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Effect of Air Gap on the Behavior of Double Web Angle Connections

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ABSTRACT: *The Indian Code for steel design IS: 800 recommends the polynomial model to predict the moment-rotation behaviour of double web angle (DWA) connections. The size parameters that influence the behaviour of DWA connections are the depth and thickness of web angle and the bolt gauge distance. A nominal air gap distance of not more than 10 mm is provided between beam and column, while assembling the connections for fabrication conveniences. This air gap distance is found to have considerable influence on the connection flexibility and the ultimate moment capacity as observed from the earlier studies on other type of beam column connections. Hence, numerical studies are conducted by varying the air gap distance to study its influence on the connection behaviour. Finite element (FE) modeling of DWA connection is carried out based on the previous experimental program. The performance of developed FE model is validated by comparison with experimental results and then the models are utilized to carry out the parametric study to understand the influence of air gap distance on the moment-rotation behaviour of DWA connections.*
Keywords - *air gap distance, double web angle connections, moment-rotation behaviour, polynomial model, semi-rigid analysis.*

1. Introduction

The flexural behaviour of beam to column connection is defined by moment-rotation ($M-\theta_r$) relationship, where the moment transmitted by the connection is related to the relative rotation between connecting members. The $M-\theta_r$ relationship is necessary, in lieu of connection test curves from which a sufficiently reliable determination of connection initial stiffness can be made. This will allow the end restrained effect to be realistically taken into account in the design of members of a frame. The capacity of a connection to provide rotational resistance strength, stiffness and deformation capacity can be assessed directly from a connection moment-rotation curve. DWA connections are usually considered as partially restrained type connections or more specifically, as simple shear connections. This means that DWA connections are modeled as pins and are assumed to transfer only shear to the supporting structural elements even though partially restrained type connections can transfer moments up to approximately 20 percent of those of fully fixed connections.

Mc Mullin and Astanch [1988] conducted several tests on DWA connections and concluded that their behaviour can be divided into three distinct regions during loading; a tee-hanger region, a shear beam region, and a compression region. Kishi and Chen [1990] developed the $M-\theta_r$ relationships of semi-rigid steel beam-to-column connections. Yang et al. [2000] carried out FE analysis of DWA connections subjected to axial tensile loads, shear loads and a combination of both. Hong et al. [2001] studied DWA connections subjected to monotonic axial tensile loading, shear loading and combined loading to establish the effects of the bolt gage distances and angle thickness. Yang and Lee [2006] studied the $M-\theta_r$ relationship of DWA connections and proposed two simplified analytical models for predicting the initial stiffness and ultimate connection moment. Though number of tests are reported on DWA connections, it does not involve the influence of consideration of air gap distance on the connection behaviour. Prabha et al. [2007] conducted numerical studies by varying the air gap distance between beam and the column of top and seat angle connections and concluded that the behaviour of FE model with higher air gap distances is flexible than the model without air gap distance. Based on their studies, the polynomial model suggested by IS:800 [2007] for top- and seat-angle connection is revised by including a new size parameter, the air gap and the proposed model is found to be more representative. In line to this, the effect of air gap distance on the behaviour of DWA connections are to be studied.

One of the objectives of this paper is to develop a reliable FE model based on the previous experimental programme [2005] to simulate the behaviour of DWA connections. The FE modeling is conducted using

ABAQUS software which provides an interactive and graphical environment that allows for easy modelling and generating complex geometry into meshable regions. Based on the validated model, a parametric study is performed to investigate the influence of air gap distance on the moment-rotation behaviour and the ultimate capacity of DWA connections.

2. Previous Experimental Work on DWA Connections

The experimental setup as shown in Fig.1 for DWA connections [2005] consists of two beams of length 1m each connected to a central column of height 650mm (Fig 1). The beams and column are made of Universal Beam (UB) steel sections 306.6x165.7x11.8x6.7x46.1 of ultimate tensile strength of 410MPa. Indian Standard angle of size ISA 65x65x6 and length 180mm is used as double web angle. An air gap distance of 10mm is provided between the beam and column. The test specimen is given the Id DWA-6-180, in which 6 represents the thickness of angle in mm and 180 is the length of the angle in mm. One side of the beam is supported on hinge and the other side on roller support. High strength friction grip (HSFG) bolts of 16mm diameter and 8.8 grade are used for the connection and are tightened to a pre torque of 214Nm. The present set up has the advantage that column does not rotate, but only displaces up and down and the relative rotation between the column and beam is mainly due to connection deformation. Dial gauges are placed at every quarter effective span of the beam to measure the deflection. Strain gauges are pasted at various locations to measure the strain variation. Inclinometer is used to measure the relative rotation between beam and column. The load is applied over the center of stub column in a displacement controlled manner. There are two stages identified in DWA connections, before failure occurs. First stage is before air gap closure and the second stage is after air gap closure. In the first stage, observations are; the load is carried by the torsion of the flange leg, web leg moves like a rigid body and tension face of the web leg yields. In the second stage observations are; load is carried by the compressive thrust on the web of column and tension in flange leg bolts. Finally plastic hinge is formed in the web leg and failed.

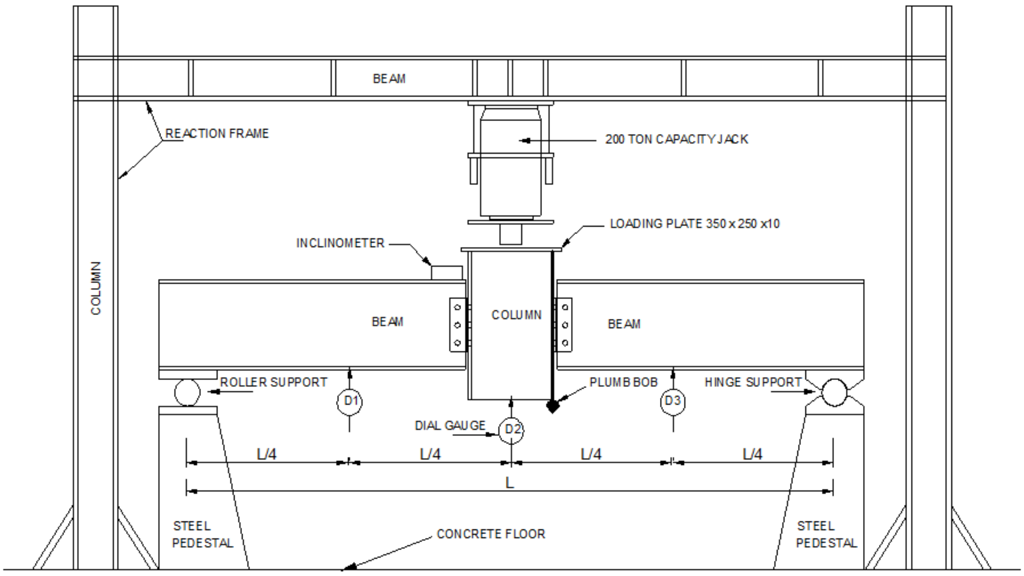


Fig. 1 Experimental set-up

3. Finite Element Analysis of DWA Connections

Three dimensional (3D) elasto-plastic nonlinear FE analysis (FEA) is carried out for evaluating the M-θr behaviour of DWA connections using ABAQUS software. The test details given in the previous section are used to develop the FE model (Fig 2). The beam, column and connection components are modeled by using continuum eight-noded solid elements with reduced order integration (C3D8R). An air gap of 10mm is considered between the beam and column. In order to simplify the model, the bolts and bolt heads are idealized as circular instead of hexagonal. Washers and fillets in the angle are not modeled to reduce the complexity. A clearance of 1.5mm is allowed between the bolt shank and hole. Based on the computational effort, convergence of the solution and by comparing with the experimental results, the final arrangement of mesh and elements are decided. The model is provided with simply supported end conditions similar to the experiment. The model is analyzed in two steps. The first is the pretension step, in this step each bolt is pre-tensioned with a force of 70 kN equivalent to the experimental torque of 214Nm on a pre-selected section of the bolt shank. In the second step, pressure load is applied on the top of central stub column.

The interaction consists of two components, one normal to the surface and the other tangential to the surface. The tangential component consists of relative motion between the surfaces and frictional shear stress if connection is done by HSFG bolts. Hard contact is given between the surfaces i.e. the surfaces separate when the contact pressure between them becomes zero or negative. While in contact the normal and shear forces are transmitted from one surface to another. The forces are transmitted by friction between members as a result of bolt pre-tensioning. Hence, the contact between web angles to beam web/column flange is given as friction surface to surface contact with a suitable friction coefficient value. The contact between bolt shank and hole is given as frictionless contact. To simulate the exact connection behaviour, finite sliding contact pair definition is given between the two surfaces, one of which is the master and other is slave surface. The master surface should be a discontinuous surface and the surface intersecting the master is called slave surface. Tie constraint is assumed between the bolt head and the respective contacting surfaces. Stress-strain relationship of steel is represented by a tri-linear constitutive model. The material properties of the connection are shown in Table 1. The material model for beams, column, angle and bolts are given in Fig 3. Nonlinear static analysis is carried out by considering geometric, contact and material nonlinearities.

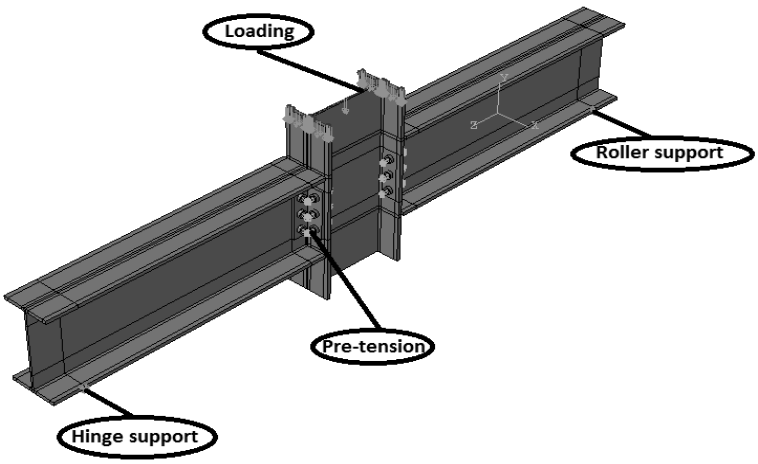
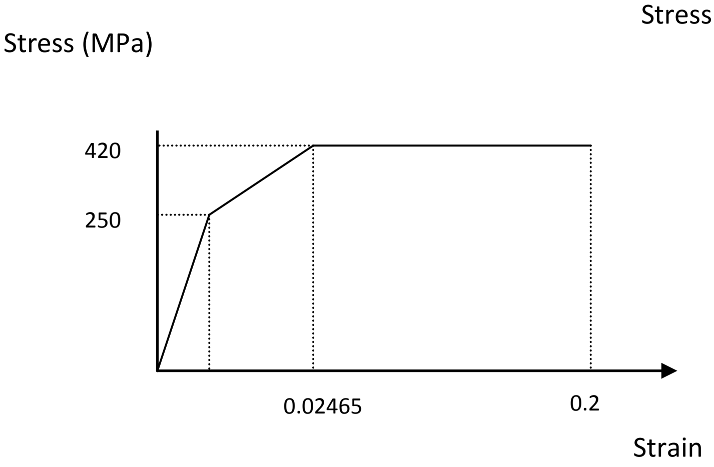


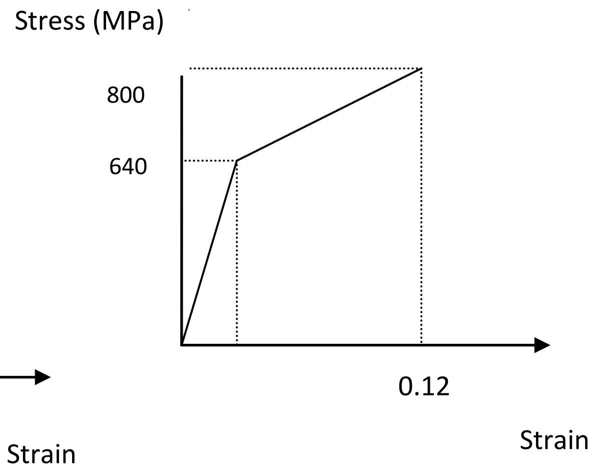
Fig. 2 FE model of DWA connection with loading and boundary conditions

Table 1. Material Properties

Connecting member	Young's modulus (GPa)	Poisson's ratio	Yield Strength fy (MPa)	Ultimate strength fu (MPa)	% Elongation
Beam, column and angles	200	0.3	250	420	20
Bolt			640	800	12



a) Beam column and angles



b) bolt

Fig. 3 Material model

4. Comparison of Results and Validation of the FE Model

The results of FE model and the experiment are compared in terms of connection failure, stress distribution and the moment-rotation behavior. The deformed shape of the connection at the ultimate stage is given in Fig. 4. For a ductile material like structural steel, von-Mises theory is one of the most well-known theories to predict failure. Hence the von-Mises yield surface criterion is used in ABAQUS to specify the start of plastic flow in the FE model subjected to compression load. Also the amount of von-Mises stress is higher in the areas close to the junction of web angle as expected (indicated by the dark shade, Fig 5). The failure mode of FE model is found to be in good agreement with the experimental observations (Fig 5). The moment-rotation curves obtained from FE analysis are compared with the experimental results in Fig 6. The connection moment is evaluated by multiplying the reaction force with the distance between beam support point and face of the column flange. It is observed that the initial slip due to bolt pre-tensioning predicted by FE analysis and experiment are similar. The second slip due to the closure of air gap is also very well captured by the FE analysis. The discrepancy in the ultimate moment capacity between experimental results and FE analysis is only 3%. As the failure load and mode of failure agrees reasonably well, this model is adopted for further parametric studies.

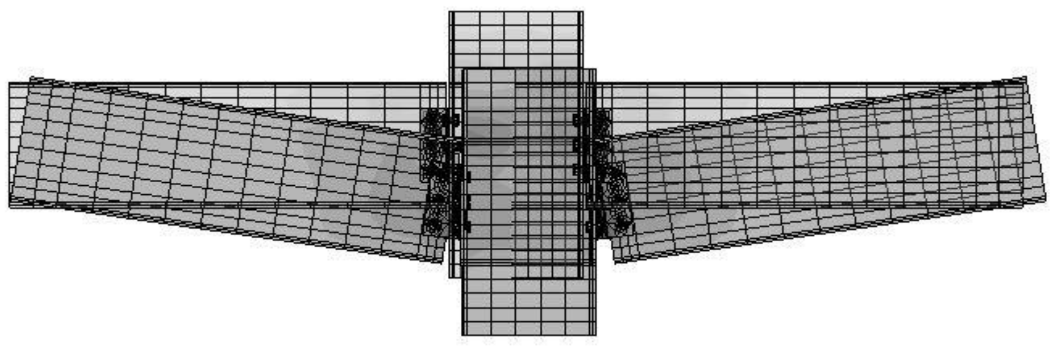


Fig. 4 Deformed shape of the connection at ultimate stage

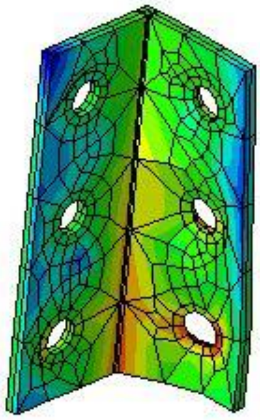


Fig. 5 Comparison of failure of the connection

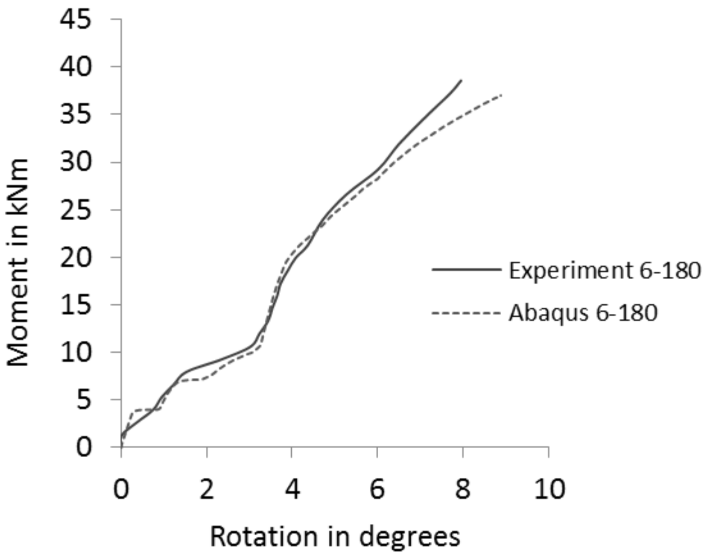


Fig. 6 Comparison of M-θ_r curves of experiment and FEA

5. Effect of Air Gap on the Connection Behaviour

Three FE models are developed to study the variation of air gap on the connection behaviour, one without air gap and other with air gap distances of 7mm and 10mm between the beam web and column flange. The graph showing the comparison of the connection behaviour with varying air gap is shown in Fig. 7. It is observed that the initial stiffness remains same up to a rotation of 0.5 degrees irrespective of the air gap distance. The first slip observed in all the FE models is the bolt slip due to the initial pretension force in the bolts. Beyond this point, there is considerable difference in stiffness as the air gap varies. The model without air gap is stiffer than the models with an air gap distances of 7 and 10mm, because the model without air gap is already in contact with the column flange, whereas in the other models there is an additional slip due to the closure of air gap distance before coming into contact with the column flange. The moment capacity of the connection has increased by around 20% for the specimen without air gap. Hence, the presence of air gap distance provides significant flexibility to the connection and has reduced moment capacity. In all the FE models, the failure of connection is by the tearing of web angle.

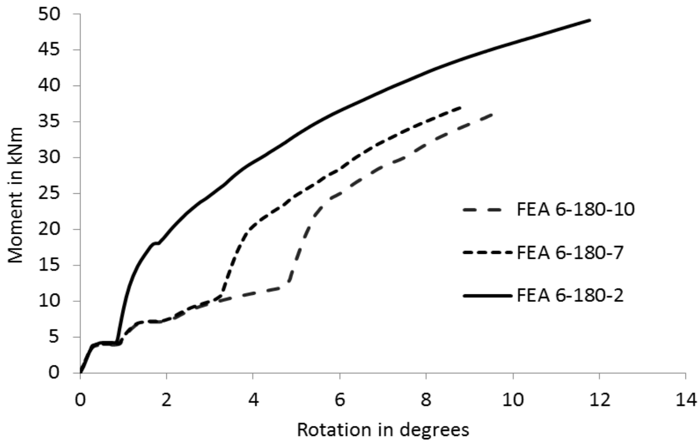


Fig. 7 Effect of air gap on the connection behaviour

6. Summary and Conclusions

In addition to the parameters that influence the behaviour of DWA connections viz. the depth and thickness of web angle and the bolt gauge distance, the air gap distance provided between beam and column for fabrication tolerances, has considerable influence on the connection flexibility and the ultimate moment capacity, as observed from the earlier studies on an another different type of connection. Hence this study focuses mainly to study the effect of this air gap distance on the DWA connections by means of numerical prediction using ABAQUS. Finite element (FE) modeling of DWA connections is performed based on the previous experimental programme. The performance of developed FE model is validated by comparison with the experimental failure modes and the results. Three finite element models are developed, one without air gap and the other two with air gap distances of 5mm and 10mm between beam and the column. The comparison study showed that the FE model with least air gap is found to have stiffer M-θr behaviour and the higher moment carrying capacity than the one with higher air gap distance, which is more flexible. Based on the present study, it is suggested to consider the air gap distance as an additional parameter while predicting the ultimate capacity and $M\text{-}\theta_r$ response of DWA connections.

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