layer reticulated shell with geometric defects of continuous collapse resistance has a certain research. Therefore, this paper will use ABAQUS finite element software to analyze this type of structure with shrinkage deformation caused by welding and prestressed cable tension, to judge the influence of welding deformation on the continuous collapse resistance of this type of structure. The effects of geometric defects and welding deformation on the continuous collapse resistance of reticulated shells will also be compared. Under the action of only self weight, find the maximum reaction force of the key member, dismantle the key member, and simulate the geometric defects of the reticulated shell structure [5]. In order to
control variables, this paper will only consider the effect of self weight without considering the influence of wind and snow load, and will consider wind and snow load in subsequent simulation experiments.

2. Introduction to the model
In this paper, based on ABAQUS, the anti-continuous collapse performance of single-layer reticulated shells is studied. For steel structure, it is very easy to produce shrinkage deformation during welding. So it is very necessary to study the influence of shrinkage deformation during welding on the anti-continuous collapse resistance of reticulated shell. This type of structure is a spatial large-span curved structure, with an overall span of 72m, a transverse length of 180m and a vector height of 7.65m. The model is shown in Figure 1 below:

![Reticulated shell model diagram](image)

**Figure 1.** Reticulated shell model diagram.

3. Results and analysis methods

3.1. Analysis method
After adding self weight to the reticulated shell, find the place where the column reaction force is the largest, and remove the column bottom constraint of the column here, that is, delete the column here in the finite element simulation software to simulate the continuous collapse of the reticulated shell due to the damage of structural column caused by accidental load (This is the method to obtain geometric defects in this paper). Then the shrinkage deformation caused by welding and the temperature stress of prestressed cable tension are introduced into the reticulated shell to analyze the influence of temperature shrinkage deformation on the anti-continuous collapse performance of the reticulated shell (as shown in Figure 2). Welding deformation is to reduce the temperature of the member at the welding node and ensure that the shrinkage of the node is consistent with that of the corresponding weld during cooling. The equivalent effect of weld shrinkage is introduced into the structural analysis. The temperature stress caused by prestressed cable tensioning is to analyze the stress of the prestressed component and the overall structure as a whole by implementing the temperature drop on the unit of the prestressed component [6], so as to simulate the prestress effect of the prestressed component on the overall structure. The research on the influence of the reticulated shells on the continuous collapse resistance is mainly divided into three areas: the first area is the part with only oblique bars, the second area is the part with only orthogonal bars, and the last area is the connection of the first two areas. The research on these three areas is mainly divided into three groups: the first group is no geometric defects and no welding deformation is introduced, the second group is geometric defects and no welding deformation is introduced, and the third group is geometric defects and welding deformation is introduced. Through the analysis of three different situations in three areas of reticulated shell, and choosing a joint between the bar and the bar in the area of obvious deformation, and analyzing the deformation displacement diagram of the joint, the influence of geometric defects and welding deformation on the anti-continuous
collapse resistance of this type of reticulated shell structure is deduced finally. The introduced temperature stress field is the temperature of weld cooling to reduce the temperature and the temperature stress field of prestressed cable during tensile simulation by cooling method, as shown in Figure 2.

![Temperature stress field](image)

**Figure 2.** Temperature stress field.

### 3.2. No geometric defects and no welding deformation

#### 3.2.1 Orthogonal region
In the absence of geometric defects and welding deformation, the simulation results of reticulated shells under the condition of dead weight only are shown in the figure 3 as below:

![Orthogonal region deformation diagram](image)

**Figure 3.** Orthogonal region deformation diagram.  
**Figure 4.** Displacement diagram.

The maximum collapse displacement of the orthogonal part of the reticulated shell under the action of dead weight is 7.6cm, and the oscillation amplitude of the component connection node No. 11410 in the obvious collapse area is 6cm. It can be seen from Figure 4 that, without the influence of welding deformation, the node has no change in displacement from 0 to 1s, but it starts to oscillate back and forth after 1s.

#### 3.2.2. Mixed region
In the absence of geometric defects and welding deformation, the simulation results of reticulated shell under the action of only dead weight are shown in the figure below:

![Mixed area deformation diagram](image)

**Figure 5.** Mixed area deformation diagram.  
**Figure 6.** Displacement diagram.

According to Figure 5, under the action of only self weight, the maximum collapse
The displacement of the most obvious collapse area in the middle of the reticulated shell is 11.4cm, while the oscillation amplitude of the joint No. 795 of the component connected with the collapse is 8cm. According to Figure 6, the displacement at the joint does not change from 0 to 1s, but changes suddenly at 1s, and oscillates downward.

3.2.3. Connection area. In the absence of geometric defects and welding deformation, the simulation results of the connecting regions of the orthogonal and mixed parts are shown in the figure below:

![Figure 7. Deformation diagram of connection area.](image)

![Figure 8. Displacement diagram.](image)

As is shown in the Figure 7 above that the maximum displacement of collapse in the connection area is 8.5cm, and the maximum amplitude of displacement oscillation of node No. 4130 in the obvious collapse area is 4cm. It can be seen from Figure 8 that there is no deformation displacement of the node from 0 to 1s, but it changes suddenly and oscillates back and forth in 1s. Based on the above simulation results, the nodes in each region oscillate under the action of dead weight due to the large span of reticulated shell, but the amplitude of oscillation is determined by the stiffness of each region.

3.3. Considering geometric defects, no welding deformation
3.3.1 Orthogonal region. In the case of geometric defects and no welding deformation, the simulation results are as follows:

![Figure 9. Orthogonal region deformation diagram.](image)

![Figure 10. Displacement diagram.](image)

According to Figure 9 above, the maximum collapse displacement of the orthogonal part is 9.5cm, and the displacement oscillation amplitude of the component connection node No. 11410 at the obvious collapse is 6cm. As can be seen from Figure 10, the node has no deformation displacement from 0 to 1s, and at 1s, due to the double effects of geometric defects and self weight, it begins to mutate and oscillate downward.

3.3.2. Mixed region. In the case of geometric defects and no welding deformation, the simulation results are shown in Figure 11 as below:
According to Figure 11, the maximum collapse displacement of the middle part of the reticulated shell is 11.2cm, and the oscillation amplitude of the member connection node No. 795 in the area with obvious collapse degree is 9cm. According to the Figure 12, the node displacement has no deformation displacement from 0 to 1s. At 1s, the node displacement suddenly changes and oscillates downward and backward. During the oscillation process, the node displacement oscillates greatly and protrudes upward at some times.

3.3.3 Connecting areas. Under the action of dead weight, geometric defects are introduced without welding deformation. The simulation results of reticulated shell are shown in the figure below:

From the simulation results in Figure 13, it can be seen that the maximum displacement of collapse in the connection area is 8.4cm, and the maximum amplitude of oscillation of node number 4130 in the obvious collapse area is 6cm. From Figure 14, the displacement of the node does not change from 0 to 1s, and the displacement of the node changes suddenly and oscillates back and forth in 1s.

3.4. Consider geometric defects and welding deformation
3.4.1 Orthogonal region. In the case of both geometric defects and welding deformation, the simulation results of reticulated shell are shown as follows:

From Figure 15, the maximum collapse displacement of the orthogonal part is 4.6cm, and
the displacement oscillation amplitude of the component connection node No. 11410 at the obvious collapse is 6.5cm. It can be seen from Figure 16 that due to the influence of welding deformation, the node protrudes upward to 5cm in 0 to 1s, and starts to vibrate back and forth in 1s.

3.4.2 Mixed region. In the case of introducing geometric defects and welding deformation, the simulation results are as follows:

![](image1)

**Figure 17.** Deformation diagram of reticulated shell.  **Figure 18.** Displacement diagram.

According to the Figure 17, the maximum collapse displacement of the middle part of this type of reticulated shell structure is 7.6cm, while the maximum collapse displacement of the part with geometric defects is 18.4cm. From Figure 18, the maximum displacement amplitude of node No. 795 is 10cm. From 0 to 1s, due to the influence of welding deformation, the node protrudes 5cm upward and oscillates downward at 1s. During the oscillation process, the node oscillation displacement changes up and down.

3.4.3 Connection area. Under the action of dead weight, geometric defects and welding deformation are introduced. The simulation results of reticulated shell are shown in the figure below:

![](image2)

**Figure 19.** Deformation diagram of reticulated shell.  **Figure 20.** Displacement diagram.

It can be seen from Figure 19 that the connection area protrudes upward, and the maximum deformation displacement is 3.7cm. The oscillation amplitude of the component connection node No. 4130 in the obvious collapse area is 5cm. It can be seen from Figure 20 that the node protrudes upward by 4.5cm in 0 to 1s, and it suddenly changes in 1s, oscillates downward to 5cm, and then oscillates back and forth.

4. Conclusion
This section discusses the influence of geometric defects and welding deformation on the continuous collapse resistance of reticulated shell. After comparing the simulation results of 9 groups in three regions, it can be seen that:

(1) The influence of welding deformation on the whole reticulated shell is much greater than that of geometric defects. Through the comparative analysis, it can be seen that the maximum collapse displacement of single-layer reticulated shell structure for the three regions is larger than the latter two cases when there is no welding deformation and geometric defects. After
welding deformation is introduced, the collapse displacement of reticulated shell decreases obviously, while the oscillation amplitude of key nodes increases slightly. However, the geometric imperfection has little effect on the collapse maximum displacement and the oscillation amplitude of key nodes.

(2) For the three areas with different stiffness, only the orthogonal bar area and the connection area have smaller collapse maximum displacement and oscillation amplitude of key nodes, while only the oblique area has larger collapse maximum displacement and oscillation amplitude of key nodes due to smaller stiffness. Moreover, the oscillation amplitude of the key nodes in the connection area is not regular due to the inconsistency of the stiffness on the left and right sides of the connection area. Therefore, the anti-collapse performance of reticulated shells can be effectively improved by minimizing the shrinkage deformation during welding.

(3) Comparing the oscillation amplitude of a key node in the orthogonal region in three different cases, it can be found that after considering the welding deformation, the oscillation amplitude of the node increases by 0.5 cm, while the maximum collapse displacement of the orthogonal region decreases by 3 cm. For the connection region, the oscillation amplitude of the node increases by 1 cm, and the maximum collapse displacement of the connection region decreases by 4.8 cm. For the oblique region, the node oscillation amplitude increases by 2 cm, and the maximum collapse displacement of the reticulated shell decreases by 4 cm, but the maximum collapse displacement of the column bottom constraint removal part reaches 18.4 cm. It can be seen that welding deformation can reduce the overall collapse displacement of reticulated shell, but for a single node, it aggravates the oscillation amplitude of the node, which makes the joint unstable. Therefore, in practical engineering, we should try our best to reduce the influence of welding deformation.

(4) The collapse displacement of the orthogonal region increases by about 2 cm when only removing the column bottom constraints of the key components in the orthogonal region, and the node oscillation amplitude hardly changes. When only removing the column bottom constraints of the connection region, the collapse displacement of the connection region hardly changes, but the node oscillation amplitude increases by 2 cm when only removing the column bottom constraints of the oblique region, and the maximum collapse displacement hardly changes. The oscillation amplitude increases by about 1 cm, so it can be seen that considering the geometric defects in the connection area has the greatest impact on the overall stability of the reticulated shell.

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