Numerical Analysis of strengthened tubular joint of lightening rod

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Abstract: The event that some lightning rod was fractured and collapsed at the tubular joint of lightning rod occurred in some transformer substation recently. The stress concentration at the tubular joint area was the main reason which caused this failure. This paper proposed the solution to recover the collapsed lightning rod and the method to strengthen the lightning rod with normal operation. The finite analysis was conducted for recovered and strengthened lightning rod by using finite element software ABAQUS. The results indicate that the proposed solutions are practical and safe and can guarantee the normal operation of substation.

Introduction

The event that some lightning rod was fractured and collapsed at the tubular joint of lightning rod occurred in some transformer substation recently. The bottom of the lightning rod is steel tube with diameter of 330mm and thickness of 8mm（Q235B）. The supporting tube is steel tube with diameter of 480mm and thickness of 6mm（Q345B）. The elevation of the top of the lightning rod is 40m. The lightning rod described above with typical tubular joint is shown in Fig. 1. The horizontal supporting tube (Ø480×6) is connected to the lightning rod (Φ330×8). The top of the lightning rod shown in Fig.1 is connected to the upper part of the lightning rod by the flange plate. The two sides of the horizontal supporting tube are connected with the frame beams and the bottom is connected with Herringbone column. The photograph of the fractured section of the tubular joint is shown in Fig. 2. It is obvious that the failure at the tubular joint was mainly caused by the tearing of the horizontal supporting tube near the tubular joint.

The paper “Investigation of failure of tubular joint of lightening rod” analysed the reason which caused the failure of the lightning rod. This paper proposed the solution to recover the collapsed lightning rod and the method to strengthen the lightning rod with normal operation. The finite analysis was conducted for recovered and strengthened lightning rod by using finite element software ABAQUS. The results indicate that the proposed solutions are practical and safe and can guarantee the normal operation of substation.

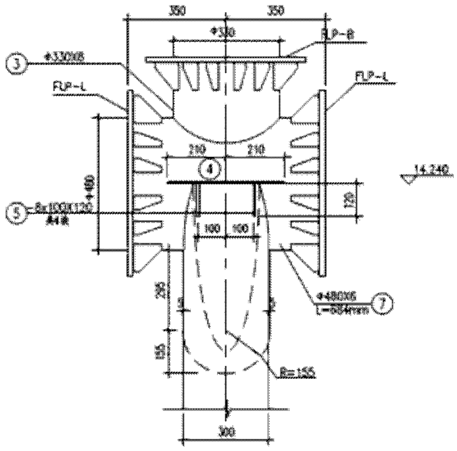

Fig.1 The structural form of the tubular joint of lightning rod

Fig. 2 The photograph showing the failure of the tubular joint of lightning rod

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Restoration and strengthening of the tubular joint of lightning rod

The structural form of the T-shaped joint of the fractured lightning rod mainly presents the problem of stress concentration, which can increase the possibility of appearance of crack at heat affected zone. The wind load also has a great influence on the fatigue failure of such tubular joints. In view of the problems above about the tubular joints of the lightning rod, this paper proposed the solution to restore the collapsed lightning rod and the method to strengthen the lightning rod with normal operation.

The principle of restoration and strengthening of the tubular joint of lightning rod is: to avoid the stress concentration of the tubular joint at the heat affected zone; the maximum stress of the control members for the restored lightning rod is no larger than the design strength and the maximum average stress is no larger than 70 percent of the design strength; the maximum stress of the control members for the strengthening lightning rod is no larger than the design strength and the maximum average stress is no larger than 70 percent of the design strength;

The stress distribution at tubular joint area of lightning rod is quite complex. The mechanical behavior of thin-wall circular shell structure under complex loading is a difficult topic even at the research area. For this project, the stability, strength and the fatigue failure are all critical questions during the design, but the current code does not give clear regulations for the design. So some structural measures are adopted at tubular joint area to avoid the stress concentration.

This paper explored the mechanical behaviour of both the recovered lightning rod model and strengthening lightning rod model by finite element analysis. The finite element software ABAQUS is used to perform the numerical analysis. The recovered model for collapsed lightning rod is shown in Fig. 3 and the strengthening model for lightening rod with normal operation is shown in Fig. 4.

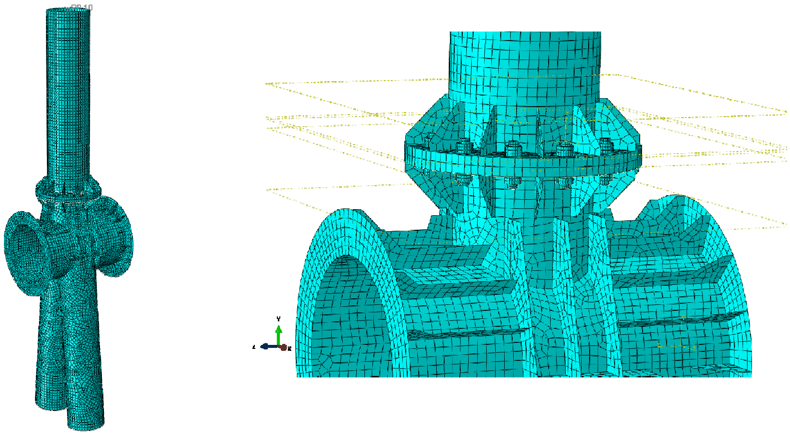

Fig. 3 Recovered model for collapsed lightning rod

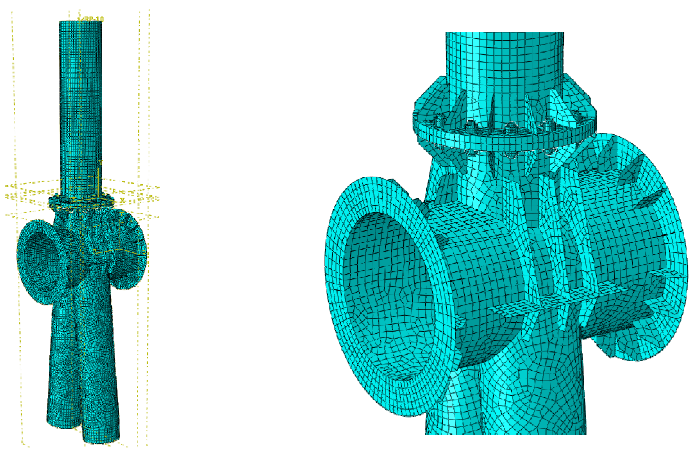

Fig. 4 The strengthening model for lightening rod with normal operation

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The ideal elastic-plastic material is used with elastic modulus of E=2.05×105MPa, Poisson's ratio of 0.3 and yield stress of 235Mpa (345Mpa for new added members). The mises yielding criterion and plastic flow rule is adopted. Herringbone column is fixed at the bottom. In order to truly reflect the actual internal force of the lightning rod, the bottom of the lightning rod is 5 times the diameter height, that is, 1.75m is modeled. A reference point is established at the top center of the lightning rod and the reference point is coupled with the top circumference of the lightning rod. The load with axial force 13.52kN, shear force 17.55kN and moment 67.24KN.m which is derived based on the load combination given in the code is imposed at this reference point. A reduced integral shell element S4R is adopted for the lightning rod, the stiffening plate and the horizontal support pipe, and solid element C3D8R for the flange plate at the bottom of the lightning rod. The element length is 16mm after grid convergentce analysis. The contact is defined between the top part and bottom part of flange plate, the screw、nut and the flange plate. The" tie" interaction is used betweem the screw and nut.

The results of finite element analysis

The stress contour of the the recovered model for the collapsed lightening rod is shown in Fig. 5~Fig. 6. The stress contour of the strengthening model for lightening rod with normal operation is shown in Fig. 7 and Fig. 8.

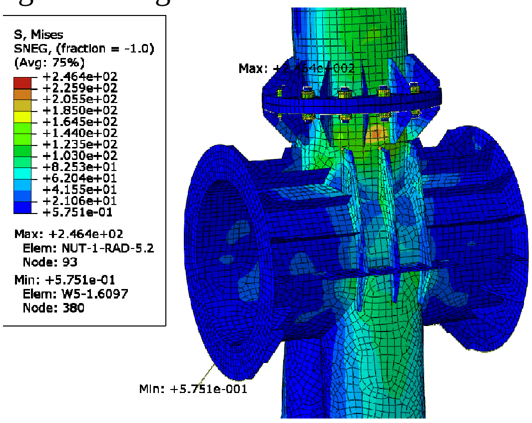

Fig. 5 Stress contour for recovered model

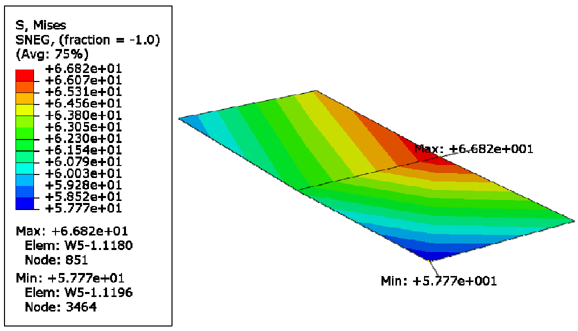

Fig. 6 The maximum stress at connecting area of lightning rod and horizontal pipe for recovered model

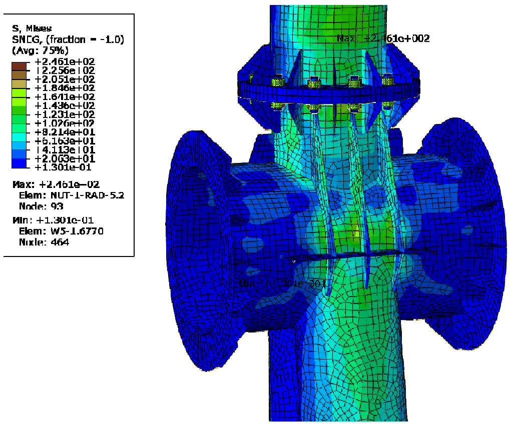

Fig. 7 Stress contour for strengthened model

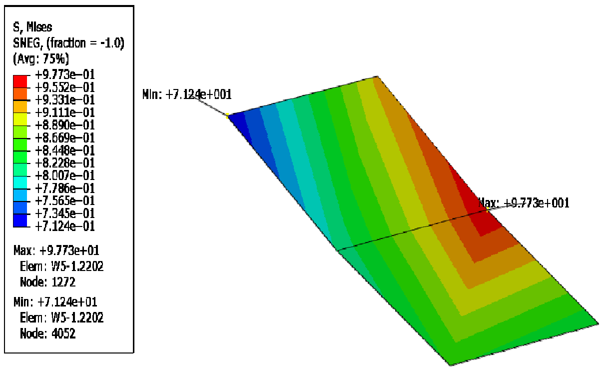

Fig. 8 The maximum stress at connecting area of lightning rod and horizontal pipe (strengthed model)

The following conclusion can be obtained based on finite element results above:

1)The phenomenon of stress concentration at the tubular connecting area between the lightning rod and the horizontal pipe is eliminated. The mechanical behaviour is improved obvious compared with original design. The maximum stress at the tubular connecting area for recovered model and strengthening model is 66.8MPa、97.7MPa which is shown in Fig. 6 and Fig. 8 respectively. The comparison of the maximum stress at the tubular connecting area for different models is shown in

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Table 1. It can be seen that the maximum stress is 2894 MPa for original model which can be found in paper “Investigation of failure of tubular joint of lightening rod”. The reduction ratio of the stress is 97.6%、96.4% respectively for recovered model and strengthened model.

2)As Figure 5 shows, the maximum stress for recovered model appears at area above the middle stiffener. The maximum stress at stiffener area is 226.1MPa<310MPa and the maximum average element stress is 150.5MPa<0.7×310=217MPa which satisfies the requirement of not exceeding the 70 percent of design strength. The maximum stress at lightning rod is 196MPa<310MPa, and the maximum average element stress is 172.2MPa<0.7×310=217MPa which satisfies the requirement of not exceeding the 70 percent of design strength.

3)As Figure 7 shows, the maximum stress for strengthened model appears at local area of one nut which does not affect the stability of the whole model. The maximum stress at horizontal pipe is 182.7MPa<215MPa, and the maximum average element stress is 145.6MPa<0.7×215=150.5MPa which satisfies the requirement of not exceeding the 70 percent of design strength.

The results of finite element analysis for recovered model and strengthened model are shown in Fig.2.

Table 1 The maximum stress at the tubular connecting area for recovered model and strengthening model

Maximum stress at tubular joint area for original lightning rod model （MPa）	Maximum stress at tubular joint area for recovered model (strengthening model) （MPa）	Reduction ration of maximum stress（%）
2894	66.8 (97.7)	97.7% (96.6%)

Table 2 The results of finite element analysis for recovered model and strengthened model

Model	Position	Stress（MPa）		Design strength （MPa）	Stress ratio
Recovered model	Lightning rod area	Maximum stress	196	310	0.63
		Maximum average element stress	172.2	310	0.55
	Horizontal supporting pipe	Maximum stress	66.8	310	0.22
		Maximum average element stress	65	310	0.21
Strengthened model	Lightning rod area	Maximum stress	185.4	215	0.80
		Maximum average element stress	144.9	215	0.67
	Horizontal supporting pipe	Maximum stress	182.7	215	0.85
		Maximum average element stress	145.6	215	0.67

Conclusion

The lightning rod is generally placed in the top of the frame, which is the highest in the substation, and the structural safety of the substation is related to the safety of the personnel and the large range of electrical equipment. The structure of the lightning rod is a static cantilever structure with no redundancy. Any structure will inevitably have some local imperfection which may cause the accident of lightning rod and ground wire column. According to the structural characteristics of the collapsed lightning rod, the failure is fatigue failure at root of lightning rod under cyclic wind load, and the development of the crack is also a long period. The stiffness of the tubular joint reduces and the deformation increases with the development of crack.

The results of finite element for both recovered model and strengthened model for lightning rod indicated the proposed solution are practical and safe and can guarantee the normal operation of substation.

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