An Innovative Graphite Sliding Bearing for Substation Structures

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Abstract: In this study, an innovative graphite sliding bearing for substation structures was proposed. The proposed sliding bearing was used to release the thermal expansion in the extra long substation structures. The main parts of the sliding bearing are two ball spherical bearings with corresponding sliding plate. The sliding occurs between graphite plate and stainless steel plate. Experimental investigation was conducted to study the behaviour of proposed sliding bearing. It is shown that the proposed sliding bearing could effectively slide under the load from two other directions. The relationship of horizontal resistant force to vertical load was obtained. The use of sliding bearing in the substation structures was studied using numerical method. A finite element model was developed to simulate the 1000 kV substation structures. It is shown that the thermal expansion could be effectively released by using the proposed sliding bearing so that the extra frame could be eliminated.

Keywords: Experimental investigation, finite element model, graphite sliding bearing, substation structures, thermal expansion

INTRODUCTION

With the development of the economy and society, the requirement of the electricity is increasing. High voltage, large capacity and long distance are development direction of the transmission system and has been paid more and more attention (McClure and Tinawi, 1987; Charles and Barron, 2004; Liao and Zhang, 2005). 1000 kV transmission line are to be increasingly built in China. Substation trusses are almost all steel structures in alternating and direct current engineering in the grade of or higher than 500 kV (CSCEPDI, 2006). The steel tubular truss-column in the shape of A has been widely used widely used in 500 kV transmission line (Brian, 2003; Fan and Wu, 2000). However, the attice steel structures are used in 1000 kV transmission due to the large electronic equipment, as shown in Fig. 1. In addition, the length of each frame also increases and is more than 50 m for 1000 kV transmission line structures. For example, the length of each frame of ZheBei substation structures is 54 m and the total length of 8 frames are 416 m. The thermal expansion effect can not be neglected in such long span structures and extra frames are used to release the thermal expansion effect which results in extra cost and land occupancy.

Sliding bearing was widely used in bridge engineering (Ramberger, 2002; Roeder et al., 1995). Bridge bearings are used to transfer the bearing reaction from the superstructure to the substructure thereby meeting the design requirements concerning forces, displacements and rotations. A central requirement to its functioning is their low rotation and deformation resistance, which ensures that no additional constraint forces will be introduced in the superstructure (Olaf and Halim, 2007). In this study, the concept of sliding bearing was used in 1000 kV substation structures to release the thermal expansion effect. Different from the bridge, the sliding bearing used in the substation structures are not covered and the durability must be considered.

METHODOLOGY

Proposed sliding bearing: The proposed sliding bearing substation structures is used to connect the steel truss beam and lattice column. The truss beam has four main pipes. The cross-section of truss beam with proposed sliding bearing at each main pipe is shown Fig. 2. The supporting plates were connected to the lattice columns. The beam truss carry vertical load (x direction) from the electronic equipment and horizontal pulling force (y direction) from the electronic cable. The thermal expansion occurs in the z direction. Therefore, the bearing should be able to slide in z direction under the load from x and y directions.

The ball spherical bearing and the graphite sliding plate are the most important part of the proposed sliding bearing. The design life of 1000 kV substation structures is about 50 year, which is much longer than the life of polytetrafluoroethylene (PTFE) commonly used in the bridge. In addition, the sliding bearing used in substation structures is not covered and tend to deteriorate. Therefore, an alternative material should be used. In this...
The compressive strength of graphite plate is larger than 20 MPa. With sufficient area the graphite could bear the load. However, non-uniform stress distribution will cause the graphite crack. Therefore, spherical bearing is used to prevent the crack of graphite plate, as shown in Fig. 3. Experimental investigation on bearing without spherical bearing indicates that the graphite plate will crack. With the spherical bearing, the graphite plate could always be parallel to the corresponding stainless steel plate with the end of the truss beams rotating in bending. The experimental result also indicates that no crack occurs with the spherical bearing.
Experimental investigation:

General: To investigate the practicality of proposed sliding bearing, experimental investigation was conducted. Both plate test and bearing test were conducted. The resistant force between graphite plate and stainless plate under different loading was obtained from the plate test. The bearing test was conduct to investigate the sliding behavior of the bearing under combined x and y direction load. Since there are four sliding bears at each ends of the truss beam, each bearing was supposed to carry 1/8 of the loads applied on the beam.

Plate test: The vertical load was applied using a 5000 kN compression machine, as shown in Fig. 4. The horizontal force was applied using an oil lifting jacks under the control of a hydraulic console. The horizontal force was measured using an force sensor with a digital display. Displacement was measured using a dial indicator. The applied vertical load was 50, 100, 150, 200 and 250 kN. With the design shape of the bearing, the compression load $T_1$ was decomposing into two loads $T_2$ and $T_3$, as shown in Fig. 7. Displacement was also measured using a dial indicator. The maximum horizontal resistant force ($F$) versus compression load ($P$) was summarized in Table 1. In calculating the horizontal resistant force presented in Table 1, the horizontal resistant force of the top plate is subtracted sine in the really structures there is only two sliding faces correspond to force vectors $T_2$ and $T_3$. The coefficient $\beta$ is defined as $\beta = F/P$ and the average value is 0.77 as shown in Table 1.

Finite element analysis of substation structures:

Finite element model: The 1000 kV substation structures was modeled using finite element program ABAQUS to analysis the effect of sling bearing, as shown in Fig. 8. The truss in the columns and beams was simulated using frame element. The element are 2-node, initially straight, slender beam elements intended for use in the elastic or elastic-plastic analysis of frame-like structures. A frame element's elastic response is governed by Euler-Bernoulli beam theory with fourth-order interpolations for the transverse displacement field; hence, the element's kinematics include the exact (Euler-Bernoulli) solution to concentrated end forces and moments and constant distributed loads. The elements can be used to solve a wide variety of civil engineering design applications, such as truss structures, bridges, internal frame structures of buildings, off-shore platforms and jackets, etc. (ABAQUS, 2004)

For frame elements the geometric and material properties are specified together using the *FRAME SECTION option. The elastic modulus for all steel are taken as 200GPa. The yield stress for steel grade Q235 and Q345 were taken as 235 and 345 MPa, respectively. Since the thermal expansion was investigated in this study, the temperatures expansion coefficient ($1.1\times10^{-5}$) and initial temperature (20ºC) were also defined. The sliding bearing was modeled as spring element in beams. The applied vertical load was 50, 100, 150, 200 and 250 kN. With the design shape of the bearing, the compression load $T_1$ was decomposing into two loads $T_2$ and $T_3$, as shown in Fig. 7. Displacement was also measured using a dial indicator. The maximum horizontal resistant force ($F$) versus compression load ($P$) was summarized in Table 1. In calculating the horizontal resistant force presented in Table 1, the horizontal resistant force of the top plate is subtracted sine in the really structures there is only two sliding faces correspond to force vectors $T_2$ and $T_3$. The coefficient $\beta$ is defined as $\beta = F/P$ and the average value is 0.77 as shown in Table 1.

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Table 3: Finite element analysis results of 8 frames substation structure

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<tr>
<th></th>
<th>Maximum load (kN)</th>
<th>Maximum displacement (mm)</th>
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<tbody>
<tr>
<td></td>
<td>Compressive force</td>
<td>Tensile force</td>
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<tr>
<td>Without sliding bearing</td>
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<td></td>
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<tr>
<td>With thermal expansion</td>
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<td>2933</td>
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<tr>
<td>Without thermal expansion</td>
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<tr>
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<td>Without thermal expansion</td>
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Table 4: Finite element analysis results of substation structures with different frames

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<tr>
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<td>Frames 3</td>
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</table>

CONCLUSION

In this study, an innovative graphite sliding bearing for 1000 kV substation structures was proposed to release the thermal expansion effect. The sliding bearing is composed of two ball spherical bearings with corresponding stainless steel sliding plate. The graphite plate was used for the consideration of durability. Experimental investigation indicates that the proposed bearing could slide under compression load up to 250 kN. Relationship between the horizontal resistant force versus compression load was obtained. It is shown that the horizontal resistant force keeps a constant value after the initial increase with the increase of displacement. Numerical investigation was carried out for 1000 kV substation structures using finite element program ABAQUS. It is shown that thermal expansion effect could not be neglected for 8 frame substation structures. Design requirement for both the load and displacement are unsatisfied. It is also shown that the 8 frame substation structure could meet the design requirement with the use of proposed sliding bearing. The analysis indicates that the sliding bearing should be used for substations having more than 4 frames.

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