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Finite element analysis of steel moment connections with the details of shear tabs and high strength bolts

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ABSTRACT

Steel moment connections provides ductility to building structures and have been commonly adopted in seismically active areas such California, Japan and Taiwan. For the ease of construction, a shear tab is usually welded to the faces of steel columns in the shop work and then the steel columns can connect the webs of steel H-beams using high strength bolts and the beam flanges can be welded to the column faces in the field. The post-earthquake investigation indicates that the connections may fail due to the lack of plastic deformation capacities. The steel moment connections with the pre-earthquake details need further improving. In the presented work, finite element analysis (FEA) is made to explore the ways of increase the plastic deformation capacities of steel moment connections. Special attention is paid to the details of bolted beam web connections and the moment capacities. It is thought that increasing the moment-capacity of bolted web connections can help reduce stress concentration and avoid early-stage fracture failures to occur at welds or near the access holes in the beam flanges. The result of FEA simulation provides evidence supporting the point.

1. INTRODUCTION

Many researchers have carried out investigations into the seismic capacities of steel moment connections with pre-Northridge details (e.g. Tsai et al., 1992). It is suggested that most of the connections may fail due to the lack of plastic deformation capacities. Considering the needs of seismic upgrading, finite element analysis (FEA) has been implemented to study the seismic performance of steel H-beam-to-box-column connections with double-shear-tab details. In the first part of the work, the FEA model is validated with the result of a full-scale connection test. Special attention is paid to the structural modeling of shear tabs and high strength bolts. In the second part, the effects of design parameters are investigated in detail. The results obtained will help study the feasibility of enhancing the seismic performance of conventional steel connections with the double-shear-tab detail.

2. FEA SIMULATION

The result of a full-scale steel connection (Tsai et al., 1992) has been simulated using the commercial software ANSYS Workbench (Ver. 16.2) (2007).

2.1 Structural Modeling

<u>Sections and material</u> The FEA simulation has the same specimen and boundary condition with the connection test. As illustrated by Fig. 1, the connection details such as shear tabs, high strength bolts, and welds are modeled in detail. In more detail, the shear tab is welded to the face of the box column. The A572 Gr. 50 steel box column is then connected to the A36 steel H-beam through the shear tab using 7 ASTM 7/8" A325 high strength bolts. F_{E70} weld material is used. Tables 1 summarizes the section sizes and steel material. For reference, the table also gives the strength properties of JIS F10T high strength bolts. The pretension of a M22 A325 high strength bolt is set to be 175 kN.

Table 1. Section sizes and strength properties

	Section	Steel	Yield strength (MPa)	Tensile strength (MPa)
Column	BOX550×550×24	A572 Gr.50	350	500
Beam	H690×320×14×24	A36	270	440
Shear tab	PL18×100×500	A36	270	440
A325 bolt			630	800
F10T bolt			900	1100
F_{E70} weld			480	520

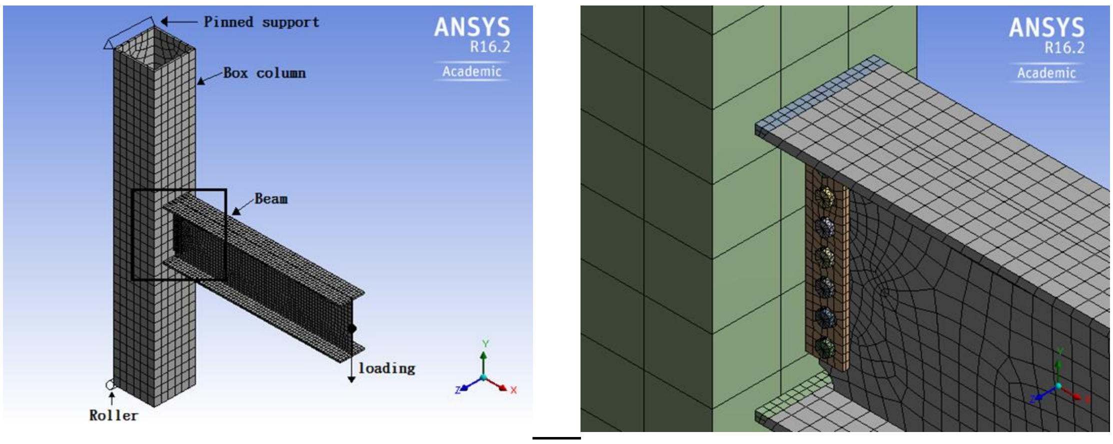

Fig.1 FEA simulation of a full-scale steel connection test

<u>Stress-strain curves</u> The elastic behavior of base metal, bolt and weld materials has been simulated using an isotropic model, and the plastic behavior is simulated using a kinematic model. Young's modulus (E) and poison ratio (v) are 200 GPa and 0.3

respectively. For the steel plates, the stress-strain relation is simulated using a bilinear relation with a strain hardening rate of 0.04. For the F_{E70} weld material, the stress-strain relation is simulated using a bilinear relation with a yield strength of 480 MPa and a strain hardening rate of 0.0036. For the A325 high strength bolt, the stress-strain relation is simulated using a bilinear relation with a yield strength of 630 MPa and a strain hardening rate of 0.05.The analysis ignores the residual stress and thermal effects in the manufacture of components.

Elements and meshing Solid45, a 3-D structural solid element, has been used. Each element has 8 nodes, and each node has 3 degrees of freedom. The mesh is generated by the software automatically.

Surface-to-surface contact elements are added in the weld material and the adjacent base metal of the beam and column. These elements are used together with finer meshes, as to capture the high stress gradients. The rest of the beam and column has rectangular meshes, which are connected at their common interface with a bonded-always, contact and target pair. Accordingly, the bolts are bonded with the nuts in the same way.

The meshes of the shear tab and beam web are connected at their common interface with a frictional-always, contact and target pair. The shear tab and high strength bolts are also connected with a frictional interface. The beam web and bolt nuts are connected in the same way. The coefficient of friction is set to be the same as the slip coefficient of high strength bolts (0.45).

2.2 Model Validation

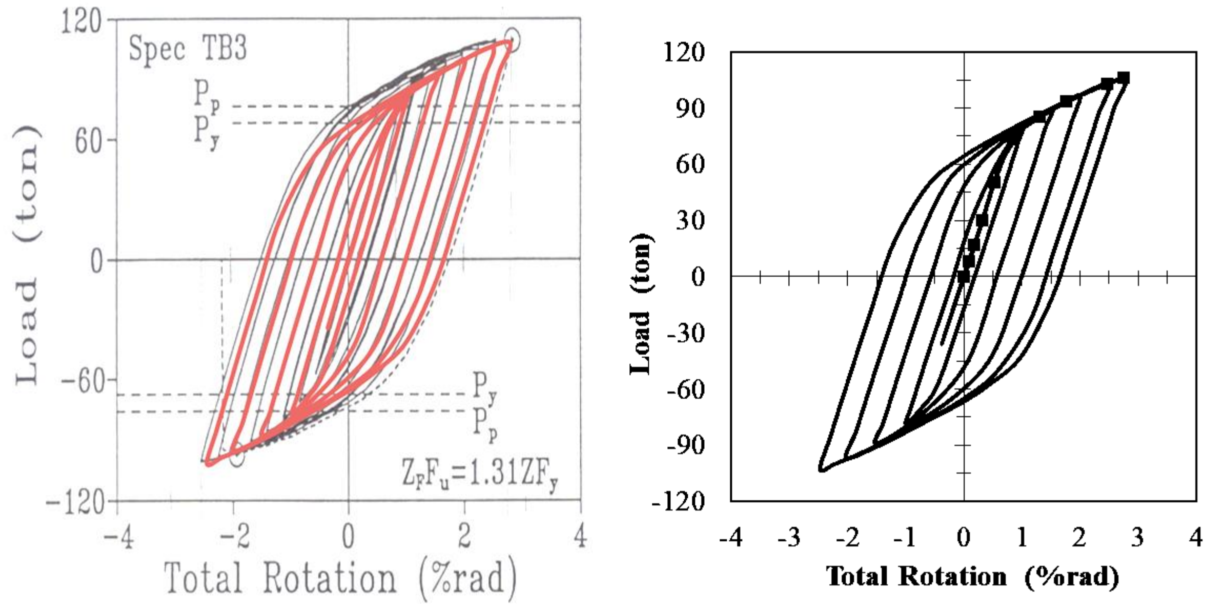

Fig.2 Comparison of FEA simulation (bold line) to connection test

Load-displacement curves As depicted in Fig.2, the load-displacement response is well simulated until the weld fracture of beam flange causes the connection to lose strength and stiffness suddenly. The connection fails at the max drift of 2.5%. The post-earthquake design code (such as AISC 2010) requires the drift of 4% at least. As also illustrated by the figure, the response to monotonic loading (■) fits well with the envelope of the response to cyclic loading. For the ease of comparing, the response to monotonic loading is simulated and compared in the following.

von Mises stress With the principle stresses σ_1 σ_2 σ_3, one may calculate the von Mises stress using the following equation (Boresi et al. 1993)

$$\sigma_\theta = \sqrt{\frac{1}{2}[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2]}$$

(1)

Equivalent plastic strain (PEEQ) With the vector component of plastic strain in the direction of i and j, ε_{ij}, one may calculate the equivalent plastic strain (PEEQ) using the following equation (El-Tawil et al. 2000).

$$PEEQ = \sqrt{\frac{2}{3}\varepsilon_{ij}\varepsilon_{ij}}$$

(2)

The distribution of von Mises stress and PEEQ in Fig.3 indicates the stress concentration near the access hole. That has prevented the yielding of the beam web, leading fracture to occur at the beam flanges.

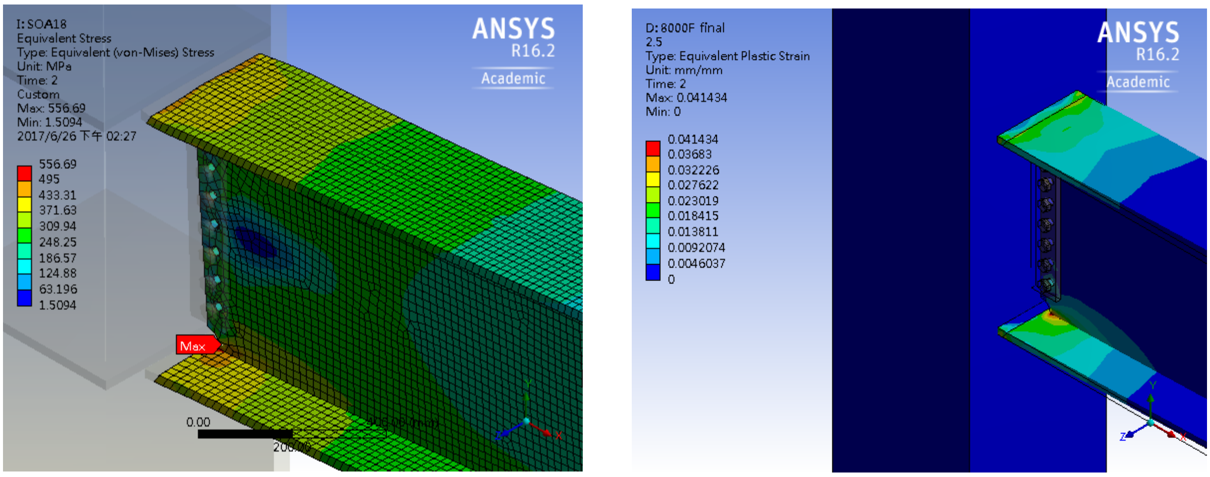

Fig.3 Distribution of von Mises stress and PEEQ at the max drift (total rotation=2.5%)

3. CASE STUDY ANALYSIS

The FEA simulation is implemented to explore the ways of increasing the plastic deformation capacity of the steel connection.

3.1 Design Parameters

It is thought that increasing the moment-capacity of a bolted web connection can help reduce stress concentration and avoid early-stage fracture failures to occur at welds or near the access holes in the beam flanges. The moment-capacity of the bolted web connection is increased by changing from a shear tab (S) to double shear tabs (D), by adding from the row number of high strength bolts from one (O) to two (T), by changing ASTM A325 high strength bolts (A) to JIS F10T high strength bolts (B), and by adding the plate thickness of shear tab from 18 mm to 28 mm. Fig. 5 gives examples illustrating the effects of design parameters. The original design case is designated as SOA-18. For reference, the case is also analyzed for reducing the thickness of shear tab to 10 mm.

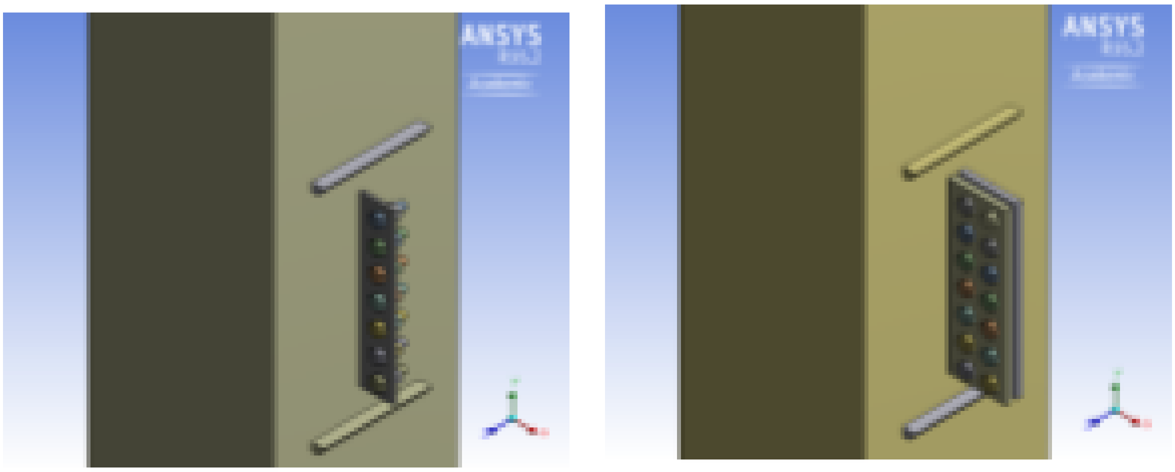

Fig.4 Details of a bolted web connection before and after seismic upgrading

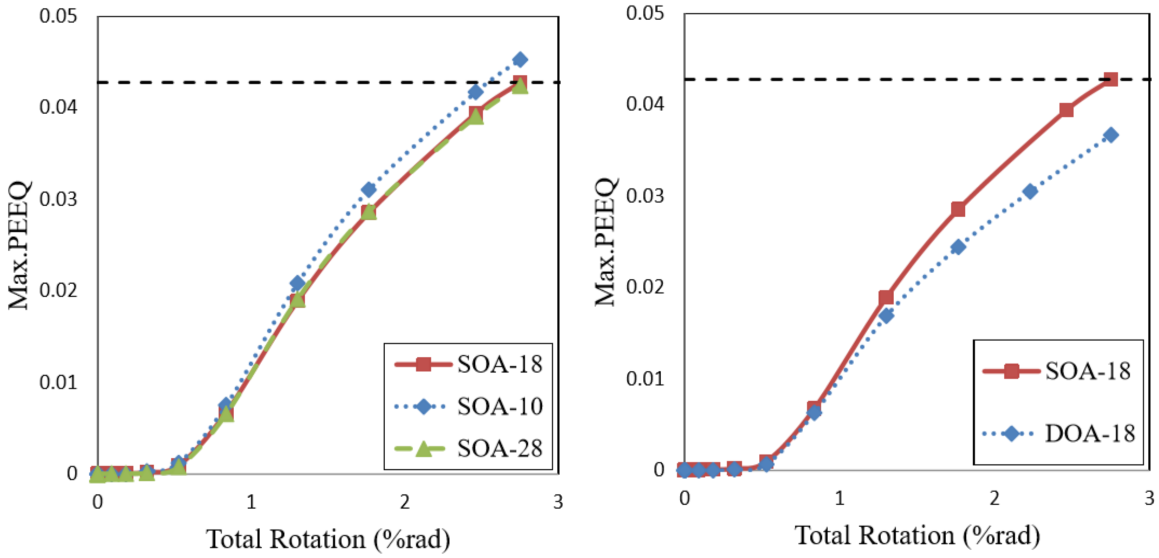

Fig.5 Comparison of PEEQ values for the plate thickness of shear tab and the number

3.2 Design Example

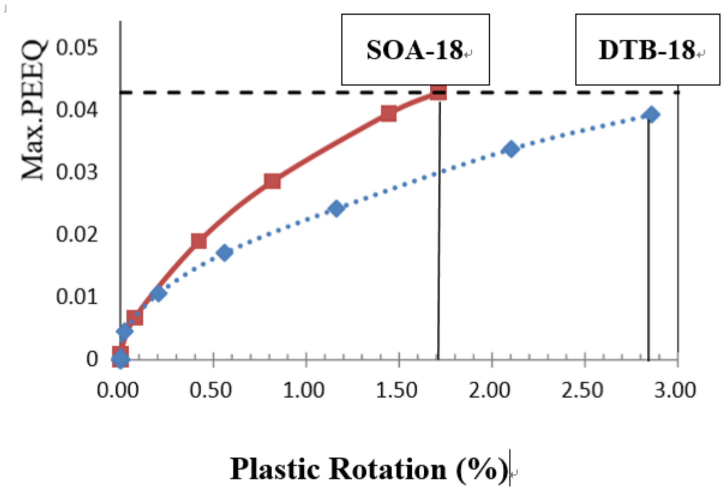

Fig. 6 Relation of PEEQ and connection rotation before and after seismic upgrading

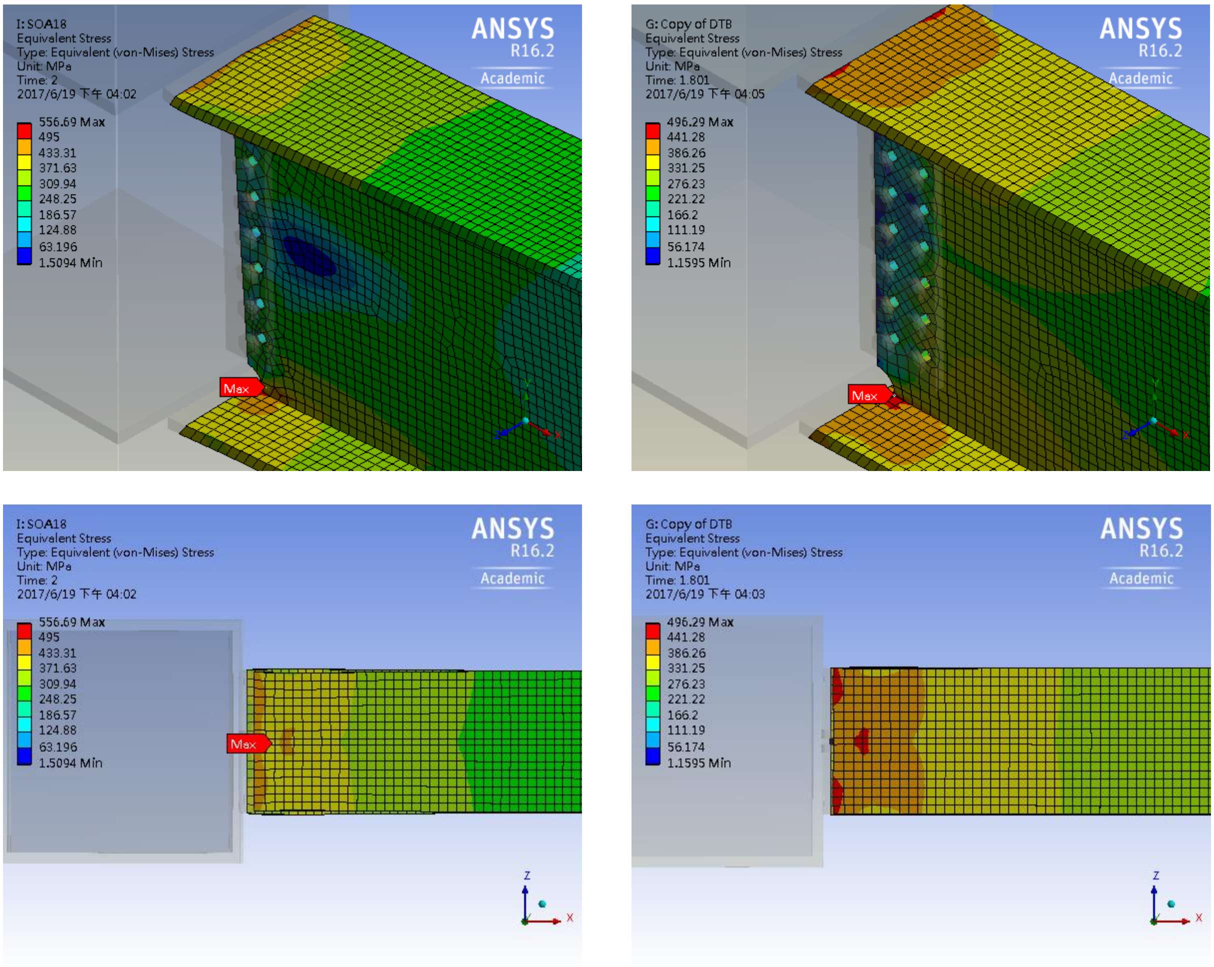

Fig.7 Distribution of von Mises stress before and after seismic upgrading

Fig. 5 also shows the effectiveness of adding to double shear tabs in reducing the stress concentration near the access holes, in comparison to adding the thickness of shear tab.

In the past, the design of steel connections was made with the assumed plastic rotation capacity of 1.5% rad. The connections probably couldn't meet the nowadays requirement (i.e. 3% rad plastic rotation). Fig. 6 shows the possibility of increasing the deformation capacity by using the double-shear-tab detail. Before the seismic upgrading, the connection fails at the drift angle of 2.5%. The max plastic rotation of the connection is 1.72%. The max PEEQ value occurs near the access hole. The PEEQ value is used as a local failure index for earthquake retrofitting. That leads to retrofit the connection using a pair of shear tabs and two rows of F10T high strength bolts (DTB-18). For the F10T high strength bolt, the stress-strain relation is simulated using a bilinear relation with a yield strength of 900 MPa and a strain hardening rate of 0.05. The pretension of a M22 F10T high strength bolt is set to be 235 kN.

Fig.7 compares the distribution of von Mises stresses before and after seismic upgrading. It is thought that increasing the moment-capacity of bolted web connections can help reduce stress concentration and avoid early-stage fracture failures to occur at welds or near the access holes in the beam flanges. The result of FEA simulation provides evidence supporting the point. As can be seen, the yielding of the beam web has prevented fracture failures to occur at welds or near the access holes in the beam flanges. As also can be seen there, the double-shear-tab detail leads the length of plastic hinge to increase to a great extent, when compared to the original single-shear-tab detail.

4. CONCLUSIONS

Steel moment connections provides ductility to building structures and have been commonly adopted in seismically active areas such California, Japan and Taiwan. The post-earthquake investigation indicates that the connections may fail due to the lack of plastic deformation capacities. Considering the needs of seismic upgrading, a series of FEA simulation has been implemented to study the behavior of a steel H-beam-to-box-column connections before and after earthquake retrofitting. In detail, at first, the FEM model was validated with test data. The model simulates the details of shear tabs, bolt and nut. Then the effects of design parameters were studied. It was found that double shear tabs can reduce the stress concentration near the access holes, greatly increasing the plastic deformation capacity of the steel connection. Finally a design example was given with tips of earthquake retrofitting. The result from the above work has shown the possibility of enhancing the seismic performance of conventional steel connections with the double-shear-tab detail.

ACKNOWLEDGEMENTS

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