EVALUATION OF VARIABLE STIFFNESS OF WIND TURBINE TOWER WITH CONSIDERATION OF FLANGE JOINT SEPARATION

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1. INTRODUCTION

Development of clean renewable energies is necessary due to the global warming. Among them, because the development of wind power has been noticed, the number of wind turbines has been increasing. Since characteristic weather conditions and terrain conditions in Japan cause great damage to wind turbines, design guidelines (Japan Society of Civil Engineers 2007, 2010) were published. In the GL Wind 2003 (Europe), the maximum wind speed verifying the fatigue strength of high-strength bolts of wind turbines is set to 0.7 time of the design wind speed and the frequency of appearance of high wind speed is extremely low. Fatigue damages due to high wind speed can be ignored. On the other hand, the frequency of appearance of high wind speed in Japan is much higher. It is very important to understand the responses of wind turbines and the fatigue behaviors throughout the operation periods. The loading conditions of tower's joints during high wind speed have not been clarified yet. So it is necessary to evaluate the fatigue strength in a strong wind condition up to the design wind speed and the response of wind turbine tower with the consideration of joint separation for establishing the design methods. In the study, we evaluate it in two steps. Firstly, a model of a tower which uses high-strength bolts at flange joints is created and FEM analyses are performed. Then, stiffness of the flange joint is determined in order to model variable stiffness of the flange joints with considering the whole wind turbine tower.

2. MODELING OF FLANGE JOINT

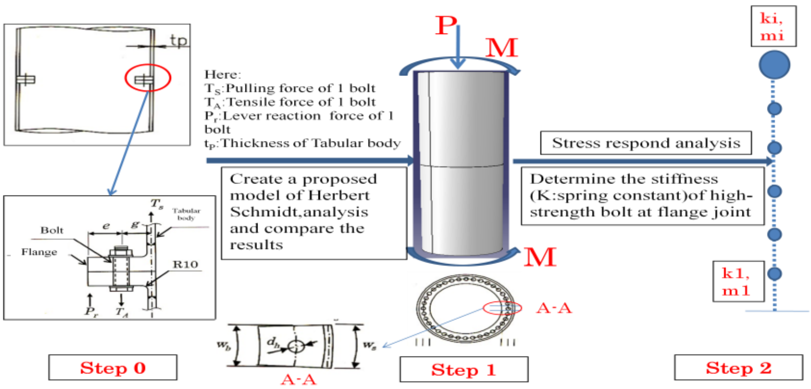

Fig.1 The flowchart of the research

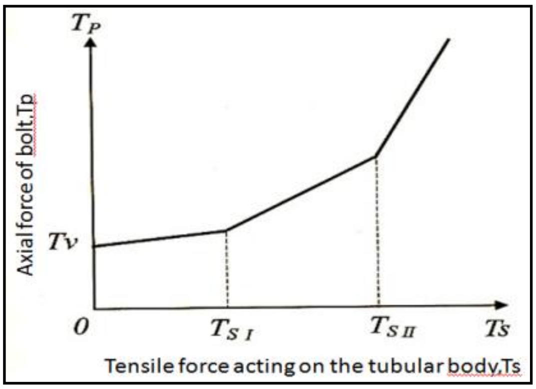

Fig.2 The relation between Tp and Ts

2.1 Step0

Firstly we examine the work of one bolt with consideration of L- flange joint separation. We create a proposed model of Herbert Schmidt (Fig.1 at step 0).By using FEM method we analysis and compare with the Herbert Schmidt's result to verify the correctness and reliability of research method. As Schimid-Neuper's evaluation formula ,we can calculate the axial force of one bolt during operation period. From the FEM analysis result we can verify and compare between calculated results using the formula and analytical results from which to draw conclusions about the reliability of the results(Fig.2)

$$T_p = \begin{cases} T_v + pT_s & T_s \le T_{sI} \\ T_v + pT_{sI} + (\lambda T_{sII} - T_v - pT_{sI})\dfrac{T_s - T_{sI}}{T_{sII} - T_{sI}} & T_{sI} < T_s < T_{sII} \\ \lambda T_s & T_{sII} < T_s \end{cases}$$

$$T_s = T_v \times \frac{(e - 0.5g)}{e + g}\ ;\ T_{sII} = \frac{T_v}{\lambda \times q}\ ;\ T_v = N_0 = 0.75 \times \sigma_y \times A_e\ ;\ q = 1 - p\ ;\ p = \frac{C_b}{C_b + C_c}\ ;\ \lambda = (1 + \frac{g}{0.7e})$$

Here:
T_p: Axial force of bolt ; T_s: Tensile force acting on the tubular body at one respective bolt
N_0: Design bolt tension ; T_v: Initial tension of bolt ; e: Distance between the end of flange bolt and center of bolt
g: Distance between center of plate of tubular body and center of bolt ; C_b: Tensile spring constant of bolt
C_c: Compressive spring constant; p: The ratio of forces inside and outside ; λ: Compensated leverage ratio
σ_y: Yield strength of bolt; A_e: effective cross-sectional area of screw

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2.2 Step1

In Step1 we will examine the response of all the bolts at one flange-joint of wind turbine tower. Using FEM software to model a part of wind turbine which has flange joint with high-strength bolts(Fig.1 at step 1),analysis and evaluate the result of response at each bolt. Besides that from the result we understand that the stiffness of the flange joint has been reduced at the time when the flange joint separated.

2.3 Step2

From the analytical results we can calculate the stiffness at each flange joint in whole wind turbine tower. Understanding the stiffness of each part in whole tower that allowed to model the whole tower like Fig.1 at step 3 simply. Analyzing this model and compare with the analytical results of the tower without investigating the effects flange joint.

3. RESULTS AND DISCUSSION

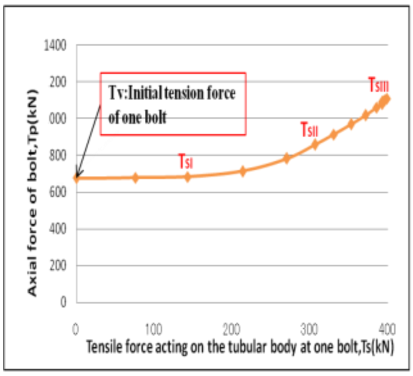

Fig.3 The relation between Ts&Tp

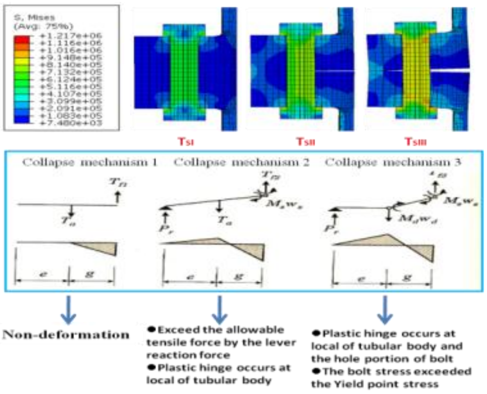

Fig.4 The stress bolt at each collapse mechanism

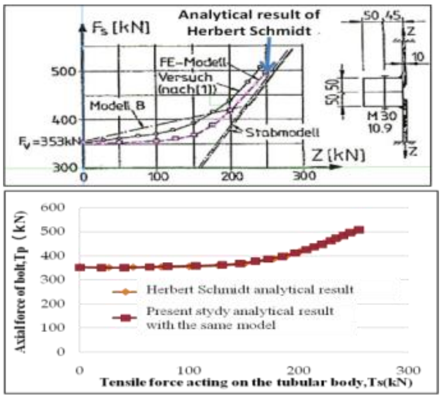

Fig.5 Compare the result between present study and Herbert Schimidt research

The relation between tensile force acting on tubular body at one bolt (Ts) and axial force of bolt (Tp)has been shown in Fig.3.From this we see that the result has been calculated by Peterson's evaluation formula and this study result are almost the same shape. Next, the bolt stress have been shown in Fig.4 corresponding to each collapse mechanism (1,2,3).In (1) non-deformation. In (2) because of leverage reaction force (Pr), tensile force in bolt exceeded allowable tensile force, plastic hinge occurs at local of tubular body, the flange joint begin separating. In (3) plastic hinge occurs at local tubular body and the hole portion of bolt, the bolt stress exceeded the Yield point stress. In the other hand with the same this study understanding we model the flange joint with high-strength bolt seem like Herbert Schmidt's model, after analyzing we have comparable result shown in Fig.5. We can see that two results are almost the same.

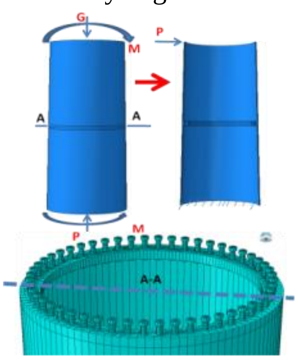

Fig.6 Flang joint model

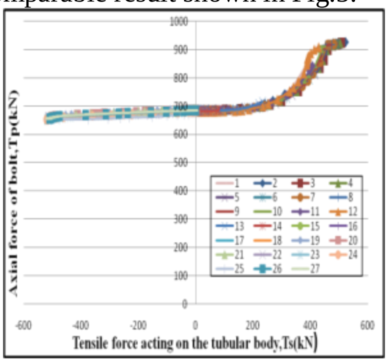

Fig.7 Ts&Tp

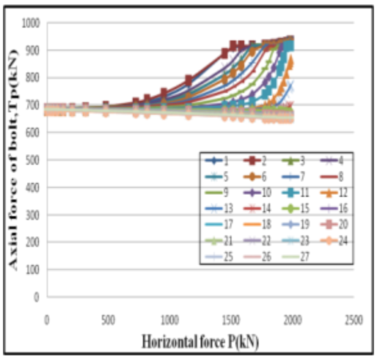

Fig.8 P&Tp

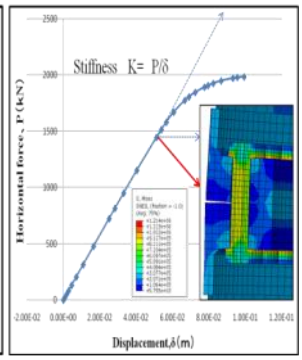

Fig.9 P&δ

In Fig .6, because of shortening the analysis time and the symmetry of tower we reduced a half the number of element(including boundary condition).In this study the half of the model has 27 bolts. In Fig.7 and Fig.8 from bolt 1 to 14 the axial forces have increased (it means that the bolts have been pulled), from bolt 15 to 27 the initial axial forces are almost unchanged (it means that tubular body have been compressed). In Fig.9 we understand that at the time flange joint began separating the stiffness of tower at flange joint has been reduced.

4. CONCLUSIONS

Analyzing of one bolts we understand the response of bolt and mechanism of flange joint during operation and the results of this study's method when compare with Herbert Schimidt research are almost the same,it means that the analytical methods of this study have high reliability

Using FEM analysis we could model and reproduce the mechanism of flange joint, from the results we understand the reducing stiffness of tower at flange joint at the time when the flange joint begin separating

REFERENCES

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