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スプリットティーの剛性・耐力に及ぼすカバープレートの影響
その 3　弾塑性数値解析

スプリットティー　半剛接合　カバープレート
引張実験　高力ボルト接合

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1. Introduction

Experimental results of Split-T connection are reported in Part 1 and Part 2. FEM modeling is used to perform numerical modeling of Split-T with cover plate. Effect of cover plate on stiffness and yield strength of Split-T is discussed based on FEM modeling in this part.

2. FEM modeling

2.1 FEM model

FEM model is created by ABAQUS. Length and thickness of cover plate (L_c and t_c) are used as parameters, and the dimensions of FEM model are set to be same with that of experimental specimens described in Part.1. Bolt holes are 2mm lager than the bolt diameter. Only half of the specimen is modeled because of the symmetry that exists about the web plane [1]. The FEM model is shown in Figure. 1.

2.2 Boundary conditions

Bolts pretention is applied as the first load case, and to keep consistent with experimental tests, bolt's design values of pretention force (N_0) are applied in FEM modeling. Bolt's length is set to be fixed in the whole process of simulation. The 50 mm vertical displacement is applied on the nodes at the center of T-web's vertical plane to impose the load on Split-T.

2.3 Material properties

Stress-strain relation for all components except bolts are considered using bilinear constitutive model, and the mechanical properties of Split-T and cover plate are as the properties mentioned in Part 1. It is worth noting that bolts are considered to be elastic only because no local yielding of bolts observed in experimental tests. The fracture of material is not considered in this study. Modulus of elasticity and Poisson's rate are applied according to *Design Standard for Steel Structure* [2].

2.4 Verification of FEM model

To evaluate the accuracy of FEM modeling approach, a group of FEM models (t_c=12mm) are created according to experimental tests, and the results are compared. Figure 2 shows deformed shape, and Figure 3 compares the load-deformation curves for both experimental specimens and FEM models

x=5.5mm and 38.5mm in Figure 2 represent the specimens which yield in MODE1 and MODE2. Deformed shape of specimens and FEM model are consistent with each other, and it is worth mentioning that yield of T-Flange and cover plate occurs at almost the same place. Furthermore, as it can be seen in load-deformation curves, the results of FEM modeling have a good agreement with that of experimental tests, which proves that the FEM modeling in present study is capable to perform numerical modeling of the Split-T with cover plate effectively.

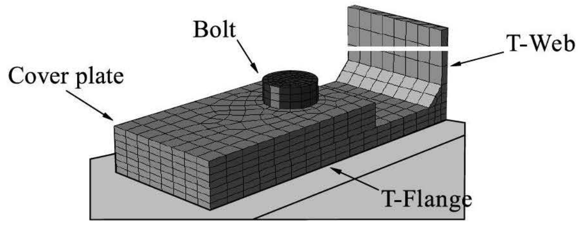
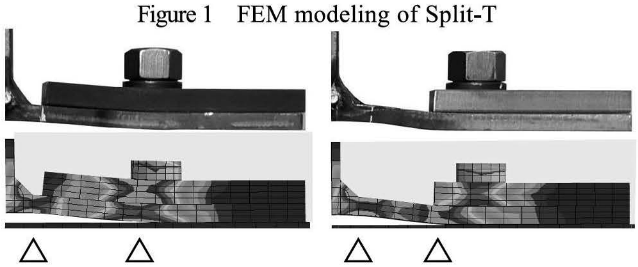
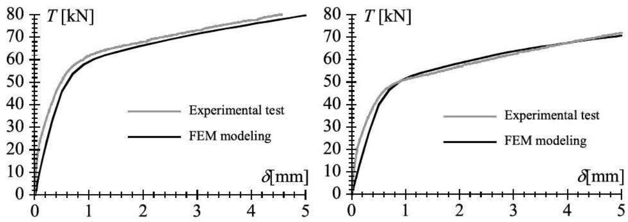


Figure 1　FEM modeling of Split-T



(a) t_c=12mm, x=5.5mm　(a) t_c=12mm, x=38.5mm

Figure 2　Deformed shape of experiment specimens (up) and FEM model (down)



(a) t_c=12mm, x=5.5mm　(b) t_c=12mm, x=38.5mm

Figure 3　Load-deformation curves

3. Results of FEM modeling

Stiffness and yield strength of both FEM modeling (group t_c=12mm, black spots) and experimental test (soft dot) are compared in Figure 4 (a) and 5 (a). The results of FEM modeling show a good agreement with the results obtained in experimental tests. To check the enhancement of cover plate on stiffness and yield strength, different from experimental specimens, not only the length of cover plate, but also the thickness is regarded as parameter in FEM modeling. Therefore, FEM model group

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t_c=16mm and group t_c=19mm are created, and the results of them are shown in Figure 4 (b), (c) and Figure 5 (b), (c).

3.1 Effect on stiffness

There is an upper limit of the enhancement of cover plate on stiffness, and the upper limit improves with the increase of cover plate's thickness. A new model of stiffness evaluation is proposed here (Figure 4 (a), Equation 3), and it is worth mentioning that only the upper limit of stiffness is attempted to be evaluated in the beginning of the research. k_f in Equation 3 (dotted line in Figure 4) is the stiffness of Split-T without cover plate, in contrast, k_c here reflects the enhancement of cover plate on stiffness.

$$k_u = k_c + k_f \quad \cdots\cdots\cdots \quad (3)$$

Here: $$k_f = 2 \cdot \frac{12 \cdot E \cdot I_f}{(L_s + r)^3} \quad \cdots\cdots\cdots \quad (3.a)$$

$$k_c = 2 \cdot \frac{3 \cdot E \cdot I_c}{(L_s + r)^3} \quad \cdots\cdots\cdots \quad (3.b)$$

I_f and I_c are the moment of inertia of T-Flange and cover plate respectively. The upper limit of stiffness obtained by Equation 3 (k_u) are indicated in Figure 4 by black line. For group t_c=12mm, k_u underestimates the upper limit of stiffness (k_{max}, gray line in Figure 4), and k_u is 0.9 times of k_{max}. For group t_c=16mm, k_u is almost consistent with k_{max}. For group t_c=19mm, the upper limit k_{max} is overestimated, and k_u reaches almost 1.2 times of it. Equation 3 is effective in the estimation of the upper limit of stiffness, and further study will be done to describe the influence of cover plates' length on stiffness.

3.2 Effect on yielding strength

Equation (1.b) accurately evaluates the upper limit of yield strength for all groups of FEM modeling, however, yield strength of experimental specimens which failed in MODE1 is underestimated by Equation (1.a) (dotted line in Figure 5). Using coefficient γ in Equation 4, the precision of evaluation improves substantially. Replacing Equation (1.a) with Equation 4, failure mode of Split-T with cover plate can be predicted much more accurately.

$$T_{y1} = \gamma \cdot \frac{2 \cdot M_{01}}{x} \quad \cdots\cdots\cdots \quad (4)$$

Here: $\gamma = 1.3$

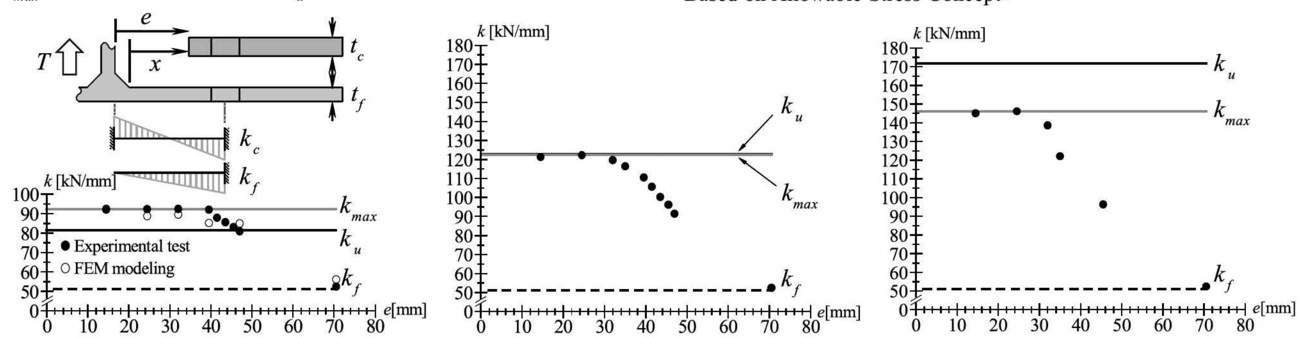
4. Conclusion

Effect of cover plate on elastic stiffness and yield strength of Split-T are discussed based on the results of FEM modeling, and a simple model is proposed to evaluate the upper limit stiffness of Split-T with cover plate.

Reference

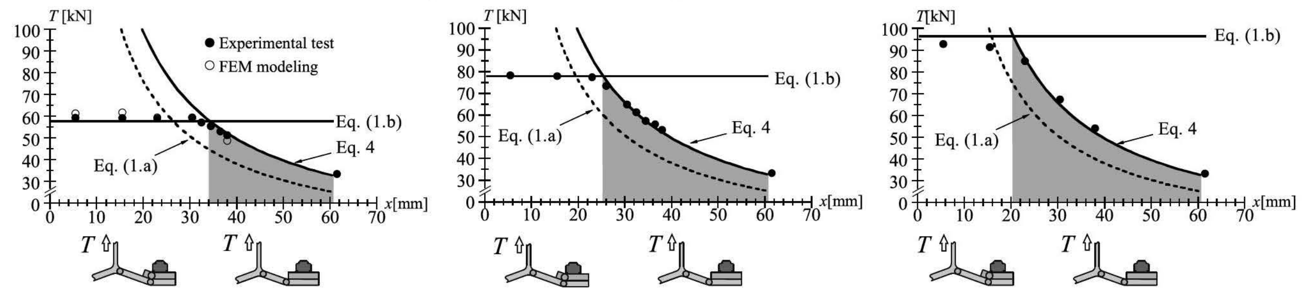
[1] Amir Saedi Daryan. et al., "Behavior of semi-rigid connections and semi-rigid frames", *Struct. Design Tall Spec. Building*. 23, 210-238(2014)

[2] Architectural Insititute of Japan : Design Standard for Steel Structure-Based on Allowable Stress Concept-



(a) t_c=12mm (b) t_c=16mm (c) t_c=19mm

Figure 4 Effect of cover plate on elastic stiffness



(a) t_c=12mm (b) t_c=16mm (c) t_c=19mm

Figure 5 Effect of cover plate on yield strengh

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