

Analysis on Static Performance of KT Type Circular Steel Pipe's Tubular Joint

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Abstract. the tubular joint of KT type circular steel pipe has abundantly existed with wide application of truss structure of long-span steel pipe. This paper analyzes the influence on joint stiffness through three major factors: thickness of major pipe t_0 , diameter of branch pipe d_i , the included angle θ between branch pipe and major pipe. It applies shell 181, three-dimensional four joints elastic-perfectly shell unit, and elastic-perfectly plastic material to establish finite element model of the tubular joint of KT type circular steel pipe in ANSYS finite element program. Considering geometric nonlinearity and material nonlinearity, this paper gets the ultimate bearing capacity of the tubular joint of KT type circular steel pipe under additional bending moment effect of different joints, has contrastive analysis on ultimate bearing capacity of tubular joint under these different situation, and explains that the ultimate bearing capacity of tubular joint of KT type circular steel pipe will have anti-index curve decrease with increase of additional bending moment M .

Introduction

The Design Code for Steel Structures (GB50017-2003) of china [1] stipulates that joint hinge model can be applied to have structural analysis when the ratio between the panel length of major pipe and external diameter is not less than 24, and the ratio between the panel length of branch pipe and external diameter is not less than 12. There are two reasons: firstly, when the member bar is thin and long, it mainly bears axial force, secondly, the regulation above is for structural overall analysis, but the situation of joint is different from member bar. Joint bending moment can usually be ignored if the member is long and thin, but the joint stiffness problem brought by jumbo size steel pipe will not only influence the calculation model of structural system and the calculation length of component, but also cannot-be-ignored influence to the ultimate bearing capacity to the joint. For example, the steel structure of 300 meters arch span sports facility at provincial capital in south east China could apply tubular joint originally, but because they cannot handle joint performance accurately, they applied thick wall cast steel on most joints, so only this item cost a lot [2]. The key project, an 80 thousand people stadium in Shanghai, applied two trussing models, which were hinge joint and overall rigid connection, to calculate separately, they discovered that the experimental result was close to rigid connection trussing model, but because the internal force of member bar calculated by rigid connection contains the content of bending moment, the load bearing strength of member bar section after hinge joint model analysis seems to be not enough [3].

Finite element model's establishment of KT type steel pipe's joint

Unit type. Finite element model applies elastic plastic shell unit, and elastic plastic shell unit usually applies two units: shell 181, three-dimensional four joints elastic-perfectly shell unit, and shell 93, three-dimensional four joints elastic-perfectly shell unit. The literature [4] compares the difference between these two calculation units, it indicates that the joint bearing moment of modelling by applying shell 181 and shell 93 are close, and they are both close to trail value. But the calculation time of the former one is short and the efficiency is high, because shell 181 is a plane unit, but shell 93 is an arc

curved unit. This paper applies shell 181, three-dimensional four joints elastic-perfectly shell unit, doesn't consider about the influence of welding line and residual stress to ultimate bearing moment of joint to simplify the model while establishing finite element model.

Finite element model of joint. After experiencing elastic stage, the stress-strain curve of common iron has gently yield point elongation, which is close to elastic-perfectly plastic, so the material of steel pipe applies elastic-perfectly plastic model. The yield strength of steel pipe is $f_y = 345 \text{ Mpa}$, elasticity modulus is $E = 2.06 \times 10^5 \text{ Mpa}$, Poisson ratio is $\nu = 0.3$. If material nonlinearity is considered, the stress-strain curve of material shall be input according to broken line, strength stage of material, when tangent modulus is $E = 2 \times 10^3 \text{ Mpa}$, is applied, classical bilinear isotropic intensity option in ANSYS program, and the yield criterion of material obeys Von Mises yield criterion and relevant flow rule.

The boundary conditions of establishing calculation model: the left boundary of major pipe is considered according to fixed end, and fixed end applies line constraint; the right boundary is considered according to slipper block; the boundary of branch pipe is free end, and the branch pipe and major both apply 3.5 times pipe diameter stretching from the root to eliminate the influence of loading condition to joint region.

After considering the joint strength of space truss, the moment is quite complex at the position of joint, which is not similar with plane structure that the bending moment of member bars are balance with each other at the position of joint, but the balance of moment can only be got finally by transferring bending moment and torque to space vector according to the space position of member bars at the position of joints. The literature [5] has analogy analysis with plane truss: if joint stiffness of joint is considered, the size of additional bending moment of joint is mainly determined by axial stiffness of branch pipe and bending stiffness of major pipe.

The loading method, which is usually applied by finite element analysis, can be divided into two types of force loading and displacement loading. It's appropriate to apply the method of force loading for having loading on space pipe joint and branch pipes, because load ratio can be easily controlled. If misconvergence is needed, it can be changed to displacement loading, whose advantage is that program misconvergence is relatively easy.

In view of researching the ultimate bearing capacity of joint under different levels of additional bending moment effect, so the loading of finite element model has to complete additional bending moment of each level, and then load the axial force of each brach pipe (this is loading method No.1). If the loading of additional bending moment of branch pipe and axial force are at the same time (this is loading method No.2), because it applies incremental method to add the load step by step in ANSYS analysis, so the axial force of additional bending moment is also increased by same incremental parameter, which cannot assure that additional bending moment can rise to pre-set level exactly at the last moment that ultimate bearing capacity is got. But the material has already entered plasticity when the joint is bearing ultimate bearing capacity, and the bearing force is related with loading sequence in plastic stage, so this paper uses loading method No.1 to get the range of ultimate bearing capacity, which is matched with the ratio between additional bending moment and axial force load, and check ultimate bearing capacity by loading method No.2.

Determination of bearing capacity. The failure mode of tubular joint can be the ultimate condition when strength reaches its bearing capacity, or it cannot continue to bear because the deformation is too big (this paper doesn't consider stability problem). Therefore, ultimate point is usually applied to be the ultimate bearing capacity on the joint that appears strength fracture, but the concept of deformation limit is applied to judge the bearing capacity of joint with deformation control, i.e. the load, when joint deformation comes to the limit to be the ultimate bearing capacity. This paper applies $3\%d$, which was presented by Lu[6], as the deformation limit. If load displacement curve has extremum and the corresponding deformation Δ_{\max} is smaller than $3\%d$, load extremum P_{\max} is the ultimate bearing capacity; on the contrary, the load $P_{3\%d}$ is the ultimate bearing capacity when the deformation is $3\%d$.

Finite element result analysis

Stress analysis. When the branch pipe is loading, intersecting line will also appears local deformation and stress concentration, and stress will decrease rapidly after departing intersection, because the intersection line of joint is complex, the difference between radial stiffness and axial stiffness is big, and the distribution of stress along major pipe's axial direction and cycle direction. The space joint will yield first at saddle point or head point, as the load is increasing, this form will forms plastic region to make stress distribution and plastic region to spread around constantly, and the joint will fail at last until outstanding local deformation exists. The stress nephogram is in figure 1. The plastic region is relatively big, because space joint is more than plane joint. The joint still have strong plastic deformation capacity from yielding to failure at last, and the failure load usually can be several times of initial yield load.

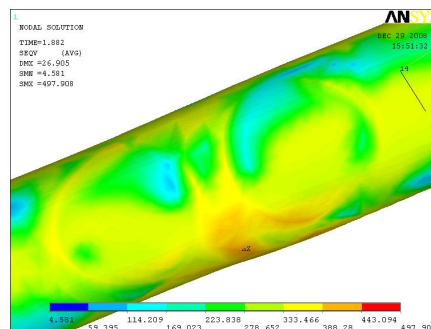
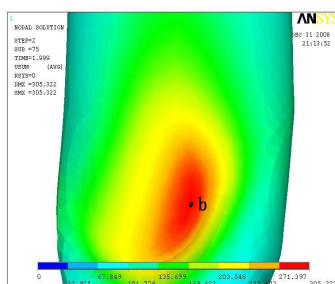
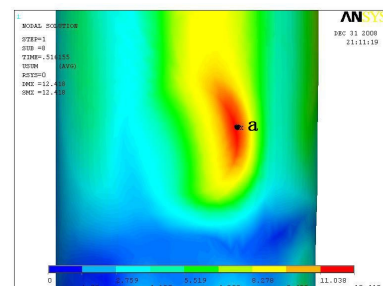


Figure1. The stress nephogram under the combined action of additional bending moment and axial force

Deformation analysis. Figure 2 is the comparison between deformation nephogram without additional bending moment. We can see that if there is not additional bending moment, the load effect will offset and the deformation is small at the location close to two branch pipes, because two branches at the same plane, one is being pulled and the other is pressed. At this moment, the maximum deformation position of major pipe's wall locates close to saddle point of intersection line and is away from a side of pulled branch pipe, which is showed in the a point of figure (a). With the enlargement of additional bending moment, the pressure of additional bending moment overlaid with the pressure of branch pipe will make the maximum deformation position of major pipe's wall to be transferred to pressed direction of bending moment effect, and moves from the position close to saddle point to the head point at the side of intersection line, which is showed in the b point of figure (b). This phenomenon indicates that the influence of additional bending moment at the maximum deformation position of major pipe's wall is more and more obvious so that additional bending moment will also produces important influence on the bearing capacity of joint. θ



(a) $M=0$



(b) $M=20\%MY$

Figure2. Comparison between deformation nephogram of major pipe's wall when the diameter of branch pipe is 500mm

The influence of additional bending moment to ultimate bearing capacity of joint. This paper analyzes the ultimate bearing capacity of joint when the major pipe's field bending moments are separately 4%、8%、12% and 16%, and at the same time, compares with the ultimate bearing capacity of joint under the situation without joint additional bending moment. Because the deformation Δ_{\max} of load extreme point is less than $3\%d_0$ when the diameter of model's branch pipe under the situation of $M=0$ and $M=0.4\%MY$, this paper applies extreme point P_{\max} of load as the ultimate bearing capacity of joint. In other situations, the load $P_{3\%d}$, when the deformation is $3\%d_0$, is selected as the ultimate bearing capacity.

We analyze the influence of additional bending moment to ultimate bearing capacity of joint through additional bending moment influence coefficient ξ of joint. Additional bending moment influence coefficient ξ is the ratio between ultimate bearing capacity of joint P_m with joint additional bending moment and ultimate bearing capacity of joint P_0 without joint additional bending moment, $\xi = P_m / P_0$. The additional bending moment influence coefficient of joint is showed in figure 4 (the M_i in the table means the yield bending moment of branch pipe). We can see that the additional bending moment has clear influence on joint bearing capacity, and the bearing capacity of the biggest joint of branch pipe also decreases 8.8% under the effect of $16\%MY$ additional bending moment. Additional bending moment influence coefficient ξ shows in exponential type curve decrease with the increase of additional bending moment M .

Conclusion and advice

This paper gets following conclusions through analyzing ultimate bearing capacity of circular steel tube's tubular joint after considering flexural rigidity:

(1). This paper indicates that ultimate bearing capacity shows in exponential type curve decrease with the increase of additional bending moment through specific finite element model analysis and comparison to different levels branch pipe's plane under additional bending moment, under the consideration of geometric nonlinearity and material nonlinearity.

(2). According to the analysis of this paper, we can see that the joint ultimate bearing capacity decreases with the increase of additional bending moment through the curve of additional bending moment influence coefficient. Therefore in the actual project, if the influence of additional bending moment to joint ultimate bearing capacity, the result is not safe or cannot reach the pre-set probability of safety.

This paper only considers four variation degrees and three pipes with different diameter, which are totally numerical models. The decrease of joint's ultimate bearing capacity reaches 27.8% in maximum in specific range of additional bending moment from the data, but there are many influence factors on ultimate bearing capacity after considering additional bending moment, so farther analysis shall be processed for its influence.

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