New Moment Rotation Model of Single Web Angle Connections

Zhengyi Kong, Seung-Eock Kim

Open Science Index, Civil and Environmental Engineering Vol:9, No:7, 2015 publications.waset.org/10002010.pdf

Abstract**—**Single angle connections, which are bolted to the beam web and the column flange, are studied to investigate their moment-rotation behavior. Elastic–perfectly plastic material behavior is assumed. ABAQUS software is used to analyze the nonlinear behavior of a single angle connection. The identical geometric and material conditions with Lipson's test are used for verifying finite element models. Since Kishi and Chen's Power model and Lee and Moon's Log model are accurate only for a limited range of mechanism, simpler and more accurate hyperbolic function models are proposed.

Keywords**—**Single-web angle connections, finite element method, moment and rotation, hyperbolic function models.

I. Introduction

A single-web angle connection consists of an angle either bolted or welded to both the column flange and the beam web. In general, this type of connection is idealized as pins and is assumed to transfer only shear loads to the supporting members. In practical engineering, a single-web angle connection exhibits semi-rigid deformation behavior, which can contribute substantially to overall force distribution in the members. As such steel frame connections should be treated as being a 'semi-grid frame" for the purpose of proper analysis and design. Therefore, it is necessary to establish moment–rotation relationship for use in practical connection design.

In the past years, several researchers have published papers discussing moment–rotation model of single-web angle connections, such as [1], [2]. But the expressions prove to be accurate only for the limited range of data.

Finite element method has been used to study the behavior of different types of connections successfully [3]-[16], but few studies has concentrated on the single-web angle connections. The purpose of this study is to develop the new formulations for determining the moment–rotation relationship of single-web angle connection using finite element method.

II. Finite Element Analysis And Verification

ABAQUS is used for analyzing the connection. To establish the effects of geometric configuration, the angle thickness, the gage distance, the angle length are selected as four main geometric parameters.

9 types of angles are investigated,
1) L93.5×93.5×5.5,
2) L93.5×93.5×9.5,
3) L93.5×93.5×13,
4) L102×102×5.5,
5) L102×102×9.5,
6) L102×102×13,
7) L125×125×5.5,
8) L125×125×9.5,
9) L125×125×13.

Three types of angle length are considered as follows: 424 mm, 520 mm, and 604 mm, shown in Fig. 1. The geometric and material details are identical with Gong's experiment [17].

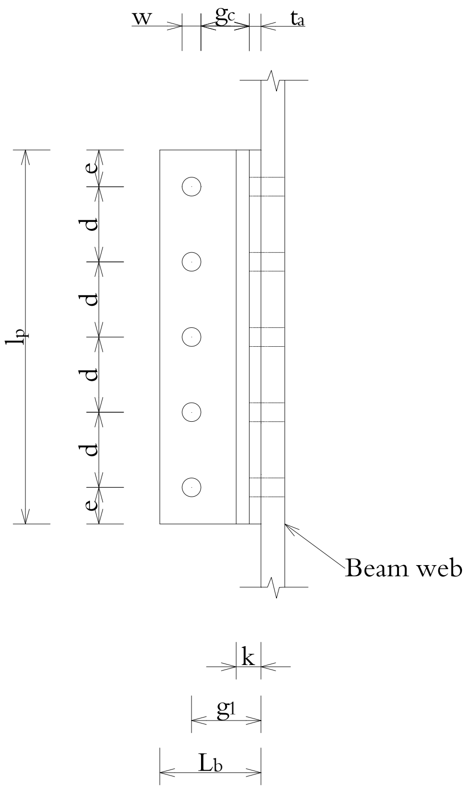


Fig. 1 Parameters of connection angle

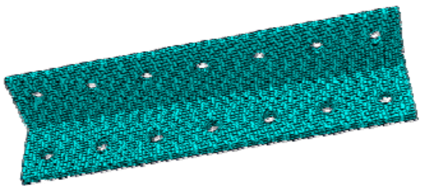
The finite element models consist of an angle, bolts, a beam and a column, all using C3D8 eight-node constant-strain brick element. Fig. 2 depicts the finite element meshes for the angle and a bolt. Elastic–perfectly plastic material behavior is assumed for the angle, bolt, beam and column members.

Zhengyi Kong, PhD Student, is with the Department of Civil and Environmental Engineering, Sejong University, 98 Gunja Dong Gwangjin Gu, Seoul 143-747, Republic of Korea; Lecturer, Department of Architecture Engineering, Anhui University of technology, Ma'anshan, China (e-mail: kzy2004@126.com).
Seung-Eock Kim, Professor, is with the Department of Civil and Environmental Engineering, Sejong University, 98 Gunja Dong Gwangjin Gu, Seoul 143-747, Republic of Korea (Corresponding author: Tel.: +82-2-3408-3291; fax: +82-2-3408-3332; e-mail: sekim@sejong.ac.kr).

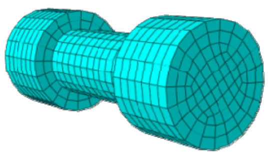
Open Science Index, Civil and Environmental Engineering Vol:9, No:7, 2015 publications.waset.org/10002010.pdf

All the contact conditions of bolt nut to angle, bolt head to column flange/beam web, and angle to column/beam are simulated in ABAQUS. The contact interactions between the bolt shanks and bolt holes are neglected.

In order to verify the results of finite element analysis, three finite element models, corresponding to Lipson's experiment, are created as list in Table 1. The moment-rotation behavior and initial stiffness can be obtained by applying load as described in Lipson's experiment [18]. The results obtained by finite element method achieve a good agreement with the test data, as shown in Table I and Fig. 3.

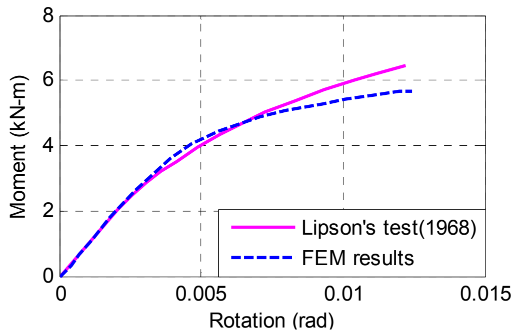


(a)

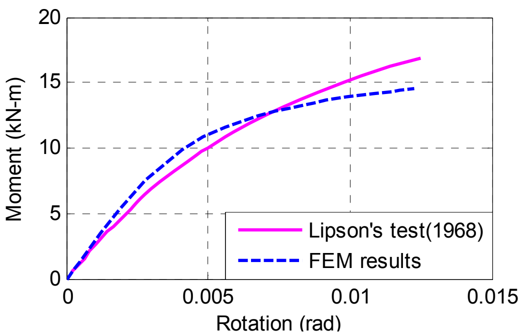


(b)

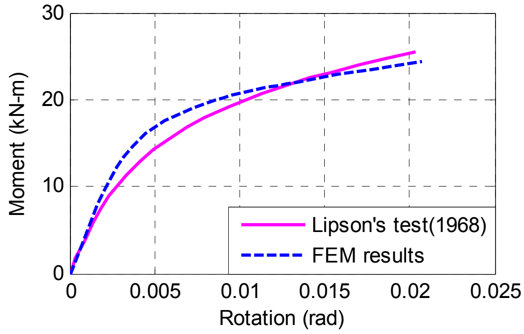
Fig. 2 Finite element models: (a) angle; (b) bolt



(a) 4 bolts (ID: AA-4/2)



(b) 5 bolts (ID: AA-5/2)



(c) 6 bolts (ID: AA-6/1)

Fig. 3 Comparison of FEM results with Lipson's test; (a) 4 bolts (ID: AA-4/2), (b) 5 bolts (ID: AA-5/2), (c) 6 bolts (ID: AA-6/1)

TABLE I
COMPARISON OF FEM RESULTS WITH LIPSON'S TEST

Specimen ID	Initial stiffness		Discrepancy
	Lipson's experiment (kN-m/rad)	FEM results (kN-m/rad)	
AA-4/2	1099	1116	1.55%
AA-5/2	2633	2716	3.15%
AA-6/1	4284	4517	5.44%

III. Moment And Rotation

A. Connection Models

Several models have been developed to represent connection flexibility. These models are generally either a sophisticated numerical method or based on test data.

In 1990, Kishi and Chen proposed power model on the basis of test data conducted by Lipson.

$$M = \frac{R_{ki}\theta_r}{\left[1+(\frac{\theta_r}{\theta_0})^n\right]^{1/n}}, \tag{1}$$

in which $\theta_0=M_u/R_{ki}$; n is the shape parameter; M_u is the ultimate moment; and R_{ki} is the initial stiffness [1].

One advantage of the model is its simplicity of having fewer parameters, and the connection stiffness and rotation can be determined directly without needing iteration. But it is difficult to reflect the ascending curve after yielding [19], [20].

In 2002, Lee and Moon proposed the log model based on SCDB (The Steel Connection Data Bank program conducted by Kishi and Chen). The equation is

$$M = \alpha\left[ln(n \cdot 10^3 \cdot \theta + 1)\right]^n, \tag{2}$$

where α and n are shape parameters [2]. But it is difficult to reflect the stable curve in the final stage.

Kishi and Chen's power model and Lee and Moon's log model are popular among many models because they have few parameters.

Open Science Index, Civil and Environmental Engineering Vol:9, No:7, 2015 publications.waset.org/10002010.pdf

B. Modeling of M-θ Curves

From the results of ABAQUS, three different types of mechanism can be found, as shown in Fig. 4. Comparison of the results of finite element models with these two models indicates the accuracy of these two equations is only for a limited range of mechanism, as shown in Fig. 5.

From the results of finite element method, two hyperbolic function models are established, which are shown in (3) and (4):

$$M = \alpha \cdot \text{arc}\sinh(\beta \cdot \theta) \quad \text{for mechanism I} \tag{3}$$

$$M = \alpha \cdot \tanh(\beta \cdot \theta), \quad \text{for mechanism II and III} \tag{4}$$

in which ε and η are shape parameters.

According to the results of FEM, if mechanism I occurs, (2) and (3) are more accurate. If mechanism II and III occur, (1) and (4) are more accurate. However, (3) and (4) are simpler.

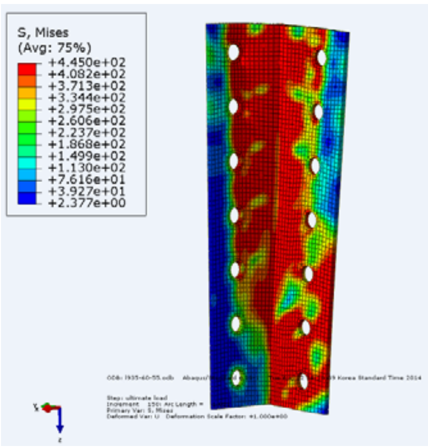
These hyperbolic function models can be easily applied to the single-angle web connections because the tangent stiffness, k_t, can be determined directly from equations without iteration.

$$k_t = \frac{dM}{d\theta} = \frac{\varepsilon\eta}{\sqrt{(\eta\theta)^2 + 1}} \quad \text{refer to (3),} \tag{5}$$

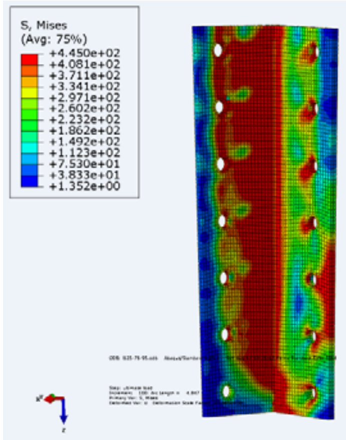
$$k_t = \frac{dM}{d\theta} = \frac{\varepsilon\eta}{\cosh^2 \eta\theta} \quad \text{refer to (4),} \tag{6}$$

in which k_t is the tangent stiffness; ε and η are the shape parameters.

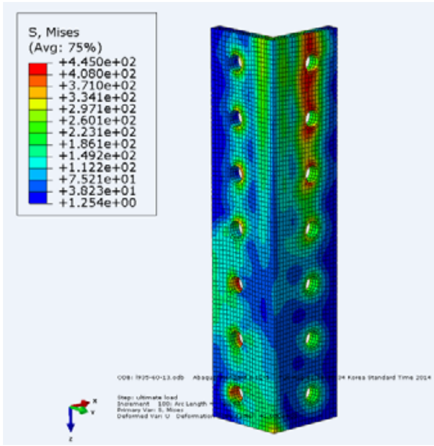
In order to verify these models, test data, which is obtained by Lipson in 1968, is utilized [18]. As can be observed in Fig. 6, the proposed models give a good curve fitting with test data. Hence, the hyperbolic function models are found suitable and adjustable for the representation of the single-web angle connection.



(a) Mechanism I

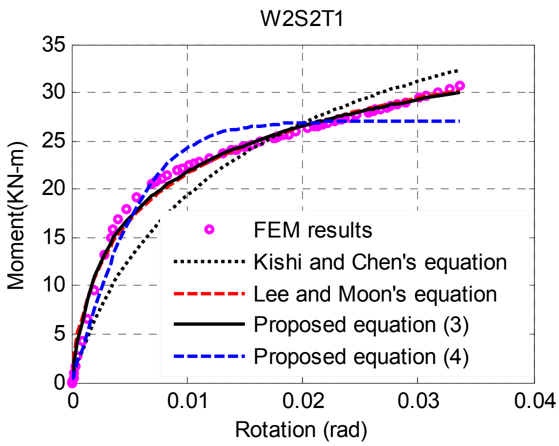


(b) Mechanism II



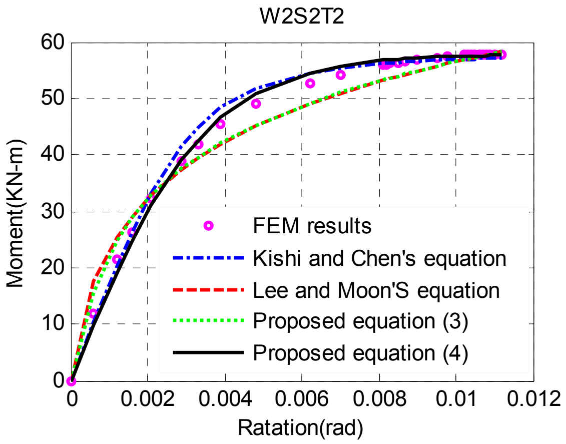
(c) Mechanism III

Fig. 4 Different types of mechanism; (a) Mechanism I, (b) Mechanism II, (c) Mechanism III

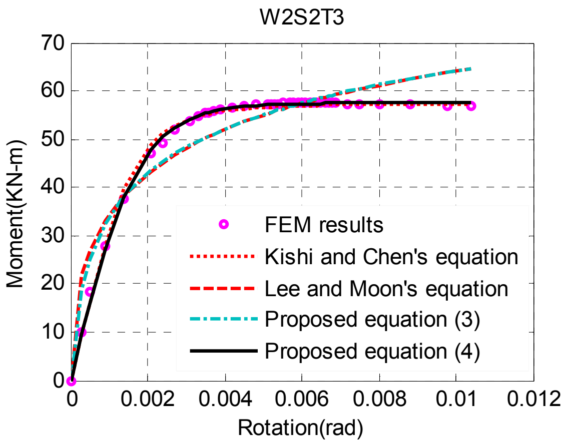


(a) Mechanism I

Open Science Index, Civil and Environmental Engineering Vol:9, No:7, 2015 publications.waset.org/10002010.pdf



(b) Mechanism II



(c) Mechanism III

Fig. 5 Comparison of M-θ curves; (a) Mechanism I, (b) Mechanism II (c) Mechanism III

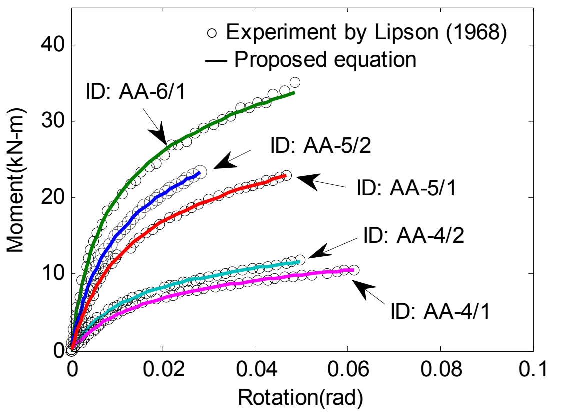


Fig. 6 Comparison of curve-fitting curves and test curves

IV. Conclusion

ABAQUS has been utilized to study the response of single-web angle connections to moment, and the test data of Gong is used to verify the results of finite element models. The result shows the finite element method is accurate. Several models have been developed to represent connection flexibility. Kishi and Chen's Power model and Lee and Moon's equation are popular among these models. According to the data of finite element models, these two models are accurate only for a limited range of mechanism considering moment and rotation. Two simpler and more accurate equations are proposed. If used in the correct range, these two equations are simpler and more accurate than existing models.

Hence, the results of the analysis can be utilized to determine the relationship between moment and rotation of single-web angle connections.

Acknowledgment

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (No.2011-0030040). This paper was also supported by the National Natural Science Foundation of China, Grant No. 51309001 and No. 51208002.

References

[1] Chen, W. F., Kishi, N. Semigrid steel beam-to-column connections: data base and modeling. J. Struct.Eng.1989, 115:105-119.
[2] Sang-Sup Lee, Tae-Sup Moon. Moment–rotation model of semi-rigid connections with angles. Engineering Structure, 2002, 24: 227-237.
[3] Krishnamurthy N, Graddy DE. Correlation between 2- and 3-dimensional finite element analysis of steel bolted end-plate connections. Comput Struct 1976; 6:381–9.
[4] Krishnamurthy N, Huang HT, Jeffrey PK, Avery LK. Analytical M-f curves for end-plate connections. J Struct Div ASCE 1979; 105:133–45.
[5] Krishnamurthy N. Modeling and prediction of steel bolted connection behavior. Comput Struct 1980; 11:75–82.
[6] Patel KV, Chen WF. Nonlinear analysis of steel moment connections. J Struct Engng 1984; 110:1861–74.
[7] Jenkins WM, Tong CS, Prescott AT. Moment-transmitting endplate connections in steel construction, and a proposed basis for flush endplate design. Struct Eng 1986; 64A:121–32.
[8] Kukreti AR, Murray TM, Abolmaali A. End-plate connection moment–rotation relationship. J Construct Steel Res 1987, 8:137–57.
[9] Kukreti AR, Murray TM, Ghassemieh M. Finite element modeling of large capacity stiffened steel tee-hanger connections. Comput Struct 1989, 32:409–22.
[10] Rothert H, Gebbeken N, Binder B. Non-linear three-dimensional finite element contact analysis of bolted connections in steel frames. Int J Num Meth Engng 1992, 34:303–18.
[11] Ziomek D, Tomana A, Waszczyszyn Z. Finite element modeling of end plate connection versus experimental results. In: Colson A, editor. Proceedings of semi-rigid behavior of civil engineering structural connections—COST C1, Strasbourg, 1992:433–42.
[12] Bahaari MR, Sherbourne AN. Computer modelling of an extended end-plate bolted connection. Comput Struct 1994, 52:879–93.
[13] Sherbourne AN, Bahaari MR. 3D simulation of end-plate bolted connections. J Struct Engng 1994, 120:3122–36.
[14] Gebbeken N, Rothert H, Binder B. On the numerical analysis of endplate connections. J Construct Steel Res 1994, 30:177–96.
[15] Bursi OS, Jaspart JP. Benchmarks for finite element modeling of bolted steel connections. J Construct Steel Res 1997, 42:17–42.
[16] Bursi OS, Jaspart JP. Calibration of a finite element model for isolated bolted end-plate steel connections. J Construct Steel Res 1997, 42:225–62.
[17] Yanglin Gong. Single-angle all-bolted shear connection. J. Const. Steel Res. 2009, England, 1337-1345.
[18] Lipson, S. L. (1968). "Single-angle and single-plate beam framing connections." Proc, Canadian Structural Engineering Conf., Toronto, Ontario, 141-162.
[19] Liu X. S., Chen, X. G. A new model for bolted-angle connections. Steel Construction, 2006, 21:44-50 (In Chinese).
[20] Liu X. S., Chen, X. G. A new design model for web-angle connections. Industrial Construction, 2007, 37:619-623 (In Chinese).