JOINT SLIPPAGE EFFECTS ON MECHANICAL BEHAVIOR OF A NEW ANTI-ICING TOWER

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Abstract: Joint slippage is the relative displacement of bolted joint under shear load, which are greater in lattice transmission tower as relatively low clamping force are used. It is well known that conventional structural analysis based on idealized joint behavior cannot match the full-scale tower tests very well. In this paper, several numerical models of a new single-circuit 220kV anti-icing tower are created to investigate the effects of joint slippage on tower deformation, inner forces and ultimate load. Experimental results available from full-scale prototype tests are also presented in the comparison and show that the real deformation of the tower can be almost three times as large as that obtained from numerical models with idealized joint behavior, the most of joint slippage effects are contributed by main leg slippage when the tower subject to flexural load, and joint slippage will obviously influence the inner force of lattice tower especially on tower head and leg. Results from the pushover nonlinear static analysis considering both joint slippage effects and eccentricity shows that joint slippage will lead to main leg premature failure and the ultimate load of anti-icing tower will greatly overestimate if joint slippage effects are not included.[1]

1. INTRODUCTION

Joint slippage is the relative displacement of jointed members that occurs when the connection is subjected to a shear load. For lattice transmission tower, greater slippage is likely to occur as the bolt diameters are small and the members joined are thin, which make these lattice transmission towers difficult to be analyzed with accuracy using classical linear methods. In this paper several numerical models of a new 220kV anti-icing tower with considering member shape and its spatial orientation, joint eccentricities and stiffness are presented. The influence of joint slippage on displacements, inner forces and ultimate load are discussed by comparing these numerical results with the experimental results available form prototype testing.

2. RESULTS AND DISCUSSION

As shown in Fig.2, numerical model without considering joint slippage effects (model I) is found grossly inadequate to predict the tower deflections. However, model III in which the joint slippage effects model on both diagonal members and main legs are considered yields very accurate results.

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Fig.3 shows that the discrepancy between model I and model III is clear especially on tower head and leg. In certain member axial load increased over than 10% squashed load due to joint slippage effects which may cause premature failure of anti-icing tower.

Fig.4 shows the load factor vs. longitudinal displacement curves. It is seen that model III yields much better response than model I represented by the experimental load-displacement results. In this load case, the tower bending capacity is influenced by joint slippage effects which reduced the ultimate load by about 15% compared with model I.

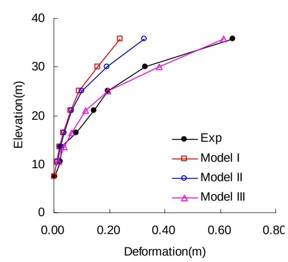

Figure 2 Displacement Results

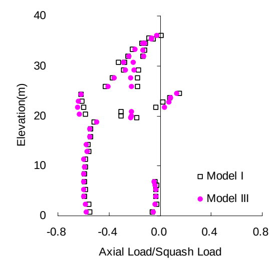

Figure 3 Axial Load Results

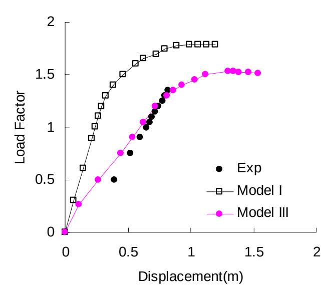

Figure 4 Load-Displacement Curves

3. CONCLUSION

The measured deflections might be as large as three times the deflections obtain from numerical model with ideal joint behaviour witch will dramatically over estimate the stiffness of lattice tower. When lattice tower suffering from flexural load joint slippage effect will dominated by main leg slippage; Joint slippage will influence the member forces especially on tower head and tower leg; Joint slippage effects will reduce the ultimate load-bearing capacity especially when lattice tower subject to heavy icing load.

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Abstract: Joint slippage is the relative displacement of bolted joint under shear load, which are greater in lattice transmission tower as relatively low clamping force are used. It is well known that conventional structural analysis based on idealized joint behavior cannot match the full-scale tower tests very well. In this paper, several numerical models of a new single-circuit 220kV anti-icing tower are created to investigate the effects of joint slippage on tower deformation, inner forces and ultimate load. Experimental results available from full-scale prototype tests are also presented in the comparison and show that the real deformation of the tower can be almost three times as large as that obtained from numerical models with idealized joint behavior, the most of joint slippage effects are contributed by main leg slippage when the tower subject to flexural load, and joint slippage will obviously influence the inner force of lattice tower especially on tower head and leg. Results from the pushover nonlinear static analysis considering both joint slippage effects and eccentricity shows that joint slippage will lead to main leg premature failure and the ultimate load of anti-icing tower will greatly overestimate if joint slippage effects are not included.

Keywords: Anti-icing Tower; Joint Slippage; Second Order effects;Inner force; ultimate load;

I. INTRODUCTION

In bolted steel construction, there are two main types of connections, depending on the load transfer mechanism: bearing type and friction type. For bearing type the load is transferred through direct bearing of the fasteners on the joining members while for friction type the load is transferred through friction between the adjoining members subjected to clamping force. The essential difference between the two types of connections is that the friction type requires that bolt be tightened to a predetermined value of pretension force which will ensure that slip in the joint will not occur at service load. However, in bearing type connections, the bolts are relatively small and slip at service load is not critical. Classical lattice towers are self-supported and constructed of angle section (L-shape) members typically bearing type connections are preferred for lattice transmission towers as their field erection is much easier.

Joint slippage is the relative displacement of jointed members that occurs when the connection is subjected to a shear load. The amount of slippage depends on the relative position of the bolts within the holes which are oversized in order to provide a construction tolerance. For lattice transmission tower, greater slippage is likely to occur as the bolt diameters are small and the members joined are thin, which make these lattice transmission towers difficult to be analyzed with accuracy using classical linear methods. Most of the latticed towers presently in service around the world were designed using traditional stress calculations obtained from linear elastic ideal truss analysis, whereby members were assumed to be concentrically loaded and pin-connected.

Tower designers have long recognized that the results of those ideal truss analysis models cannot match full-scale test results very well. Peterson [1] and Marjerrison [2] reported that during full-scale transmission lattice tower tests the analysis results would grossly underestimate the measured deflections, which might be as large as three times the theoretical linear elastic deflections. Similar observations have been reported by Kravitz and Samuelson [3] and later by Al-Bermani and Kitipornchai [4].

Lee and McClure [5-6] derived an L-Section beam finite element and successfully predicted the response and ultimate capacity of lattice towers with consideration of loading eccentricities and bounding conditions as well as material and geometrical nonlinearities. Similar advanced modeling studies were completed by Al-Bermani and Kitipornchai [7-8]. However the tower deformations predicted by these numerical models still did not agree with test results and the discrepancy was attributed to joint slippage effects.

In order to consider the influence of joint slippage in lattice tower analysis, Ungkurapinan and his collaborators [9-10] carried out an experimental study to derive more accurate joint slippage models. They conducted experiments on angle shapes bolted joints and developed mathematical expressions models to describe slip and load-deformation behavior. This experimental bolted joint slippage behavior was incorporated into a non-linear joint finite element and applied to study the behavior of transmission tower by Ahmed [11].

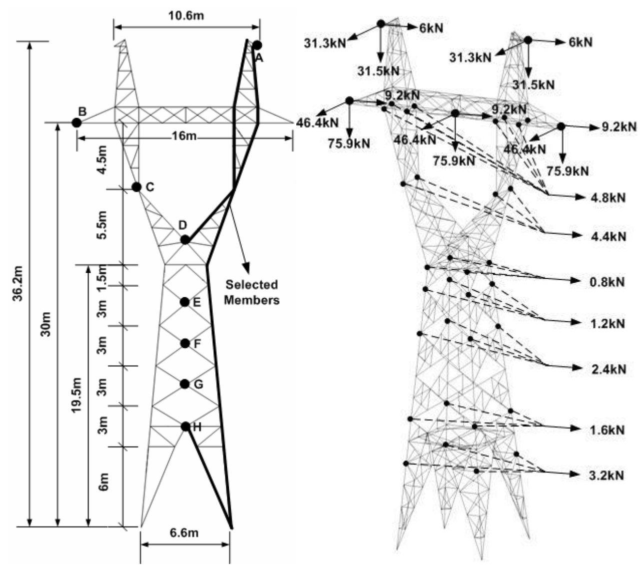
In this paper several numerical models of a new 220kV anti-icing tower with considering member shape and its spatial orientation, joint eccentricities and stiffness are presented. The influence of joint slippage on displacements, inner forces and ultimate load are discussed by comparing these numerical results with the experimental results available form prototype testing.

II. NUMERICAL MODEL

Fig.1 shows the outline of a new 30-m tall 220 kV anti-icing suspension tower which is used in areas exposed to atmospheric icing. The bending capacity when the tower is subjected to unbalanced conductor loads on the adjunct span with glaze ice accretion equivalent to 30-mm radial thickness was tested. The load (see Fig.1b) was gradually increased until tower collapse, and the corresponding deflections of points A, B, C, D, E, F, G and H (identified on Fig. 1a) were recorded after each load level.

In the numerical model, the individual members are represented by angle shapes with proper spatial orientation and eccentricities in accordance with the prototype design detailed drawings, the detail joint modeling method can be found in our previous research [12].

In order to research the influence of joint slippage three numerical models are presented. 1) Model I: without considering of joint slippage; 2) Model II: Joint slippage effects on diagonal members are considered; 3) Model III: Joint slippage effects on both diagonal members and main legs are considered.



(a) 2D Outline (b) 3D Outline

Figure 1 220kV Anti-icing Tower Outline

III. RESULTS AND DISCUSSION

The anti-icing tower subject to flexural load was analyzed. The numerical and experimental results of displacements, inner forces and load-displacement are summarized and shown in Fig.2, Fig.3 and Fig.4.

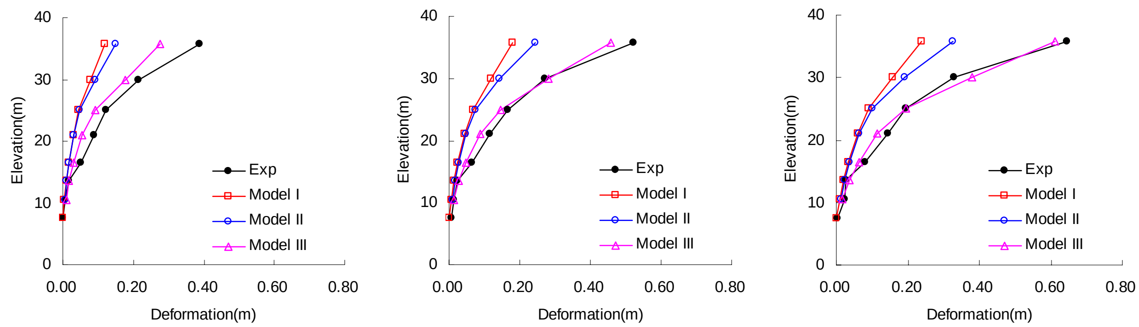
3.1 Displacement results and discussion

Fig.2 shows the displacement results at 50%, 75% and 100% design load, only the longitudinal direction results are reported as the transverse displacements are much smaller.

As shown in Fig.2, model I is found grossly inadequate to predict the tower deflections: the experimental result at point A is 3.30 times model I result at 50% load, 2.93 times at 75% load and 2.70 at 100% load. However, model III in which the joint slippage effects model on both diagonal members and main legs are considered yields very accurate results.

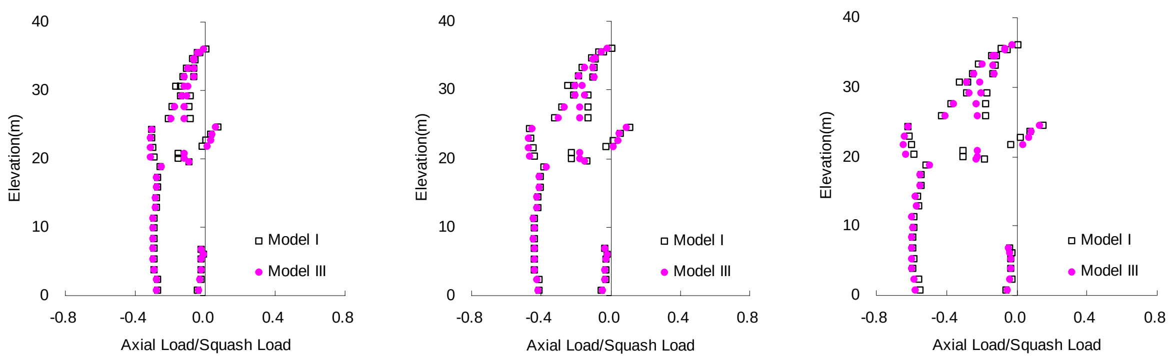
Fig.2a shows that numerical model without considering joint slippage effects (model I) yields almost the same results as numerical model with considering diagonal member slippage effects (model II), and these two analyses are not in agreement with model III very well. This indicates that most of the joint slippage effects are contributed by slippage in main leg lap-splice connections for flexural load, while slippage effects on diagonal members are negligible. This is confirmed by the results in Fig.2b to Fig.2c where the agreement between Model III and the experimental results is clear.

Those displacement results in Fig.2 clearly indicate the inability of numerical model without joint slippage (model I) to predict tower deflections and the good agreement of numerical predictions accounting for joint-slippage effects with the measured tower deformation, especially at higher load levels.



(a)50% (b)75% (d)100%

Figure 2 Longitudinal Displacement Results



(a)50% (b)75% (d)100%

Figure 3 Axial Load Results of Selected Members

3.2 Inner force results and discussion

Fig.3 shows the inner forces results of main leg members (identified on Fig.1a) at 50%, 75% and 100% design load, only the axial forces are presented as axial loads are dominated in members.

Fig.3a shows that when the load is relative small, model I and model III agree with each other. However, as the load is increased this agreement is progressively lost as shown in Fig.3b and Fig.3c. As we can see in Fig.3c, the discrepancy between model I and model III is clear especially on tower head and leg. In certain member axial load increased over than 10% squashed load due to joint slippage effects which may cause premature failure of anti-icing tower.

3.3 Ultimate load and discussion

Fig.4 shows the load factor vs. longitudinal displacement curves of point A (identified on Fig.1a). It is seen that the numerical model including joint slippage effects on both diagonal and main leg members (model III) yields much better response than numerical model with ideal joint (model I) represented by the experimental load-displacement results. As indicated in Fig.4, model I is unsafe as it overestimates the ultimate capacity by nearly 28% compared with experimental results, while model III with joint slippage effects overestimate the capacity by 9%. In this load case, the tower bending capacity is influenced by joint slippage effects which reduced the ultimate load by about 15% compared with model I.

As observed above when large vertical and transverse load are applied on the tower head, large deflections of the loading points will cause important second order effects (global P-Delta effects) which cause further bending in the legs thus reducing the ultimate load-bearing capacity of tower.

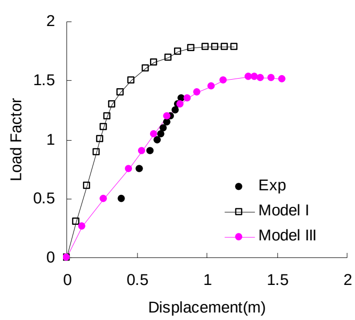


Figure 4 Load-Displacement Curves (Point A)

IV. CONCLUSION

Accurate prediction of the ultimate load capacity of lattice transmission towers is very important for the safety of transmission lines. The traditional structural analysis models which ignore joint slippage effects are inaccurate in predicting the global response of lattice towers. In this paper several models were presented and the numerical predictions were compared with experimental results. The main conclusions of the study are as follows:

1) The measured deflections might be as large as three times the deflections obtain from numerical model with ideal joint behavior witch will dramatically over estimate the stiffness of lattice tower. However, numerical models that incorporate joint slippage effects both on the diagonal members and the main leg splice connections can predict the tower displacements with reasonable engineering accuracy. When lattice tower suffering from flexural load joint slippage effect will dominated by main leg slippage;

2) Joint slippage will influence the member forces especially on tower head and tower leg which may cause the premature failure of lattice transmission tower.

3) Joint slippage effects will reduce the ultimate load-bearing capacity especially when lattice tower subject to heavy icing load. Accurate failure analysis with consideration of both joint slippage and eccentricity effects has been demonstrated in this paper.

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