



NUMERICAL ANALYSIS OF SLIDING FRICTION COEFFICIENT AND THE NORMAL PRESSURE BETWEEN THE CABLE WIRE

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Abstract- In this paper, the wire pressing device is designed, the range of true positive pressure, curves of steel friction coefficient changes with positive pressure. Describe the change trend of friction coefficient is: with the increasing pressure, friction coefficient of cable parallel wire decreased significantly, but when the pressure increases to a certain value, the friction coefficient decline is slowing down, and finally tends to a certain value. The curves of friction coefficient changes with positive pressure, provides a method and basis for the practical engineering of steel wire in the ultimate friction shear stress accurately, set up and stay cable as layered slipping model provides important parameters of bending stress analysis. From the numerical simulation method analyzes the positive pressure parallel wire between the start. This paper first parallel wire contact problem of two cables are analyzed with the classical theoretical solution and the FEM software ANSYS, to verify the feasibility, using ANSYS to solve the contact problem of accuracy and precision. On this basis, the strand steel beam of contact analysis, the preliminary inquiry arching effect on cable parallel wire.

Index terms: Stay cable; positive pressure arch effect; mechanism; friction coefficient; ANSYS; contact analysis.

I. INTRODUCTION

The cable as the main load-bearing components of cable-stayed bridge, determines the cable-stayed bridge's operation. In the past 10 years, some domestic and foreign cable important cable-stayed bridge because of "sick" work and retired early, make people pay more attention to durability of the cable, although the domestic research on durability of external cable has been doing a lot of work, but there are still problems many did not get the desired solve, adversely affecting the normal operation of the cable, cable-stayed bridge in the design reference period, also hindered the healthy development of the national economy [1]. According to the engineering experience, the cable fatigue is the factors influencing the durability of the cable anchorage zone, and the bending stress concentration is the decisive factor leading to fatigue failure of the cable end. However, our country in the bending fatigue research level lags far behind the developed countries [2].

As the main load-bearing components of cable-stayed bridge, the cable on the stiffness and the economy of the whole cable-stayed bridge structure plays an important role in [3, 13]. But in recent years, our country some cable-stayed bridge in the bridge design reference period is the frequent occurrence of cable replacement phenomenon, seriously affected the normal use of in-service cable-stayed bridge, and brought a huge economic burden, highlights the importance of cable durability problems. The cable is the main load-bearing components of cable-stayed bridge; it is accompanied by the cable-stayed bridge system together with the birth, development. With the development of cable-stayed bridge, the cable-stayed bridge has been developed in the layout of a variety of ways [4, 5, 14, and 15]. Such as single cable plane, double cable plane, fan form and radiation type etc. At the same time, because of the complexity of the cable and connection, stress, cable stayed bridge external medium, so that the cable from the start there are technical problems of anchorage, fatigue, vibration, with both at home and abroad on these problems of continuous exploration, the cable will be developed.

For a long time, the cable fatigue analysis, considering only the principal stress and ignored the local bending stress of [6], however, the bending fatigue stress has important impact on the fatigue properties of the cable wire. In the recent ten years, the cable bending fatigue (stress change is caused by the direct cause of fatigue of cable, cable fatigue which by the cable local bending stress due to the change of known as the cable bending fatigue [7]) problem has attracted wide attention in the world. In this paper, the cable parallel wire applying positive pressure

utilization device designed by the authors, the positive pressure applied to actual working condition of steel cables, the true positive pressure range. Through the determination of the magnitude of the positive pressure values within this range corresponds to with clean lines, describing the wire friction coefficient with positive pressure changes: with the increasing pressure, friction coefficient of cable parallel wire decreased significantly, but when the pressure increases to a certain value, the friction coefficient decline is slowing down, and the final tends to a certain value. The change trend of friction coefficient changes with positive pressure, for practical engineering in the wire between the ultimate friction shear stress f orbital accurately provides method and basis, establish and cable for the layered slipping model provides important parameters of bending stress analysis [8].

Method through the experiment and theoretical calculation to determine the existing theories cannot shear stress accurately calculated on the limit friction between wires, so by the experiment to determine the ultimate friction shear stress is more practicable. By using the experimental method to determine the limit of determination of friction shear stress is: through the experiment, the cable under real operating conditions, scope of internal steel wire by the true positive pressure, friction coefficient threshold determination. The accurate analysis of visible to the cable in parallel wire friction coefficient and the normal pressure on the ultimate friction shear stress determination is very important. But the survey found that, so far, the accurate analysis of cable parallel wire friction coefficient and the normal pressure, some of the work can not meet the need to accurately determine the limit friction shear stress. Analysis of the work should be carried out so that the cable parallel wire friction coefficient and the normal pressure, to accurately determine the wire between the ultimate shear stress value.

II. WIRE EXTRUSION PRESSURE THEORY AND FINITE ELEMENT SIMULATION

2.1 Overview of the development of the cable technology

Parallel wire cable (PWC) consists of several parallel wire, section does not require is hexagonal, the number of the steel wire can be selected according to the requirements of stress, the physical properties and parallel wire strand consistent [9, 10, 11, 12]. For cables longer, in order to meet the transport requirements (can be wound around a drum), need to make the cable

has a twist angle; from the test that twist angle less than 4 degrees can make the elastic modulus and fatigue damage reduction, the section of regular hexagonal or missing hexagon closely arranged, the left slightly twisted 2~4 degrees, steel cable outside along the cable length direction of continuous winding dextral fine steel wire or fiber reinforced polyester belt, the outer squeeze directly with single or double polyethylene cable sleeve for protection, this is the so-called semi parallel cable (see Figure 1), the flexural performance is good, can be coiled, with long-distance transport conditions, suitable for factory machinery production, has replaced the pure parallel wire cable.

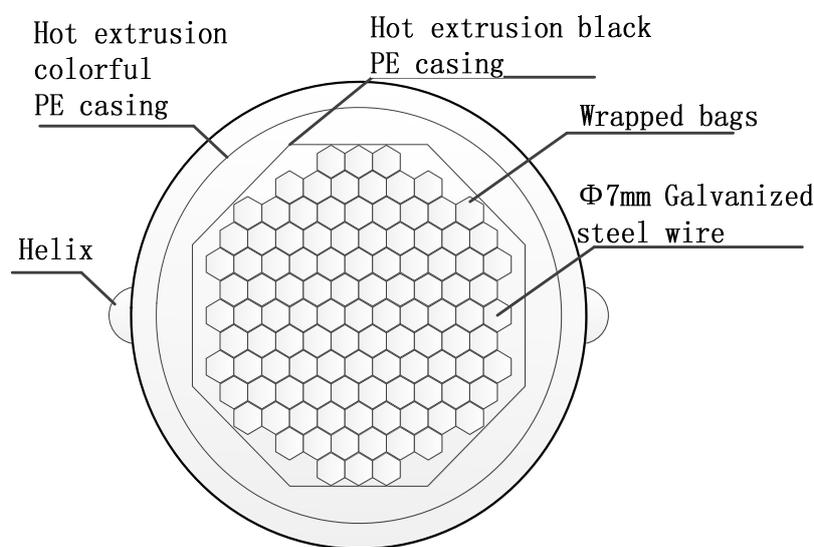


Figure 1. Parallel wire cable schematic cross section structure

2.2 Theoretical derivation wire extrusion pressure

Determination of friction coefficient of steel in light weight and small plane loads of the test, as shown in Figure 2, the uniform slow rotating tight screws to adjust steel grade, when the wire comes down to stop, the screw rotation height conversion plate lifting angle, anti friction coefficient $\mu = \tan \theta$, through adjust the pressure load on the steel tank to required for determining the wire is pulled pull value size, and then calculate the friction coefficient corresponding to different pressure.



Figure 2. Friction coefficient test under the action of gravity

The two experiment data of regression analysis, as shown in Figure 3, a trend of gradual decrease in linear regression model, but to maintain the level of the basic. The test values are worth to the size of the coefficient of friction is more reasonable for 0.2108. The experimental data accord with normal distribution.

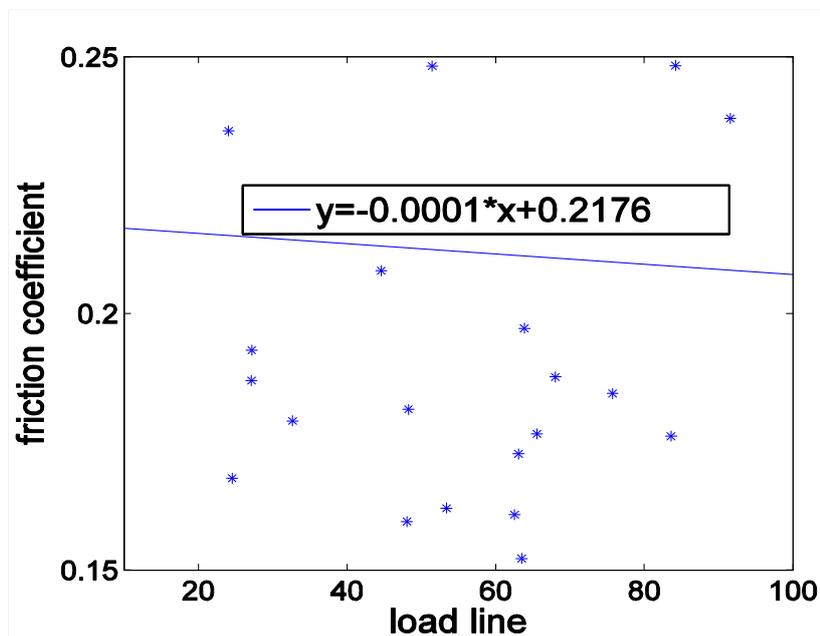


Figure 3. Different pressure of friction coefficient of steel wire measurement

2.3 The contact problem in elasticity

The cable corrosion includes corrosion cable parallel wire and anchor head rot base. According to the physical and chemical environment of the cable wire and cable force, wire corrosion can be divided into: corrosion fatigue, fretting wear candle, stress corrosion, candle and oxygen etc. The candle is the most common corrosion, stress corrosion is all corrosion types of destructive and harmfulness of a maximum. The cable wire corrosion is the main reason leading to cable bearing in reducing stress and residual service life.

According to the current level of technology, in one hundred years of bridge design reference period, cable-stayed bridge on the need for 4? 5 times for cable, seriously affect the normal use of the cable replacement costs, design costs that exceed the cable-stayed bridge, putting a heavy burden on the national economy. With the rapid development of economy, the traffic of the increasingly high demand, long span cable-stayed bridge has become an urgent need, this puts forward higher requirements for cable durability technology, and these technologies over the coverage of existing construction experience and research results, it illustrates the importance of durability problems research.

III. FINITE ELEMENT SIMULATION OF WIRE TRANSFER MECHANISM

3.1 The contact finite element analysis method

Cable stayed bridge is making specific process is: high strength steel crude material, placed in the row wire rack, towed by a traction machine, according to drawing, parallel together, after twisting machine twist, fastening, and then winding steel wire or fiber reinforced slightly twisted wire strand forming polyester belt, traction steel wire into the plastic extrusion machine, wrapped in hot extrusion of high density polyethylene, according to the design requirement of precise feeding, ends of the installation supporting cold cast pier anchor the finished cable. Cable molding, wire beam mild twist, so that each outer steel wire with spiral wound in the form of inner steel wire (referred to as "filament"), this time on the cable applied tangential, will be due to the existence of twist angle to make the internal and external layers of the wire between the extrusion stress.

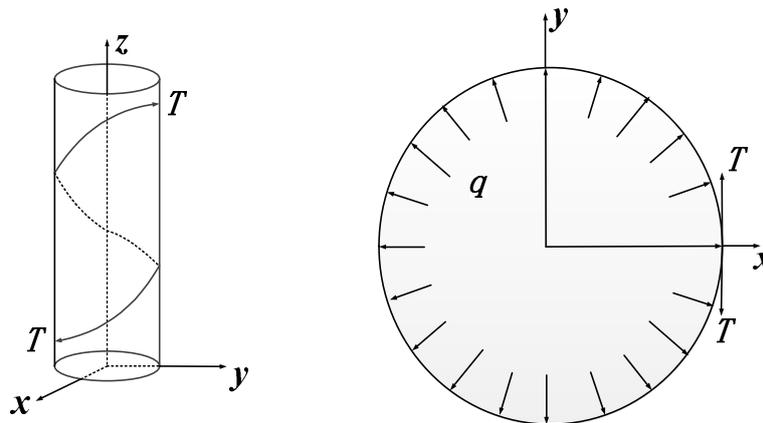


Figure 4. Spiral steel wire stress diagram

As shown in Figure 4, when the wire ends by a tangential force T , radial equivalent line between the steel wire and the cylinder pressure, set the pitch of the spiral line is L , coiling radius is r , while helix parameter equation:

$$\begin{cases} x = r \cos t \\ y = r \sin t, \quad t \in [0, 2\pi] \\ z = L \cdot t / 2\pi \end{cases} \quad (1)$$

The parameter t for the helix angle of rotation, the (1) for each type of differential:

$$\begin{cases} dx = -r \cdot \sin t dt \\ dy = r \cdot \cos t dt \\ dz = \frac{L}{2\pi} dt \end{cases} \quad (2)$$

The variable Z respectively x, y derivative, and substituted into (2):

$$\begin{cases} \frac{dz}{dx} = \frac{z'}{x'} = -\frac{L/2\pi}{r \cdot \sin t} \\ \frac{dz}{dy} = \frac{z'}{y'} = \frac{L/2\pi}{r \cdot \cos t} \end{cases} \quad (3)$$

Take half a pitch to force analysis. A tangential force T and xoy of the horizontal angle, because the equivalent wire and cylinder pressure between the directions of cylinder radial cross section, is projected onto the xoy plane stress is shown in Figure 5.

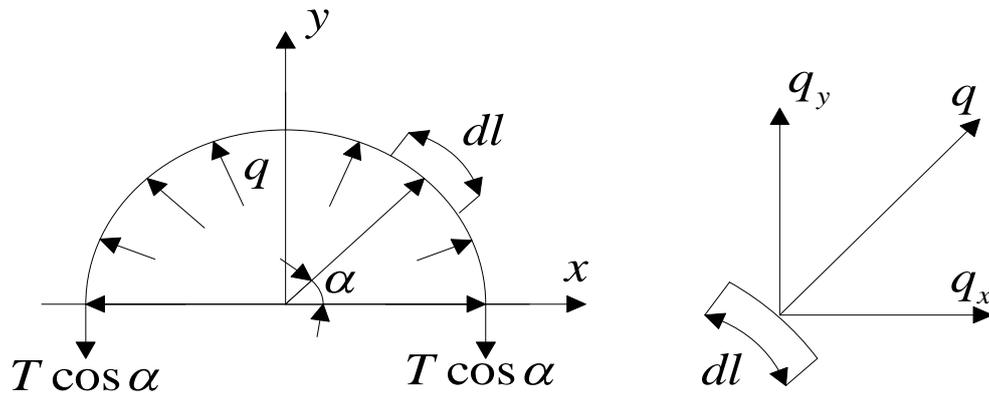


Figure 5. The xoy plane stress

Analysis of the rotation angle of the spiral line alpha dl:

$$dl = \sqrt{dx^2 + dy^2 + dz^2} = \sqrt{r^2 + \left(\frac{L}{2\pi}\right)^2} dt \quad (4)$$

Then:

$$\frac{dl}{dt} = \frac{\sqrt{4\pi^2 r^2 + L^2}}{2\pi} \quad (5)$$

The line angle:

$$\sin \alpha = \frac{L / 2\pi}{\sqrt{r^2 + (L / 2\pi)^2}} = \frac{L}{\sqrt{4\pi^2 r^2 + L^2}} \quad (6)$$

$$\cos \alpha = \frac{2\pi r}{\sqrt{4\pi^2 r^2 + L^2}} \quad (7)$$

3.2 Positive pressure finite element simulation

The initial strain element is given by the Δ/L , Δ/L (here is the unit length by node I and J position to define the difference between the length of zero strain) and L_0 (as shown in Figure 6). For cable options, negative values of strain said in a relaxed state. For breach of options, positive strain in the split state representation. Here the gap value must be as per unit length value input. ISTRN is less than 0 and KEYOPT (3) = 0, then the surface is initially slack.

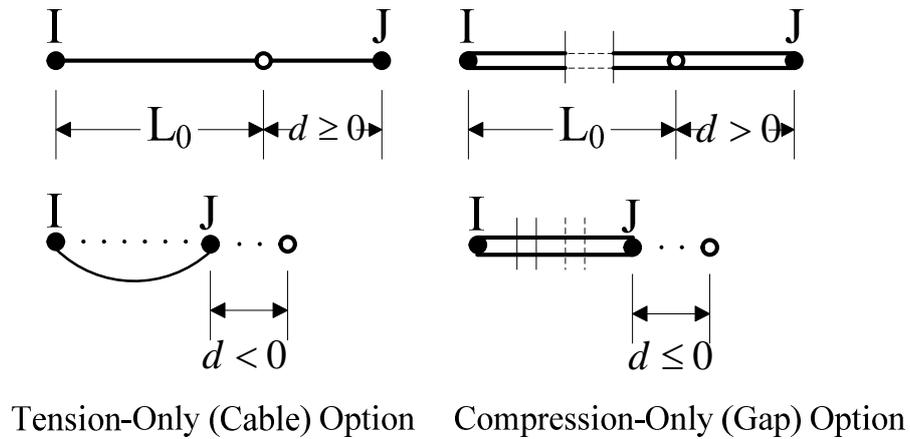
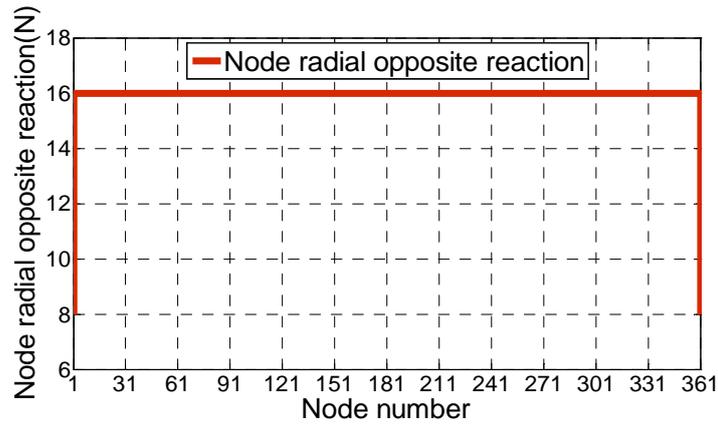


Figure 6. The initial strain element

Spiral linear modeling outer wire to realize the parameterized modeling to cycle through the variables in the model does not consider the inner ring, steel wire (wire) deformation, simulation only outer wire, steel wire radial displacement constraint to the outer ring core wire circle, two ends of tension through the initial strain, the cooling method of equivalent simulation, general post processing to extract outer steel wire the radial force, the equivalent node force conversion cost theory in the derivation of pressure load collection degree Q . The initial strain method, the cooling method are the establishment of different grid density and contrast model, in order to compare the theoretical prediction.

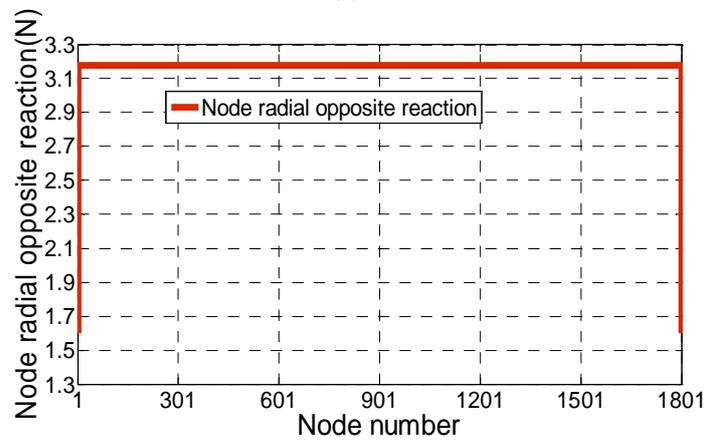
3.3 Finite element simulation of initial strain

Figure 7 respectively spiral line bisection steel beam in 360 copies (a), 1800 copies (b), 3600 copies (c) of the node radial stress, as can be seen from the graph with the helix fraction of encryption, node radial force value and helix encryption ratio inversely related to reduce, and node radial total values force to maintain the basic constant.



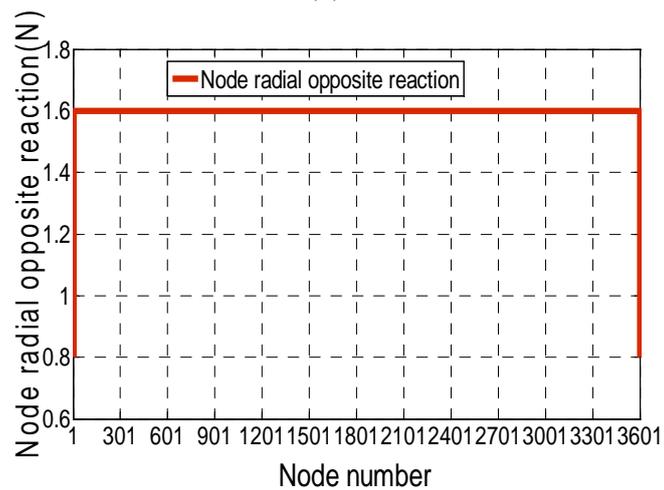
The initial strain method of Helical line 360 equal division

(a)



The initial strain method of Helical line 1800 equal division

(b)



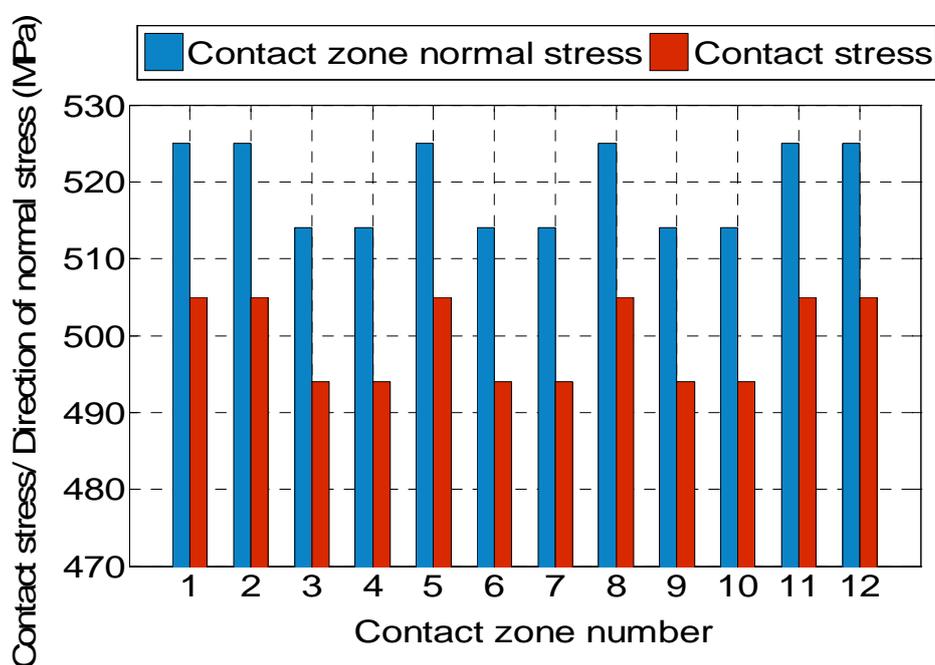
The initial strain method of Helical line 3600 equal division

(c)

Figure 7. Spiral line bisection steel beam in 360 copies (a), 1800 copies (b), 3600 copies (c) of the node radial stress

3.4 Wire transfer mechanism

Two wire classic contact finite element calculation, mainly is the contrast of contact normal stress, the third principal stress and contact stress, $1 \times 7\Phi^s$ 15.0mm strand model in the same for the three stress are compared, at the same time also includes the contact force and the equivalent line pressure to, due to classical contact stress contour shape is similar to that of the steel wires, to save space, the save lots of images, in order to form of description.



Contact zone normal stress & contact stress distribution

Figure 8. Steel strand in the equivalent line pressure under 17.619N/mm

Figure 8 can be seen, $1 \times 7-\Phi^s$ 15.0mm steel strand in the equivalent line pressure under 17.619N/mm, the ring to the contact area, the contact surface of 1 2, 5, 8, 11, 12 of the normal stress is about 525MPa, the contact stress is about 505MPa. Contact 3, 4, 6, 7, 9, 10 of the core wire core zone of contact surface normal stress is about 495MPa, the contact stress is about 515MPa.

IV. EXPERIMENTAL RESULTS

4.1 Case calculation of theoretical value

Steel strand twisting distance of 12 times the nominal diameter of 16 steel strand. This chapter selects the strand cables use more $1 \times 7 - \Phi^s 15.0\text{mm}$ cable-stayed bridge as analysis object, steel wire size allowable deviation of various parameters such as shown in Table 1.

Table 1. Steel wire size allowable deviation of various parameters

Steel Structure	Nominal Dia(mm)	Dia tolerant	Strand area(m*m)	Reference quality
1*7	9.7	+0.3	56.3	420
	10.8		73.7	157
	13	-0.2	99	168
	14.8		137	1099
	15.7		151	1179
	17.6		189	889
(1*7)C	12.8	+0.4	112	1504
	15		164	1280
	17.6		220	1760

Nominal 7 wire diameter $D_n=15.2\text{mm}$ most commonly used steel strand stayed cable section of the object of analysis in this case, based on the theoretical model, object analysis this section case as the core wire and twisted in a steel 6 wire on the periphery of the outer ring of the steel wire, neglecting the effect with the squeeze between layers of steel wire.

4.2 Establishment of the model

Figure 9 is $1 \times 7\Phi^s 15.0\text{mm}$ steel strand, the finite element contact model. In order to better control the quality of grid, the contact area set up multi-layer transition zone, and rotational symmetry segmentation by plane, grid size from the contact area to the transition zone gradually smooth transition. The outer and inner layer of wire from top to bottom in turn is divided into 1 to 12 contact zone. 1, 2, 5, 8, 11, 12, six contact zones for peripheral ring to contact area, 3, 4, 6, 7, 9, 10 as the core wire core area of contact.

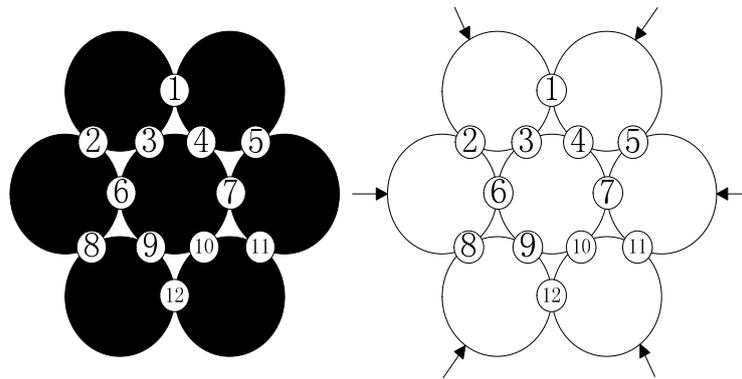


Figure 9. The finite element contact model

4.3 Finite element simulation analysis of plane finite element models

Finite element simulation of planar model using the PLAN82 element with 8 nodes is 2D, higher order elements with 4 nodes PLAN82, has higher accuracy for the hybrid grid quadrilateral and triangular, even the irregular shape. Analysis of two wire contact, adapt to the circular curve outline border wire appearance or not on the results and the precision of the. PLAN82 unit of each node has two translational degrees of freedom, can simulate the plane entity structure, but also can be used as the plane element (plane strain and plane stress), can also be used as elements.

It can be seen in Figure 10, the state of plane strain changes with the contact area of the grid density, contact relative displacement from 6 parts gradually tends to be stable, with a small oscillation, but the amplitude of the oscillation is micrometer, the relative error percentage changes with the grid density final hovering at 2.5%~3%. When the contact area is divided into 2 parts, contact displacement relative error is only 1.5%, but at the contact zone of the unit size is larger than the contact half width value, the results have some distortion.

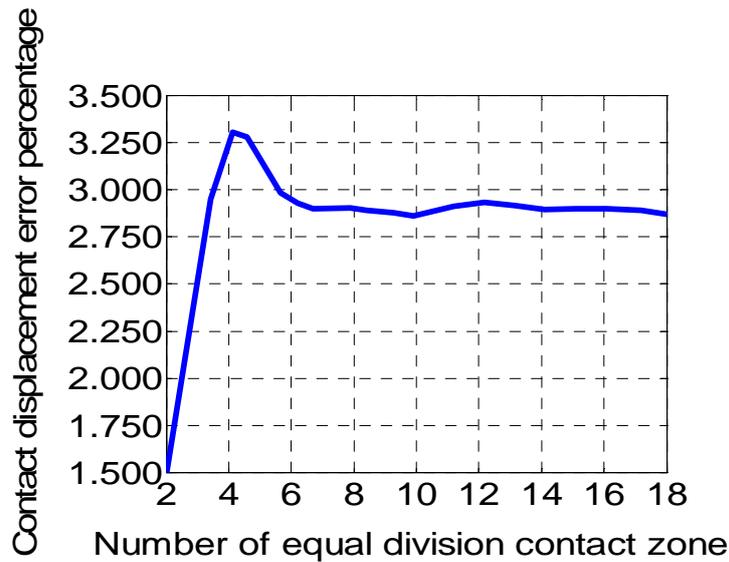
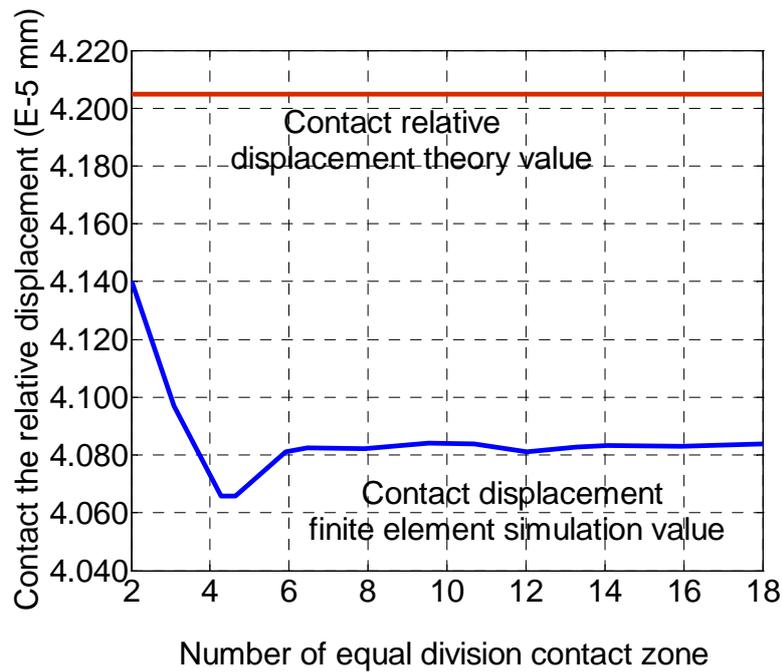


Figure 10. The state of plane strain changes with the contact area of the grid density

V. CONCLUSIONS

In this paper, the cable wire as the research object, in the research situation at home and abroad on the basis of the force on the cable, the finite element simulation software series. The plane steel wire in the end bearing cable force, under the action of internal twist, between the

outer ring wire and core wire equivalent line pressure simulation; by force unit and plane strain elements of two steel in bridge under the condition of contact stress analysis of fine contrast should be flat, determine the cable in the actual project contact lower stress; through the 2D planar grid drag and freedom of network analysis contact, sliding on cable 3D solid elements, between the mesh quality, quantity of demand in accuracy and balance; the contact wire plane unit of simulation, the ring to the contact area, core wire core contact force percentage were studied; stress by comparing the $1 \times 7\Phi^s$ 15.0mm steel and the equivalent line pressure half after the two steel classical contact, the simplified calculation model for cable 3D entity unit flexural slip.

REFERENCES

- [1] Chatterton, W.J. A green method for cable diagnostics coupled with selective cable restoration - re-use instead of replace, 2010 IEEE PES Transmission and Distribution Conference and Exposition, pp.1-4, 2010.
- [2] Vejdani-Jahromi, M.; Nagle, M.; Trahey, G.; Wolf, P., Ultrasound Shear Wave Elasticity Imaging Quantifies Coronary Perfusion Pressure Effect on Cardiac Compliance , IEEE Transactions on Medical Imaging, Volume: Issue: 99, pp.1-10, 2014.
- [3] Sun Quansheng; Yu Haiying et al., Application of Kalman's Filtering Method in Construction Control for Cable Replacement of the Cable-Stayed Bridge , 2010 International Conference on Electrical and Control Engineering (ICECE), pp.471 - 475, 2010.
- [4] Xiongwei Shi ; Wei Feng, Mechanical analysis of cable-stayed bridge with low towers and its advancement , 5th Advanced Forum on Transportation of China (AFTC 2009), 239 - 242, 2009.
- [5] Xin Li; Li Liang; Kaili Chen, Experimental study on the dynamic properties and dynamic responses of cable-stayed bridge with steel arched tower 2010 International Conference on Mechanic Automation and Control Engineering (MACE), pp.4566 - 4570, 2010.
- [6] Carstea, I. Carstea, D, An Inverse Problem for Electric Stress in Cable Terminations, 8th International Conference on Telecommunications in Modern Satellite, Cable and Broadcasting Services, pp.26-28, 2007.

- [7] Sloan, F.; Nye, R.; Liggett, T., Improving bend-over-sheave fatigue in fiber ropes, Proceedings OCEANS 2003, 1054 - 1057, 2003.
- [8] Wei Zhou et al., Testing System for the Friction Coefficient of Airstrip, 2010 International Conference on Mechanic Automation and Control Engineering (MACE), pp, 5799 - 5802, 2010.
- [9] C. Lan;W. Zhou;H. Li, Damage Propagation Monitoring and Fatigue Properties of Parallel Wire Cable, Proc. SPIE 7294, Nondestructive Characterization for Composite Materials, Aerospace Engineering, pp. 10-16, 2009.
- [10]Krut, Sebastien; Company, O.; Pierrot, F. , Force performance indexes for parallel mechanisms with actuation redundancy, especially for parallel wire-driven manipulators , 2004 IEEE/RSJ International Conference on Intelligent Robots and Systems, 2004. (IROS 2004). Proceedings, 3936 - 3941, 2004.
- [11]G. Sen Gupta, S.C. Mukhopadhyay, S. Demidenko and C.H. Messom, "Master-slave Control of a Teleoperated Anthropomorphic Robotic Arm with Gripping Force Sensing", IEEE Transactions on Instrumentation and Measurement, Vol. 55, No. 6, pp. 2136-2145, December 2006.
- [12]Daode Zhang et al., research on chips' defect extraction based on image-matching, International Journal on Smart Sensing and Intelligent Systems, vol. 7, no. 1, pp.321 – 336, 2014.
- [13]Quansheng Sun, Xiaoguang Guo, et al.,Research on the application of BP neural network in construction control for cable replacement of the cable-stayed bridge, 2010 Sixth International Conference on Natural Computation (ICNC), pp.914 - 918, 2010.
- [14]Li Xin, Liang Li, Wang Fuchun,Numerical Simulation of Vibration of Highway Cable-Stayed Bridge with Steel Arch Tower Due to Moving Vehicle Loads, Advanced Materials Research,1614-1620, 2011.
- [15]Wen, Yongkui, Sun Limin,Parametric Study on Vibration Control Scheme for Steel Tower of Large Span Cable-Stayed Bridge,Tongji Daxue Xuebao/Journal of Tongji University, vol. 34, pp.296-301, 2006.