Sustainable Solutions in Structural Engineering and Construction
Edited by Chantawarangul, K., Suanpaga, W., Yazdani, S., Vimonsatit, V., and Singh, A.

ISBN: 978-0-9960437-0-0

EVALUATION FOR RESIDUAL AXIAL FORCE OF CORRODED HIGH TENSILE BOLTS

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This paper presents a method for evaluating the residual axial force of corroded high strength bolts in experiments, and analysis measuring the axial force of corroded high strength bolts. In order to reproduce the axial force reduction due to corrosion, the test specimens were made by cutting the bolt head widthwise or the height-wise with an initial axial force. The curve of axial force lowering is prepared with a reduced thickness in height and width of bolts as a parameter. Therefore, the residual axial force can be estimated by the thickness reduction of bolt. Moreover, we measured the residual axle force of real corroded high strength bolts, taken from a bridge removed from service for a long time, and inspected an axis drop curve. In order to classify corrosion shapes, we measured the three-dimensional surface shape of corroded high strength bolts without contact, and considered the relationship between the surface shape of corroded high strength bolts and the axial force reduction.

Keywords: Corrosion, High strength bolt, Residual axial force, Three-dimensional surface shape, Analysis.

1 INTRODUCTION

If the axial clamping force of the high strength bolt is reduced, the friction force disappears, and the joint's capacity for transmitting the force is lost. Therefore, control of the axial force in the bolt is important. In this paper, we aim to establish how the residual axial force is related to thickness reduction caused by corrosion in a high strength bolt both experimentally and analytically.

2 BASIC EXPERIMENTS USING BOLTS OF NEW MATERIAL

2.1 Experiment Outline

The residual axial force in a high strength bolt is determined as follows. After attaching two axial strain gauges to the bolt head shown in Fig. 1, the strain is measured when tightening the bolt. The bolt is then placed under tension using a testing machine until the same strain is produced, and the axial force in the bolt is defined by this strength force. In these experiments, after first tightening a brand-new M22 high-strength bolt to a prescribed axial force using a double plate, we shaved the bolt head and nut to provide a uniform thickness reduction, and then determined the residual axial force using the same experimental method.

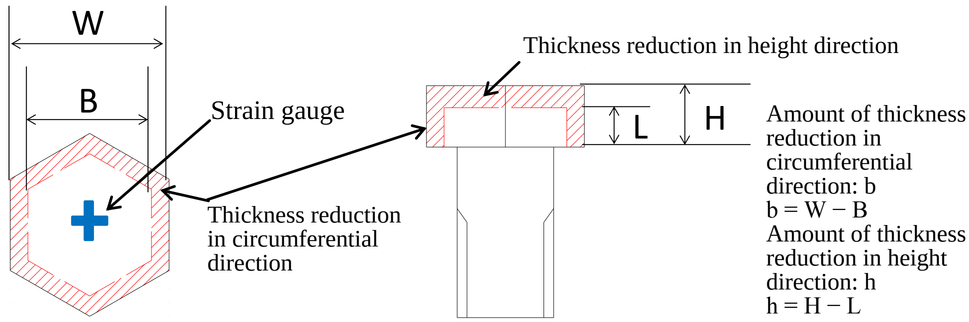

Figure 1. Machining method for high-strength bolt.

2.2 Experimental Results

Figure 2 shows the relationship between the amount of thickness reduction and the proportional residual axial force, for variations in axial force with thickness reduction of the bolt and nut. The thickness reduction is shown in green and red for the bolt head and nut. The dashed line shows the approximating curve for the experimental results (Ohno *et al.* 1994) for the history of the uniform thickness reduction in the circumferential direction of the bolt head and nut. These experimental results correlate roughly with the experimental result history. For the bolt head, the axial force for the thickness reduction in the height direction decreases compared with that in the circumferential direction.

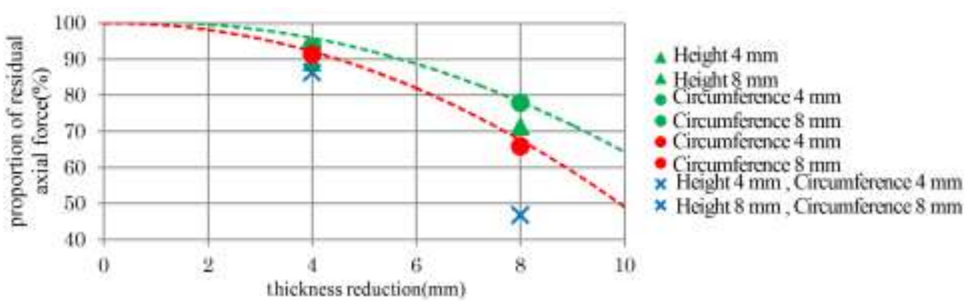

Figure 2. Relationship between proportion of residual axial force and thickness reduction.

3 FEM ANALYSIS

3.1 Analytical Model

The analytical model is shown in Fig. 3. For simplicity, the model assumed a circle of radius r = 18 mm for the bolt head of an M22 high strength bolt. The analysis assumed a completely elastoplastic material with modulus of elasticity of 210 GPa, a Poisson ratio of 0.3, and a yield stress for the high strength bolt and base material as 900 and 245 MPa, respectively. The boundary conditions, as shown in Fig. 3, are that the x-axis direction is fixed from the left side of the bolt, the y-axis direction from the bottom of the base material, and a forced displacement is applied as an initial axial force in the y-axis direction to the bottom of the bolt. We studied cases for a thickness reduction in either the height or circumferential direction and the case for a thickness reduction in both directions.

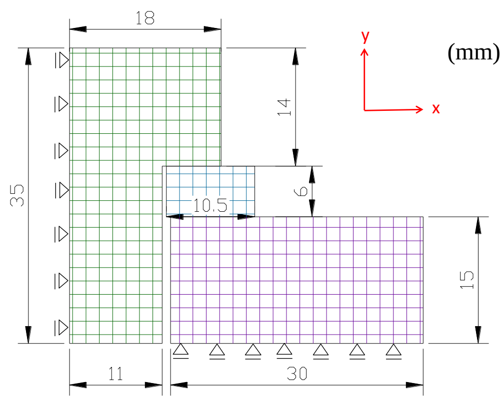

Figure 3. Analytical model.

3.2 Analytical Result

Figure 4 shows the relationship between the proportional residual axial force and the amount of thickness reduction in either the height or circumferential directions for the high strength bolt head. The proportional residual axial force was calculated using the axial force initially introduced by applying an assumed forced displacement of 225 kN. The thickness reduction in height and circumferential direction is plotted in green and blue, respectively, where the analytical results are given by (△), and their approximating curves by dashed lines.

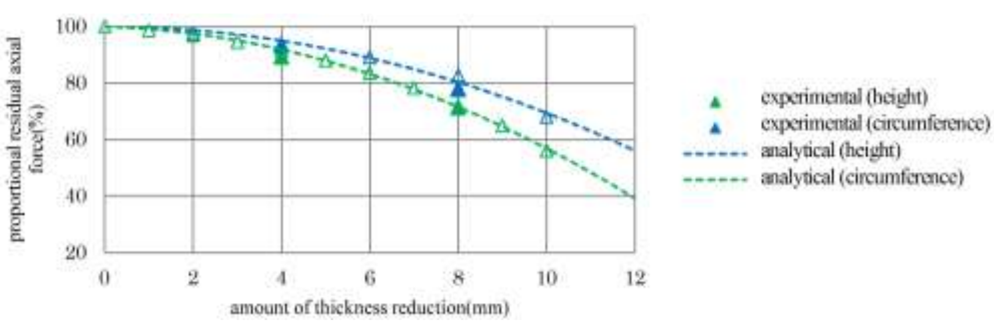

Figure 4. Relationship between amount of thickness reduction of bolt head and residual axial force.

The ▲ in Fig. 4 shows the experimental results; the green area shows the thickness reduction in the height direction, and the blue area shows the thickness reduction in the circumferential direction. The experimental and analytical values agree for thickness reduction in the height direction. In the circumferential direction, the experimental values gave a proportional residual axial force, which was smaller than the analytical value.

4 EVALUATION OF AXIAL FORCE IN HIGH STRENGTH BOLT

Figure 5 shows the relationship between the corrosion volume ratio for thickness reduction in the bolt head and nut, and the proportional residual axial force. To correspond with the analytical model, a circle of radius r = 18 mm was assumed for the high strength bolt head. The volume ratio for the amount of corrosion is found by dividing the volume of the high strength bolt subjected to corrosion by the volume of a sound (uncorroded) bolt. Fig. 5 shows that the results are scattered, but it can be seen that the proportional residual axial force decreases according to the square of the corrosion volume ratio.

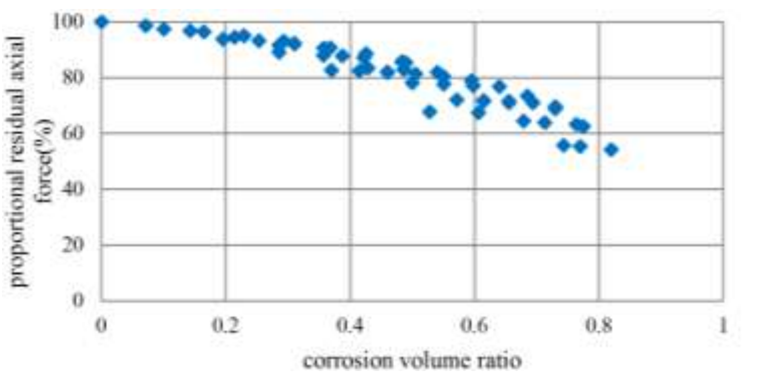

Figure 5. Corrosion volume ratio and proportional residual axial force.

A comparison of the analytical results shows that there is a greater effect on the decrease in the axial force for a greater thickness reduction in the circumferential direction than in the height direction. By separating scenarios into cases where a) the thickness reduction in the height direction is larger than in the circumferential direction and b) where it is larger in the circumferential direction than in the height direction, we calculated the proportional residual axial force as follows:

$$\text{for } h \geqq b\,,\quad N = 100 - \left(N_h + N_b \cdot \frac{b}{36} \right) \quad (\%) \tag{1}$$

$$\text{for } h < b\,,\quad N = 100 - \left(N_b + N_h \cdot \frac{h}{14} \right) \quad (\%) \tag{2}$$

where h is the amount of thickness reduction in the height direction, b is the amount of thickness reduction in the circumferential direction, N is the proportional residual axial force, Nb is the rate of decrease in axial force when there is a thickness reduction of b in the circumferential direction, and Nh is the rate of decrease in the axial force when there is a thickness reduction of h in the height direction. Fig. 6 shows a comparison between the proportional residual axial force estimated from Eqs. (1) and (2), and the analytical results. The estimated and analytical results agree, and it is therefore possible to calculate the residual axial force in a bolt, which has been subjected to a uniform thickness reduction in the bolt head using the estimation method given in Eqs. (1) and (2).

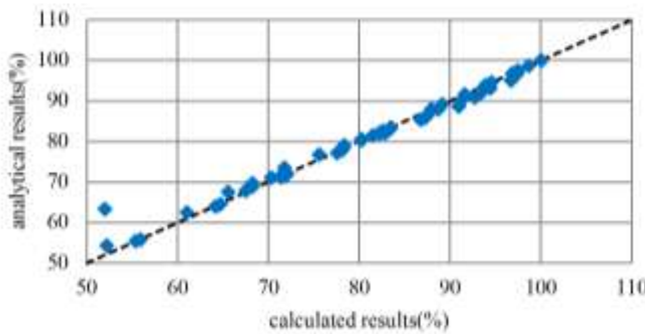

Figure 6. Comparison of analytical and calculated results.

We investigated how the proportional residual axial force is related to the amount of thickness reduction for a simultaneous reduction in both the bolt head and nut. The relationship for a uniform thickness reduction in the circumferential direction of a nut has been investigated previously (Ohno et al. 1994). N(nut) is the rate of decrease in axial force with thickness reduction of the nut as found from this diagram, and N(bolt head) is the rate of decrease in axial force with thickness reduction of the bolt head as found from calculations in Eqs. (1) and (2). From basic experimental results obtained for the bolt, it is assumed that the rate of decrease in the axial force for the bolt and nut together is 80% of the sum of each individual rate of decrease. Using this assumption, the proportional residual axial force N for a high strength bolt subject to corrosion can be expressed by:

$$N = 100 - \left(N_{(bolt\,head)} + N_{(nut)} \right) \cdot 0.8 \quad (\%) \tag{3}$$

5 EXPERIMENTAL FOR AXIAL FORCE IN CORRODED HIGH STRENGTH BOLT

5.1 Classification of Corrosion Type

The bolt head and nut were classified according to corrosion type of the high strength bolt. As shown in Fig. 7, we assumed four types: uniform, trapezoidal, reverse trapezoidal, and hourglass. By matching the amount of corrosion thickness reduction, we found that those with little corrosion are often of the uniform type, those with a medium degree of corrosion are often of the hourglass type, and those with a large amount of corrosion are often of the trapezoidal type.

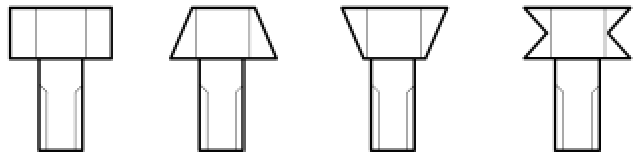

Figure 7. Classification of corrosion.

5.2 Application of Evaluation of Axial Force in High Strength Bolt

A comparison of the proportional residual axial force calculated by the estimation method with that measured by a strength-testing machine is shown in Fig. 8. The ±40% error between the experimental and estimated results is shown as an additional dashed line. Bolts plotted using × are those which had little corrosion thickness reduction, but showed a significant reduction in axial force. For bolts indicated by ×, it is possible that the initial axial force was not appropriately controlled. Thus, we consider the results ignoring the bolts shown as × for which the initial axial force is problematic. When we compare the estimated and experimental results, we see that most of the bolts fit within the range defined by the additional ±40% error lines.

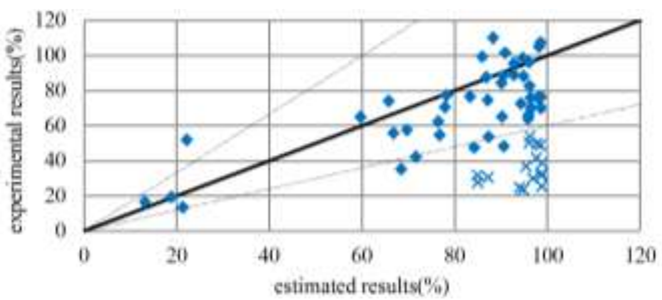

Figure 8. Comparison of estimated and experimental results.

6 CONCLUSIONS

The rate of decrease in axial force following thickness reduction in both the bolt head and nut can be estimated using 80% of the sum of their respective rates of decrease.

We used an M22 high strength bolt in this experiment. We verified the validity of the estimation method for the proportional residual axial force. A comparison with experimental results using the estimation method has enabled us to understand the behavior of the proportional residual axial force when it decreases with corrosion thickness reduction.

References

Ohno, T., Natori, T., Murakoshi. J., The study on the measurement for clamping force of corroded high strength bolt, *Proceedings of the Annual Conference of the Japan Society of Civil Engineers*, Vol 49, 518-519, 1994.