# ANALYSIS OF THE STRUCTURAL BEHAVIOUR OF SHORT SUSPENDERS IN LARGE-SPAN TIED ARCH BRIDGES

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## SUMMARY

In the case of a tied arch bridge, this paper focus on the behaviour for spatial structure of large span tide arch bridge's short suspender. According to the changes of suspender's nodes on two sides under various loads, solid model is set up at finite element software, which is used to analyse the variation of stress and stress amplitude of short suspenders' consolidation and non-consolidation section, and the differences of the additional internal forces in the tied arch bridge's short and long suspenders under dead load, vehicle load, or ultimate limit state. Depending on the additional internal force rules and stress amplitude rules of different suspenders, the behaviour for spatial structure of tide arch bridge's short suspender has been discussed.

**Keywords:** *Large span tied arch bridge, short suspender, static and dynamic analysis, Computational Analysis.*

## 1. INTRODUCTION

The suspender is a key component of the large span tied arch bridge, but it's also easy to wear. The suspender decides the structure safety and service life of the bridge. In recent years, the Yibin Nanmen Bridge, Xinjiang Kongque Bridge and Fujian Gongguan Bridge collapsed because of the damage of short suspender. The destructive power of short suspender caused widespread concern.Through the three-dimensional finite element model and partial sub-model which are composed of bridge deck, arch rib and short suspender, which are established by ANSYS software, this paper tries to explore the static and dynamic structural behaviour of the flexible suspension rods and the comparison of long and short suspender's bending moment, Shear force and failure characteristics.

## 2. FINITE ELEMENT MODEL

We use the finite element software MIDAS /CIVIL to analysis the finite element model of a bridge [1] whose length is 120m, the rise is 28.5 M and the distance of suspenders is 6.6m, and we use beam elements to simulate when we simulate the suspenders. When we establish the model of a whole bridge, we choose the suspender and the arch rib to have a common node; the suspender and the cross beam and the crossbeam to have a common node. Therefore we can assume that the 6 degree of freedom deformation of two ends of the suspenders nodes, which is at the ultimate state of dead load, vehicle load and bearing capacity, is the fixed deformation of the connecting end of suspender with arch rib and the connecting end of the suspender with the bridge deck which is under the OVMLZM (k) 7-85 I type anchorage.

Using the finite element software ANSYS to establish a solid model of the suspender, we can assume that the 6 degree of freedom deformation of two ends of the suspenders nodes, which is at the ultimate state of dead load, vehicle load and ultimate limit State, is the deformation of the connecting end of suspender with arch rib and the connecting ends of suspender with beam and bridge deck under the anchorage of consolidation. So before we establish a solid model of the suspender, we make some assumptions first:

1) Assume that the deformation of suspenders and bridge deck is the result of the deformation of the suspender consolidation section and bridge deck.
2) Assume that the deformation of the bridge deck's nodal end of the suspender is the deformation of the suspender consolidation section, the beam and the bridge deck.
3) Assume that the steel beams in the suspender are a whole system when ignore the effect of friction between the steel wire.

When we discuss the stress and the stress amplitude of the suspender, because the upper and lower ends of suspender were wrapped in arch rib and the beam and bridge pane, and the connection of suspender with arch rib and the connection of beam and bridge deck which are crossed by the suspender cannot be completely freely deformed. Therefore, we make the anchorage length on the suspenders' two ends and the length of suspenders which cross the arch rib and beam with bridge deck as the length of consolidation on two ends of the suspenders. In the ANSYS model, we make the nodal deformation of consolidation's surface and the deformation on two end nodes of suspender the same, so that we can make the solid model of suspender.

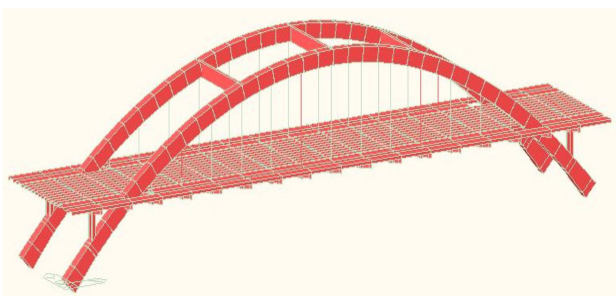

***Fig. 1.*** *Full bridge finite element model.*

As shown above, the Fig. of the suspenders' lower end is the number of suspender on the two sides of the Tied Arch Bridge, and suspender number in the front side is corresponding to the front N#, and the suspender number in the back is corresponding to the back N#.

## 3. THE DYNAMIC AND STATIC STRESS AND DEFORMATION OF SUSPENDER

### 3.1. The short suspender's stress situation under the state of dead load

The suspender is mainly subjected to axial tension [2]. However, displacement deformation will occur at the arch rib and bridge deck of the main arch of Tied Arch Bridge, which may cause the displacement deformation of the upper and lower ends of suspender which connect with arch rib and bridge deck. This kind of displacement deformation is mainly reflected in the displacement deformation of the upper and lower ends of suspenders' consolidation. The displacement deformation of the upper and lower ends of suspenders' consolidation causes the generation of additional internal force in the upper and lower ends of suspenders.

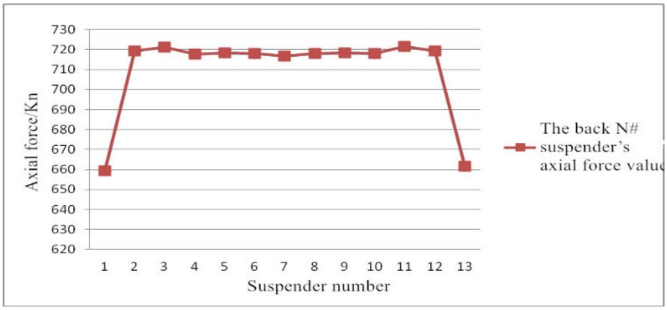


***Fig. 2.** Line chart of suspender's axial force value under the state of dead load.*

From Fig. 2, we can get rod 1# and rod 13# have minimum axial force under dead load, while the symmetric rod 3# and rod 11# have maximum axial force under dead load, and rod 1# and rod13# are the short suspenders on both sides of the Tied Arch Bridge. From the figure, we can see the change of axial force between rod 1# and rod 2# and that between rod 12# rod 13# is much more than the axial force between the adjacent rods. And the main reason is the column which connects with the arch rib will bear a partial dead load of rod1# and rod13#. Therefore, the boundary conditions of the suspenders' left and right sides are totally different from those of the other short suspenders'.

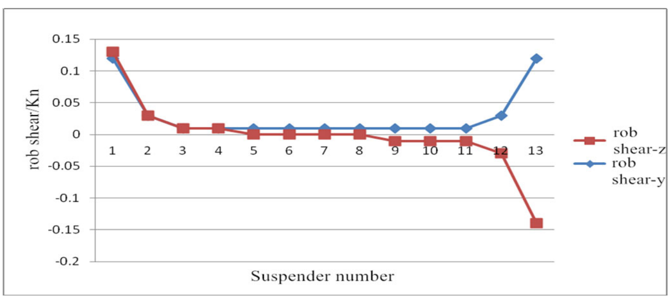


***Fig. 3.** Line chart of rob shear value of front N# under the state of dead load.*

Due to the symmetry of Tied Arch Bridge, the front and back suspender is basically the same in the internal force and displacement deformation. Therefore, the front suspender N# is the main research object.

From Fig. 3, we can get the rob shear values of the front and back short rob 1# and short rob 13# is the largest in the bridge deck's transverse shear-y and the bridge deck's longitudinal shear –z. Because the short suspender's relative stiffness--EI/l of the tied arch bridge is large, and the short suspender's deformation capacity is relatively weak, the short suspender cannot release the deformation which caused by connecting the arch rib, which cause the short robs' shear value bigger and the stress condition more complicated.

Under the state of dead load, the connections which are between upper end of the suspender and arch rib, and between the lower end of the cross beam and bridge surface, result in the displacement of arch ribs and beams and bridge deck, which lead to the displacement and rotation changes of the suspenders' upper and lower nodes.

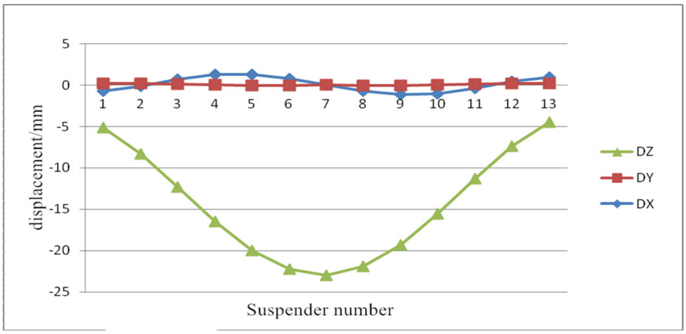


***Fig. 4.*** *Displacement line chart of the arch rib of front rob N# under the state of dead load.*

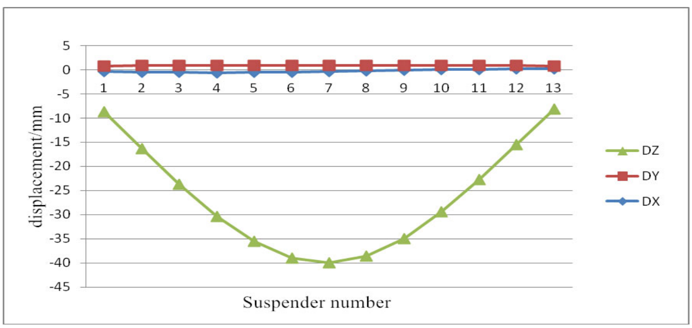


***Fig. 5.*** *Displacement line chart of bridge deck ends of the front rob N# under the state of dead load.*

Under the state of dead load, the bridge vertical displacement--DZ value of the suspender's arch rib and bridge deck ends changes a lot, but slope variability of sections of the line changes relatively regular. The column on two ends will share short rob 1# and rob13#'s part effect of dead load, resulting in the bridge vertical displacement--DZ value of the1# and 13# short suspender's arch rib and bridge deck ends is smaller than the rest of the value. The vertical displacement along the bridge of arch rib is smaller than the vertical displacement along bridge of bridge deck ends, that's because the bounded arch springing limits parts of the vertical displacement of arch rib [3], and the closer it's to the arch springing, the more limited the vertical displacement of arch rib is.

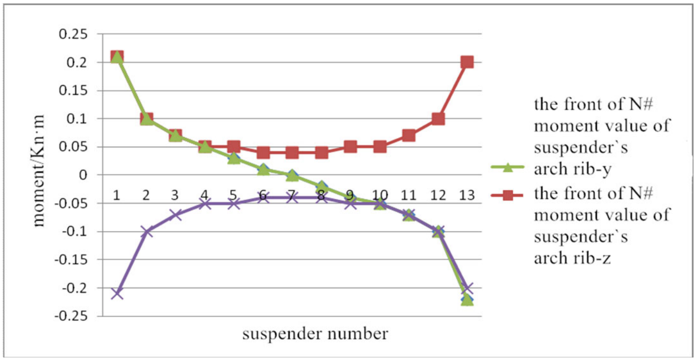


***Fig. 6.*** *Line chart of moment value of suspenders' arch rib nodes under the state of dead load.*

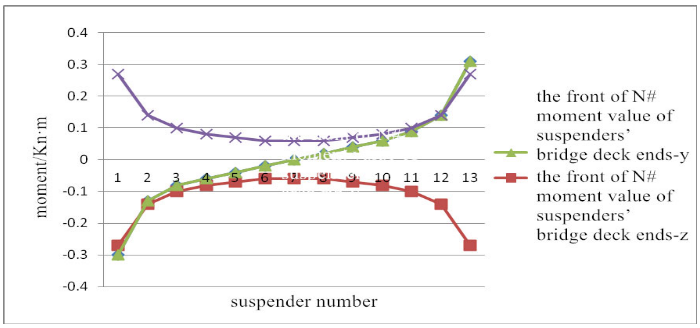


***Fig. 7.*** *Line chart of moment value of suspenders' bridge deck ends under the state of dead load.*

From the two figures, we can conclude that because of the limitation of arch springing, the closer the suspenders' arch rib and end of bridge deck ends are to the arch springing, the more limited the vertical and horizontal displacement deformation of arch rib is. Meanwhile, due to the two sides of the short suspenders is in the junction of arch rib and column, resulting in the bending stiffness of short suspenders is larger than that of long suspender, and deformation capacity of suspender is much smaller than that of other long suspenders. Under the influence of dead load for a long time, the additional internal force of the short suspenders on the two ends cannot get release, and accumulates at arch rib and deck end of the short Suspenders for a long-term, which is bad for the global stress of short suspenders.

### 3.2. The stress situation of short suspender under the state of vehicle load

The vehicle load of this paper mainly focus on the suspenders' spatial stress characteristic and displacement changes especially the internal forces and displacement of the arch rib and bridge deck ends of suspender when the bridge is at its maximum, and ignore the additional external force which is produced by the speed change of vehicle and the slamming on the brakes of the vehicle in the process of vehicle driving and the uneven pavement of bridge deck.

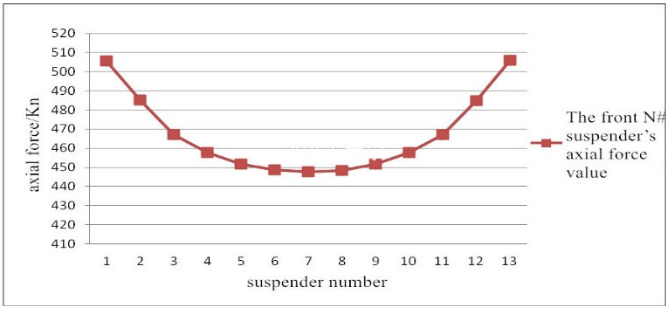


***Fig. 8.*** *Line chart of suspender's axial force value under the state of vehicle load.*

From Fig. 8 we can get rod 1# and rod 13# have the maximum axial force, and rod 7# in the middle of the bridge has the minimum axial force. The rod 1# and rod 13# on the left and right sides are in the junction of short suspenders and the column, resulting in 1# and 13# short suspenders' relative stiffness larger and the short suspender's natural frequency--EI/l higher. Therefore, bending capacity of short suspender 1# and 13# are smaller than other long suspenders, and the change of vertical displacement is smaller than other long suspender, and the axial force of short suspender 1# and 13# is relatively bigger.

Due to the symmetry of Tied Arch Bridge, the front and back suspender is basically the same in the internal force and displacement deformation. Therefore, the front suspender N# is the main research object.

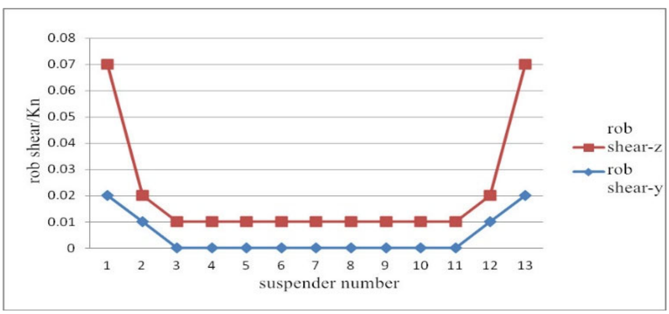


***Fig. 9.*** *Line chart of rob shear value of front N# under the state of vehicle load.*

From Fig. 9, we can conclude that, due to bending stiffness of the left and right sides of short suspenders are much bigger than the other bending stiffness of the suspender in vehicle load, which caused that adaptation to the change of the longitudinal displacement of deck is relatively weak. Therefore, the shear force generated at the ends of the suspender 1# and suspenders 13# are bigger than that of others [4].

Under the effect of the vehicle load, the displacement which occurred at the arch rib, the beam and bridge deck has led to the displacement and rotation changes of suspender's nodes. We make the maximum displacement and rotation of upper and lower ends as the main research object, and then get 6 degree of freedom deformation of the upper and lower suspender's nodes under the vehicle load.

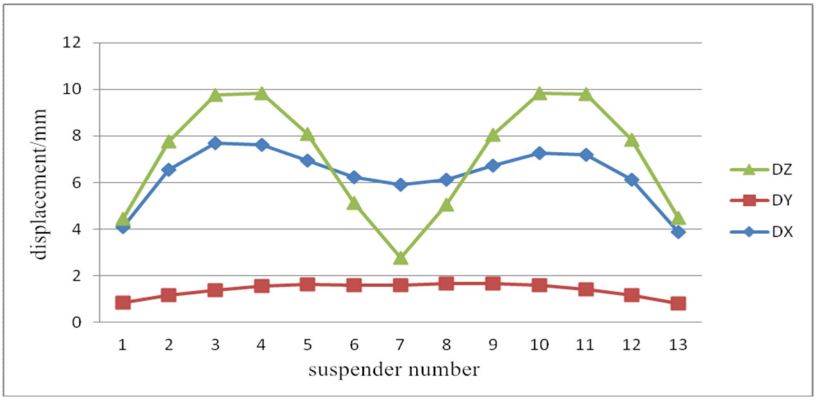


***Fig. 10.*** *Displacement line chart of the arch rib of front rob N# under the vehicle load.*

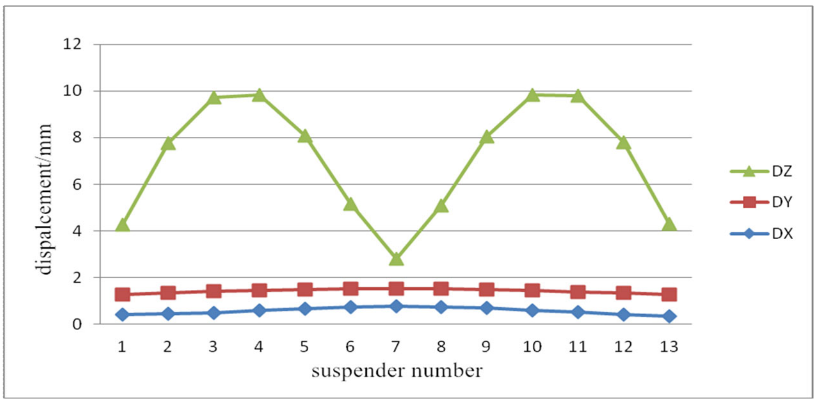


***Fig. 11.*** *Displacement line chart of the bridge deck of front rob N# under the vehicle load.*

From Fig. 10 and 11, we can conclude that the arch springing on left and right sides is bound, which lead to the vertical and horizontal displacement at arch rib end of the nearest suspender to the arch springing is smaller than that of other suspender. Therefore, the short suspender 1# and 13# on the left and right side cannot reduce the impact of suspender's arch rib end's deformation well which caused by the vehicle, which is a disadvantage for the load condition of suspender [4].

Under the state of vehicle load, there is little difference between the vehicle displacement of tied arch bridge's short suspender s on both side and that of the long suspender in the mid. But the length of short suspenders on the left and right sides is smaller than that of the long suspender in the mid of the bridge, so the relative vertical displacement of the short suspenders on both sides of the bridge is bigger than that of the long suspenders in the mid of the bridge.

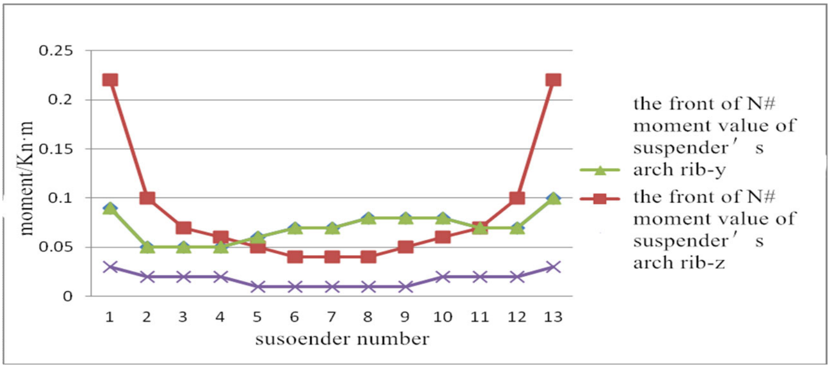


*Fig. 12. Line chart of moment value of suspenders' arch rib nodes under the state of vehicle load.*

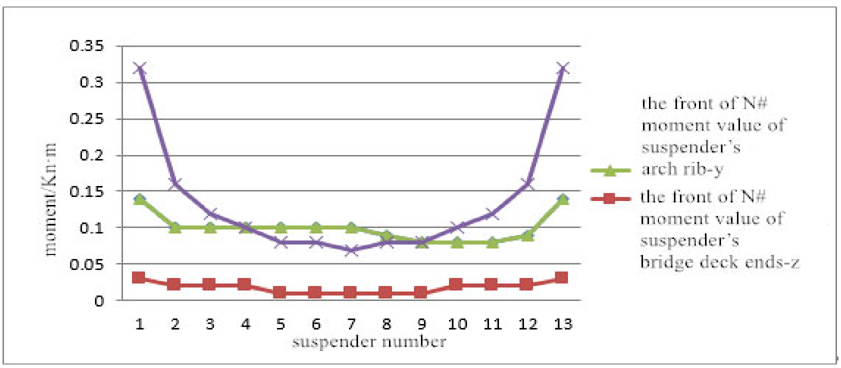


*Fig. 13. Line chart of moment value of suspenders' bridge deck ends under the state of vehicle load.*

Under the effect of vehicle load, the additional moment—z occurs at the front and back suspender which can make suspender arch rib end and the bridge bent. Because short suspender 1# and 13# are in the junction of arch rib and column, so the short suspender's bending stiffness is bigger than other rod bending stiffness. Under the effect of vehicle load, the short suspenders' vertical and horizontal displacement of suspender arch rib and deck ends on two sides are smaller than others suspenders', but the left and right sides' suspenders' additional bending moment – z is the biggest. Under the effect of vehicle load, the same vehicle's gravity is bigger than the longitudinal force of the car, and therefore the suspenders' additional bending moment - z on the left and right sides of short suspenders 1# and 13# is bigger than other suspenders'. The arch rib and deck ends' displacement occurs with the vibration of the deck. Because the relative stiffness--EI/1 of the short suspenders on the two sides is bigger than that of other suspenders, and adaption to the displacement of the short suspenders is weaker, which makes the two sides' short suspenders' change of displacement smallest, the additional bending moment biggest and the stress condition the most complicated under vehicle load.

## 4. COMPUTATIONAL ANALYSIS UNDER THE ULTIMATE LIMIT STATE

We have discussed the influence of the dead load, vehicle load to the short suspender of tied arch bridge. We also need to focus on the stress difference between the short suspender and other suspenders at a tied arch bridge. The basic combination of structural ultimate limit state [5]:

$$\gamma_0 S_{ud} = \gamma_0 (\sum_{i=1}^{m} S_{Gid} + S_{Q1d} + \psi_c \sum_{j=2}^{n} S_{Qjd}) \tag{1}$$

=1.2×dead load+1.4×dead load of vehicle.

We have discussed the impact on the suspenders under all kinds of loads. So in the normal operating state of the tied arch bridge, we also need to focus on the suspenders' stress situation under different kinds of load combinations. This paper mainly discusses the stress conditions of short suspenders and the differences of stress condition among other suspenders. Therefore, we can make the solid modelling of the suspender according to the three assumptions above.

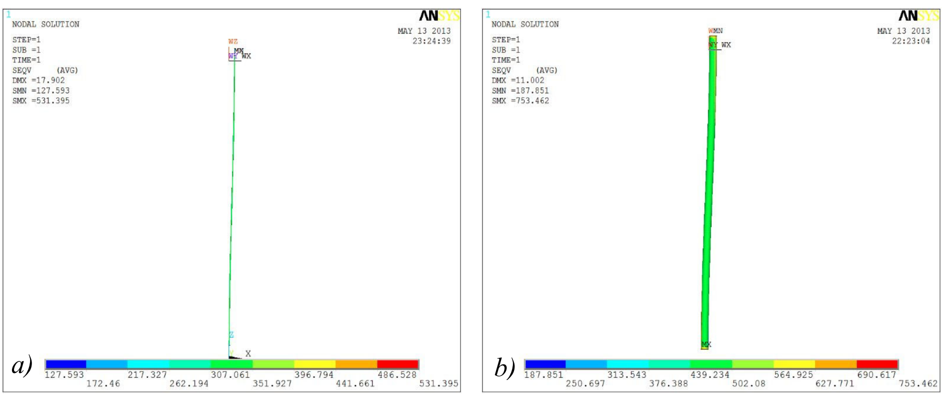


***Fig. 14.*** *a) Ultimate limit state unconsolidated segment 1# suspender Von Mises stress distribution diagram (MPa); b) ultimate limit state suspender segment 7# suspender distribution diagram (MPa).*

Due to the phenomenon of stress concentration at the joint region of the suspenders' consolidation section and non-consolidation section, stress concentration occurs at junction between the consolidation section of upper and lower ends and non-consolidation section [6].

From the figures above, it concludes that the maximum stress and the maximum stress amplitude are at short suspender 1# and suspender 13# at the left and right sides under the ultimate limit state. Thus, if the tied arch bridge is under normal operation, the suspenders' consolidation section is too long , the left and the right sides of short suspenders stress values and stress amplitude will be maximum, which is unfavourable for the suspenders' anti fatigue ability and the extension of service life.

## 5. CONCLUSION

This chapter analyzes suspenders' stress condition and amplitude condition of suspenders' non-consolidation stress under the effect of different loads through finite element software MIDAS / CIVIL and ANSYS, for a tied arch bridge under various loads. We draw the conclusions: All suspenders suffer the force and moment from the beam. Short suspenders need to suffer the bending moment and shear force, resulting from the long-term deformation of bridge deck and arch rib, which may increase the additional internal force of short suspenders, and make the tied arch bridge's behaviour for structure more complex. Under the dead load for a long-term, the additional internal force at the short suspenders' two ends cannot be released, resulting in the accumulation of additional internal force at the short suspenders' arch rib and deck end. Therefore, the short suspenders' anchors bear huge flexural failure and tensile failure stress, which may cause the reduction of suspenders' and anchors' working qualities and the damage of short suspenders in tied arch bridge.

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