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ORIGINAL RESEARCH
PAPER



Behavior of L-shaped steel angle under prying force using Revit program

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ABSTRACT

Prying force formation at bolts is considered as an important problem in steel connection design. It affects the connection bearing capacity, ductility and serviceability negatively by increasing stresses induced inside connections. In the present work, behavior of steel connection under prying force is studied. A connection of steel beam-column has been modeled using software Revit program. Tension load is applied increasingly and the connection displacement has been measured until failure. Finite element simulation of steel angles under the effect of tension load and prying force has been studied. It is found that the connection has three phases of bearing behavior. Plastic hinge formation noticed increased with prying force presence.

KEYWORDS

prying force, steel connections, L-shaped steel angle, Revit

1. INTRODUCTION

Two L-shaped steel AISC 14.1 [1] $L_{3/2} \times 3_{1/2} \times 3/8$ are connected to steel beam I-section $W8 \times 35$ horizontally and to a steel column I-section $HP10 \times 42$ vertically as it is shown in Figs 1 and 2, which represents top and isometric view of the beam column under loading. I-section steel column selected to be rigid enough to prevent side sway or deflection could be occurring due to load in order to study the behavior of angles under prying force without the effect of any side sway or deflection. L-shaped steel angles are connected to two bolts in each side Grade 10.9, A325 [1] (one side washer) with diameter of 16 mm where the horizontal layout section of the bolts is perpendicular to the column layout see Fig. 1. A tensile load P_u is applied on beam horizontally in order to investigate the prying force behavior induced at the bolts. A simulation of the problem using Autodesk Revit 2020 [2] is as shown in Fig. 1, it can be noticed from Fig. 1a that the load is applied horizontally parallel to the centerline. Using equilibrium method [3], the action of load will be doled out equally to the bolts resulting equal prying force quantities at each bolt depending on physical and chemical properties of the steel material as well as depending on angle thickness which is in this case 10 mm thickness. Checking verification of overall buckling start with determining inertial moments [3]. Previous researchers investigated numerically the influence of imperfections on the buckling behavior [4].

Inclination of load P_u at an angle θ could be affect the quantity of prying force appears on each bolt; in this case where the load will be inclined from the centerline at an angle θ , the load P_u should be analyzed into two components P_{ux} in x -direction and P_{uy} in y -direction leading to different prying force quantities in each bolt. Farajpour [5] use an equilibrium equation to calculate the ultimate prying force in T-section [5]. The present work will focus on the behavior of angles under prying force with a tension load P_u parallel to centerline ($\theta = 0$) assuming that the prying force equally doled out on the four bolts as it is cleared in Fig. 1a [1].

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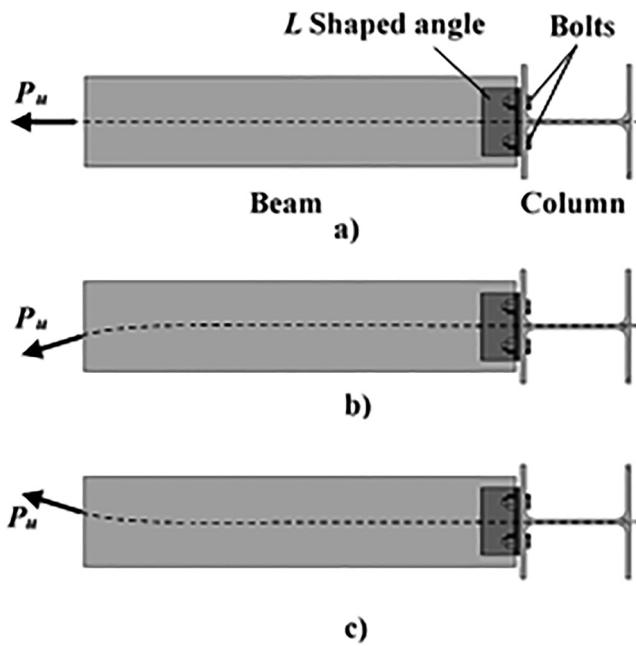


Fig. 1. Top view of the system under tension load

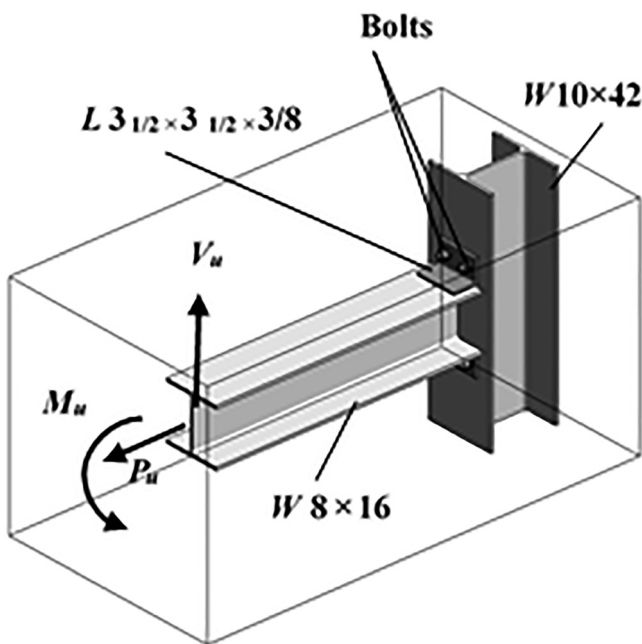


Fig. 2. Isometric view of the system under tension load

When the tension load P_u is applied, bolts will be under tension, the reaction in each bolt will be P_1 , P_2 , P_3 and P_4 and prying force arises at angles edges. To amplify prying force effect a moment M_u and a vertical load V_u are applied at the edge of the beam as shown in Fig. 2. Hiding part of column in Revit simulation to show the load action and reactions as it is shown in Fig. 3a and b.

Ignoring the effect of prying force and using equilibrium method, taking summation of loads at the direction of the centerline will lead to the following equilibrium simple equation:

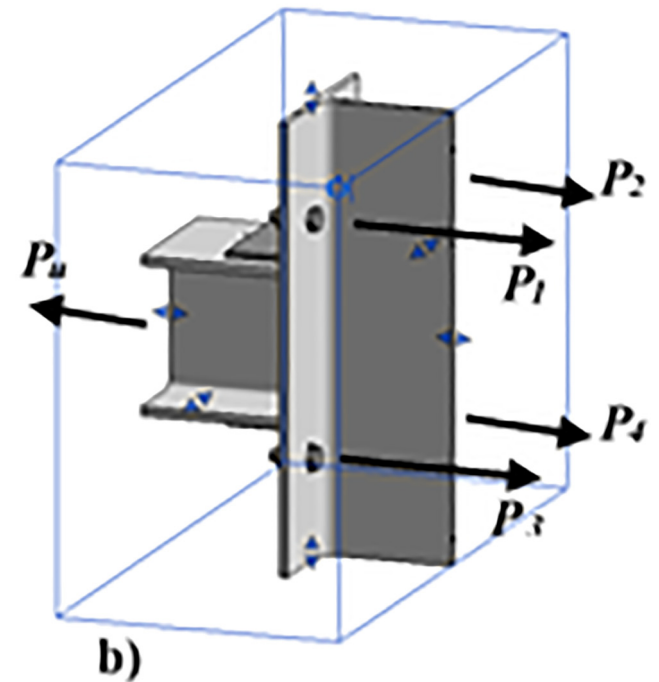
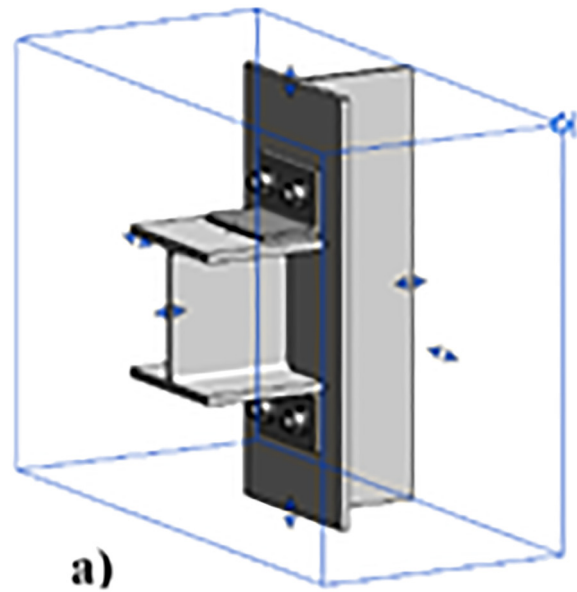


Fig. 3. Steel angles under loading

$$\sum F_{\text{at centerline direction}} = 0, \quad (1)$$

$$P_u = P_1 + P_2 + P_3 + P_4. \quad (2)$$

2. METHODOLOGY

Prying force effect appears at corner edges directly above the bolt centerline, it will spread alongside edge of the angle, of course prying force depends on the angle thickness, but also it depends on the bolts-angles connection. In order to take the prying force into account, it is necessary to re-write Eq. (2) to be as follows as Eq. (3), (see Fig. 4),

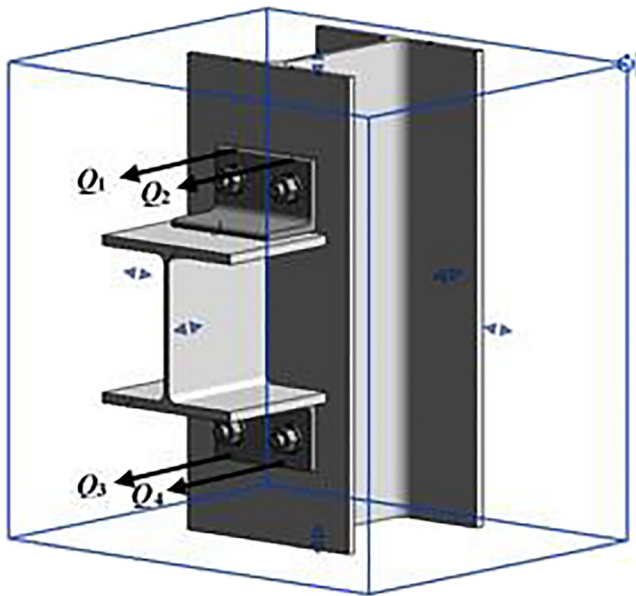


Fig. 4. Prying force effect

$$P_u = P_1 - Q_1 + P_2 - Q_2 + P_3 - Q_3 + P_4 - Q_4, \quad (3)$$

where Q is the prying force. Figure 4 shows the supposed places of prying force effect. The negative signs refer to the direction of prying force which will be in the opposite side of bolt reactions.

If $Q_1 = Q_2 = Q_3 = Q_4 = Q$, let $P_1 + P_2 + P_3 + P_4 = \lambda$, then from Eq. (3) $P_u = (P_1 + P_2 + P_3 + P_4) - 4Q$, then the prying force Q will be:

$$Q = \frac{\lambda - P_u}{4}. \quad (4)$$

When the linked pane of the angle is enlarged it will be clear that the bolts are under high tension load and the angles start to deform, at this stage a plastic hinge creates at bolts. The exact place of plastic hinge may depend almost on the following factors [6, 7]:

- Distance between bolts;
- Physical and chemical properties of the materials;
- Type and specification of bolts;
- Amount of load applied;
- Angle thickness.

Figure 5 shows a finite element simulation of the angles under loading. The bolts elongate under high tension and a small distance occurs in between the angle face and the column flange. The stress concentration in angle could be determined at each element corners, which is in this case a cubic element with 12 stress point, 3 at each corner (see Fig. 5).

Finite element simulation of the L-shaped steel angle could be differing from one connection to other depending on the load applied, bolts and connection type. Bending moment diagram for the angle connected to the I-section beam is shown in Fig. 6, where the maximum bending

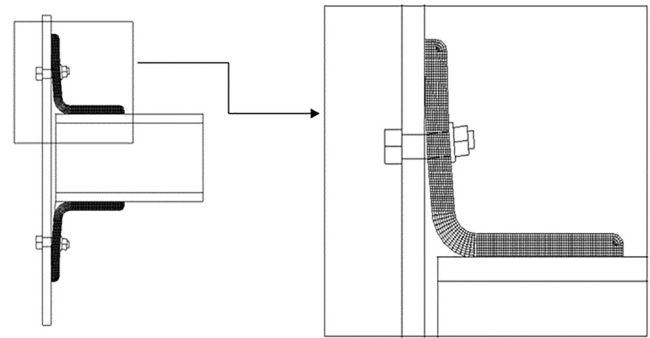


Fig. 5. Finite element simulation of angle using Revit program

moment M_1 occur in the middle of the beam where P_u applied, while M_2 at each side where the effect of bolt reactions occurs. Plastic hinge mechanism shows the supposed weakness points of the bolts, while in the middle of the steel I-section beam there is one plastic hinge if the height of the I section is neglected. Determination of plastic hinge could be little differing from the shape in Fig. 6 if the beam thickness is considering into account, in this case two additional plastic hinges could be occurring at the two sides of P_u .

3. LOAD DEFLECTION BEHAVIOR UNDER TENSION LOAD

In order to conflict angle behavior in the initial stage at the zone where the time of applied load act directly on the angle head, it is important to locate the angle thickness which will be in this case converge to 10 mm, in this case the efficient load to create the first group of deflection will be reaches to 280.00 kN as it is shown in Table 1.

The second stage of load start in region between the initial load is $P_u = 352.1$ kN and the load is $P_u = 353.35$ kN at this stage the angle ductility decreases and the prying force increased significantly. However, load deflection combination in steel sections is complicated criteria when it will be deals with time as the time zone need careful cautions

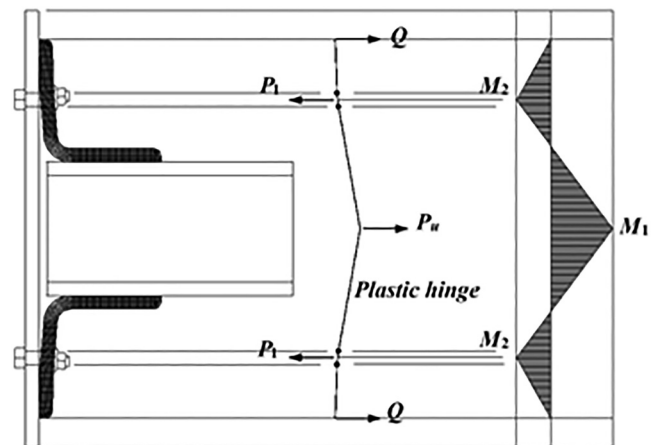


Fig. 6. Bending moment diagram and plastic hinges

Table 1. Load deflection relation

P_u (kN)	197.2	200.0	201.4	201.9	202.1	202.3	202.4	203.2	203.3
Def. (mm)	0.023	0.024	0.025	0.026	0.028	0.029	0.030	0.033	0.035
P_u (kN)	204.4	205.0	206.2	207.1	208.3	209.1	209.7	210.0	211.2
Def. (mm)	0.039	0.042	0.046	0.048	0.050	0.052	0.053	0.054	0.056
P_u (kN)	212.2	213.3	214.4	215.4	216.3	217.5	218.7	219.1	220.0
Def. (mm)	0.057	0.058	0.060	0.061	0.062	0.063	0.064	0.064	0.065
P_u (kN)	221.2	222.0	223.4	224.7	225.1	226.3	227.4	228.3	230.0
Def. (mm)	0.066	0.067	0.068	0.069	0.069	0.071	0.072	0.071	0.072
P_u (kN)	232.4	234.5	235.0	236.1	237.7	238.7	239.0	239.5	240.0
Def. (mm)	0.074	0.075	0.075	0.076	0.076	0.077	0.077	0.078	0.078
P_u (kN)	242.2	244.5	246.2	248.4	250.1	252.4	255.8	258.3	260.0
Def. (mm)	0.078	0.079	0.079	0.080	0.080	0.081	0.082	0.082	0.082
P_u (kN)	262.4	265.1	267.4	270.0	273.9	276.2	278.4	279.0	280.0
Def. (mm)	0.082	0.083	0.084	0.084	0.082	0.084	0.083	0.082	0.081

to locate the optimum value that make prying force appears without any deflected or failure in the angle part connected to it. Of course, the behavior depends significantly on the section thickness [8, 9], but in order to configure the prying force effect locally, it is important to maintain the plate thickness at the existing value. Table 2 shows the second stage of the initial load applied with respect to deflection measured in millimeters.

Making use of the load deflection curve behavior, it is recognized that the number of points load-deflection curve depending on the above data. The second stage of the initial quantity of prying force lies between 230.00 and 240.00 kN load zone. Plastic hinge occurs near the point that the prying force converge to its maximum amount (see Fig. 7).

4. RESULTS DISCUSSION

From the load-deflection curve, it can divide the curve, depending of the angle behavior, into three zones as listed below:

- Zone 1:** the initial applied load starts with 197.42–207.54 kN and the corresponding deflections were 0.023–0.046 mm. At this zone it can be indicated that there is no prying force found and also no plastic hinge deformed where the relationship between the load and the deflection is linear;
- Zone 2:** where the load applied start from 198.02 to 272.22 kN, where deflection converges to 0.082 mm. At this stage the relationship between the load and the deflection becomes non-linear where the increase in the deflection values more than the increase in the applied load. The results of this study are in agreement with those of the previous study by Kombate et al. [10]. This stage indicates that the angle flange is under ductile behavior due to the

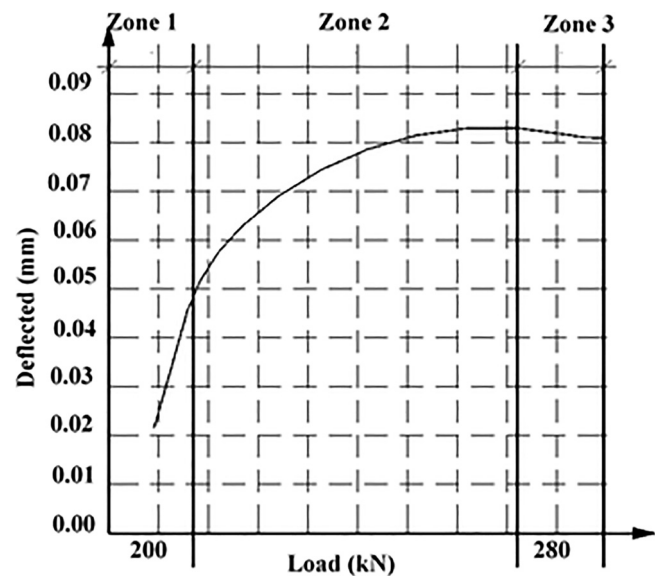


Fig. 7. Load-deflection curve

plastic hinge, and the prying force has been formed at the end of the angle flange;

- Zone 3:** where the load intensity above 280.00 kN and at this stage the deflection decreases to less than 0.082 mm. At this stage where it is the last stage of the of the curve where it can be seen that there is a decrease in the load capacity of the angle with the increase in deflection up to the failure.

5. CONCLUSION

The use of angle as a connection part in buildings is widely spread. The angles are usually connected to other parts by using bolts. The behavior of the angle under tensile load

Table 2. Load deflection relation for second stage

P_u (kN)	352.1	353.2	353.3	357.3	359.6	364.6	373.5	381.1	392.2
Def. (mm)	0.094	0.099	0.119	0.234	0.487	0.649	0.871	0.881	0.891

depends on many points, like number of bolts rows, thickness of angle and the applied load. In this research, a model for a steel connection has been made by using Building Information Modeling (BIM) in Revit program, then a tensile load has been applied to the angle and the deflection has been noticed. It was found, due load-deflection curve, that the connecting angle had three phases of behavior. Firstly, the deflection has linear relationship with the applied load where neither prying forces nor plastic hinge formed. Then plastic hinge formed with a prying force at the end of angle flange. At this phase the relationship between the load and the deflection is nonlinear and this nonlinearity increases up to the failure occurs in the angle flange where there was an increase in the deflection with a decrease in the load capacity.

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