NONLINEAR FE ANALYSIS ON PRYING OF TOP- AND SEAT-ANGLE CONNECTIONS

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1. INTRODUCTION

The subject of prying force working on top- and seat-angle connection assemblage drew attention a number of researchers in their experimental and analytical studies. Some of them indicated that the prying force can be as high as 33% of the bolt force and cannot be ignored. In the LRFD specification for the design of steel connections, AISC represented prying force formulas for tee-hanger connections. The formulas are also to be used to estimate the prying action of top- and seat-angle connections. However, the specific guidelines have not been adopted in that LRFD specification for the design against prying action of top- and seat-angle connections. With the availability of more sophisticated computational and analytical tools, it can be possible to provide designers with more consistent design procedure against prying action not only for tee-hanger connection, but also for other FR and PR connections.

This study is aimed to extend the authors recent research works which will establish several findings: (1) Examine the validity of proposed finite element (FE) model of predicting moment-rotation characteristics of top- and seat-angle connection comparing with experimental results; (2) observing bolt pretension effects on moment-rotation behavior of the connection and on prying action; (3) investigating the influence of connection parameters on bolt prying; and (4) visualizing the effect of prying action on bolt implying FE techniques.

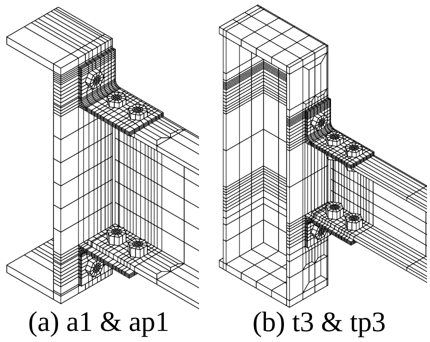
2. ANALYSIS TECHNIQUE

In order to efficiently simulate the real connection behavior, connections are modeled using eight-node solid elements, and all components of test-connection including shapes of bolt shank, head, and nut are precisely taken into account in the FE modeling. The mesh examples of FE model are shown in **Fig. 1**. In analyses for the cases of a1, a2, and t3, bolt pretension is ignored and the other three cases of ap1, ap2, and tp3 have been performed implementing pre-stress in bolts. The bolt pretension level is taken to be 40% of the ultimate tensile strength of bolt. The analyses identified with a1, a2, ap1, and ap2 are taken from Azizinamini et al.'s test data [1]; and t3 and tp3 are taken from Harper's test data [2]. Harper identified the test as 'TEST3' in his Ph.D. thesis [2]. Contact surface algorithm is applied as boundary condition in the analyses of both phases. Imposed displacement was employed on the middle section of stub column as the method of loading. Material properties used in the analyses are collected from relative tests data. The yield stress and ultimate strength of flange angels are taken from the mean value of coupon test results and similar values are assumed for beam and column. Bolt yield stress and ultimate strength are assumed based on the nominal properties of A325 steel, since no coupon test results were reported for beam, column and bolt. The material behavior of steel is represented by a bilinear elasto-plastic stress-strain relation. Isotropic strain-hardening is taken into consideration in the constitutive model. Connection geometries used here are shown in **Table 1**.

Table 1 Geometrical properties of connections used in the analysis

FE model ID	Column section	Beam section	Top- and seat-angles				Bolt diameter (in.)
			Angle section	Length (in.)	Gage on column flange (in.)	Gage on beam flange (in.)	
*a1, ap1	W14×38	W14×38	6×4×$^3/_8$	8	2½	2$^1/_4$	$^7/_8$
*a2, ap2	W14×38	W14×38	6×4×½	8	2½	2$^1/_4$	$^7/_8$
*t3, tp3	W8×24	W8×21	6×3½×$^3/_8$	6	2	2$^1/_4$	$^7/_8$

*Bolt pretension in a1, a2, t3 is ignored; and in ap1, ap2, tp3 is considered.



(a) a1 & ap1　　(b) t3 & tp3

Fig. 1. Mesh of FE model

Key words: finite element method, moment-rotation behavior, prying action, semi-rigid connection, monotonic loading

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3. RESULTS ANALYSIS

3.1. Comparison of Moment-Rotation behavior

The M-q_r curves obtain from FE analysis using ABAQUS code and experimental results [1 & 2] are shown in **Fig. 2**. **Figure 2** shows a good approximation of FE technique comparing with experimental M-q_r curves. It is also studied that the spread of yield area and the deformation at the ultimate state of connection predicted by FE analysis show a good similarity with those of experimental results. This evidence proves that prying action can be studied with sufficient accuracy using the FE model.

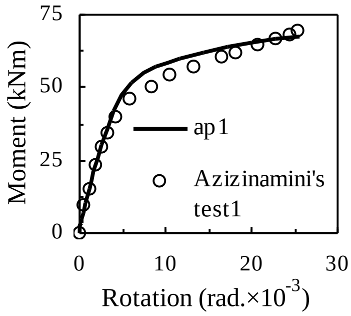

Fig. 2. Performance of FE analysis

3.2 Bolt pretension effect on moment-rotation behavior

Figure 3 shows the influence of bolt pretension on M-q_r curves predicted by FE analyses. This study shows, consideration of bolt pretension can cause increment of the initial connection stiffness by 30% to 75% and the ultimate moment by 0.2% to 0.5%.

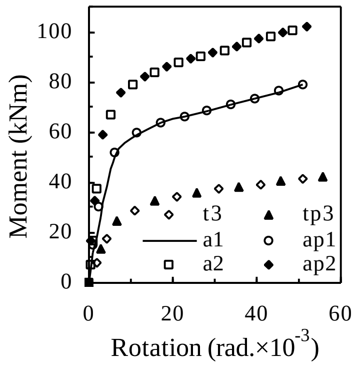

Fig. 3. Bolt pretension effect on moment-rotation behavior

3.3 Bolt pretension effect on prying action

Top angle vertical leg develops pressure on the column flange due to primarily bolt preloading and later top angle deformation. Summation of these two forces is displayed by FE analysis as contact pressure, which is shown in **Figs 4 & 5**. The pretension force 128.4 kN (0.4F_u) is implemented in cases of ap1 & ap2 and is absolutely ignored in cases of a1 & a2. It is evident from **Fig. 4** that bolt pretension may cause slightly increase prying in bolt at its plastic moment. However, FE analysis shows the same prying for both cases at or after the ultimate state of connection.

3.4 Influence of connection parameters on bolt prying

All geometrical parameters of connections ap1 and ap2 are the same with the exception of flange angle thickness. The flange angle thickness of connections ap1 and ap2 are 3/8 in. and 1/2 in., respectively. **Figure 4** shows that prying in case of ap1 developed more rapidly than in case of ap2 due to reduction of flange angle thickness.

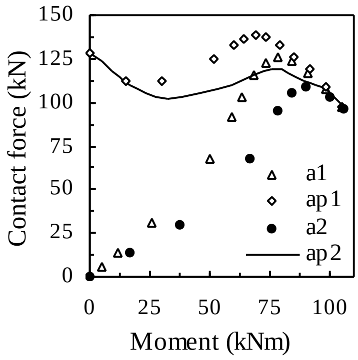

Fig. 4. Prying action on bolt

3.5 Relation of bolt prying with connection strength

Relation between prying action and connection stiffness is shown in **Fig. 5**. In weak connection, prying grows adversely comparing with that of stiff connection from the very beginning of loading.

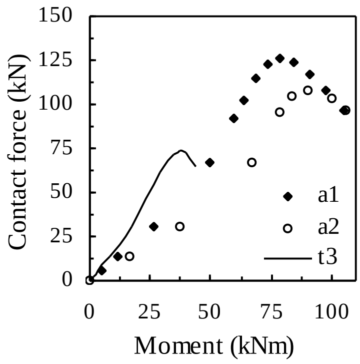

Fig. 5. Connection stiffness effect on prying action

4. CONCLUSIONS

This study is primarily verified FE technique comparing analysis results with test data. Using the verified FE model, parameter study is also conducted to observe their influence on praying action and this study exposes that,

1. M-q_r curve of top- and seat angle connection can be rigorously predicted by means of FE technique.
2. Bolt pretension substantially increases the initial connection stiffness, but practically has no influence on the ultimate moment of connection.
3. Bolt pretension has no influence on prying at the ultimate state of connection.
4. Reduction of flange angle thickness can develop large prying force.
5. Prying develops more rapidly in weak connection than in stiffer one.

REFERENCES

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