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Shear behaviour of trapezoidal column panels. I: Experiments and finite element modelling

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ABSTRACT

The behaviour of joints exerts an important influence in the overall performance of steel and composite structures, both in deformations and in ultimate resistance. As a consequence, a considerable effort has been carried out in recent years to better characterize the behaviour of joints in these kinds of structures. Modern codes, including Eurocodes 3 (EC3) and 4 (EC4), have included these research advances so that they may be used in common practice.

The method adopted in EC3 and EC4 to characterize the connections is the so-called component method. One of the most important components is the column web panel in shear, and its behaviour has been investigated thoroughly for the case of rectangular shear panels arising when the beams have equal depths. However, the case of trapezoidal column panels, formed by beams of different depths at each side of the column, has not been researched as much. Formulae or design recommendations for the shear behaviour of steel beam-to-column joints with beams of unequal size are not currently included in design codes.

The aim of this paper is the characterization of the shear behaviour of trapezoidal column panels. In order to isolate the shear behaviour from other components, stiffened beam to column connections with commercial sections are experimentally tested. Also, finite element modelling and analysis are carried out to compare results, and a mechanical model is proposed. Current modelling procedures are tested and the results compared with those coming from the experiments and numerical simulations.

1. Introduction

The characterization of steel joint behaviour and properties has been a matter of research for a number of years, and all the accumulated knowledge has been compiled to a large extent in currently available structural steel design codes. One important aspect is the behaviour of the column panel subjected to the shear forces arising from the moments of the adjacent beams as well as the shear forces acting on the columns. A correct definition of the column panel zone deformations under static conditions is of great importance due to its influence on the overall sway behaviour of the frame. An increase in frame drift due to panel zone shear deformation may render the frame unserviceable. This may even happen for commonly considered rigid joints. Modelling of the column panel is also important for the avoidance of local failure under ultimate limit state conditions.

Krawinkler et al. [1] reported the importance that panel shear deformations have on the frame behaviour under lateral loads, and proposed a formulation for the stiffness and resistance of shear panels of beam to column connections with beams of equal depths. An alternative formulation has been proposed in the Eurocode 3, part 1.8 [2] following the component method [3–5]. These and other proposed methods allow introducing the flexibility of joints in both the elastic and inelastic range in order to assess the frame response [6,7] and also including high strength steel [8].

The lines connecting the flanges of beams of unequal depths define a trapezoid within the panel column zone. Hoogenbroom and Blaauwendraad [9], and Curtis and Greiner [10] have proposed analytical and computational methods to characterize the shear behaviour of isolated quadrilateral panels. More recently, Hashemi and Jazany [11] have investigated the connection detailing of joints of unequal beam depths under seismic loads. One of their conclusions is that inclined stiffeners connecting the lower flanges of the beams perform better than the horizontal ones. Jordao et al. [12] have studied the performance of this type of joints for high strength steel without the use of web stiffeners. As a consequence, the stress field at the panel zone becomes rather complex due to the fact that the compression, tension and shear components are all coupled together within the panel zone. The common failure mode of the experiments carried out in [12] was web buckling due to compression. Within the context of the component method, they propose a joint model based on two subpanels delimited by 3 levels of load introduction coming from the beams. A suitable

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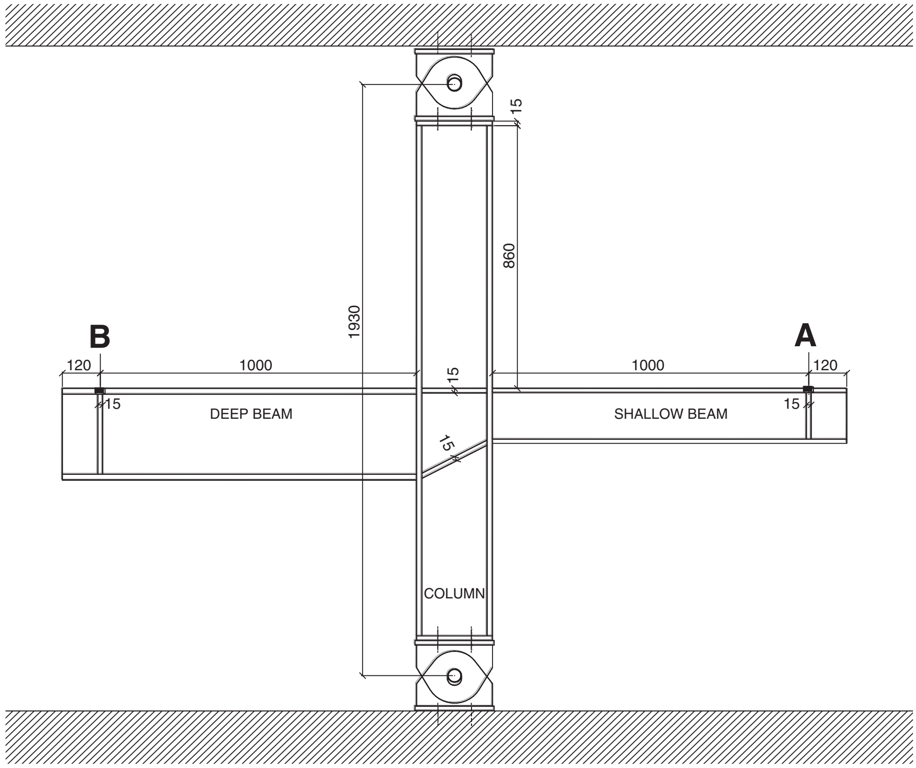

Fig. 1. Experimental setup.

modelling of the joint for global analysis can be achieved by considering the cruciform element proposed by Bayo et al. [13,14].

Work remains to be done to better characterize the complex behaviour of steel joints with beams of unequal depths and trapezoidal panels. The study involves a large number of variables and intervening factors. In this paper, experimental work and numerical (finite element) results are presented that provide important information to characterize and model this type of joints. The moment rotation diagrams depend on a large number of material, geometrical and loading variables.

The research presented concentrates on the shear stiffness and resistance of the trapezoidal panel zone and the additional contribution provided by the elements surrounding the panel such as the column flanges adjacent to the panel. These elements play a major role in the joint post-elastic reserve shear strength and stiffness. Since the aim is to study the shear behaviour and component of the panel zone, stiffeners are included to avoid the effects of other components such as the column web in tension and compression, and to prevent their interaction with the shear component as much as possible. Furthermore, an inclined stiffener in the lower part of the panel assures trapezoidal behaviour. Consequently, only stiffened fully welded connections were considered in this investigation.

The moments acting at both sides of the joint are the most important contribution to the panel shear force, and they are usually considered as the load variables characterizing the strength and stiffness of the joint. However, the beneficial effect of the column shear should also be considered (particularly in the case of short columns) in the joint stiffness and strength as proposed by Krawinkler et al. [1]. The deformation is defined in terms of the average shear distortion of the panel zone (PZ), and it is measured in this investigation by means of two inclinometers located on the middle section of the panel. The deformations on both sides of the panel (the shallow and deep sides) will be considered as well. The aim is to understand the mechanisms of deformation and characterize the moment rotation curves for the shear component of the trapezoidal panel.

2. Experimental work and finite element models

The experimental work has been carried out in two different prototypes with beams of unequal depth. The overall scheme is illustrated in Fig. 1. The column is pinned at both ends and actuation is applied at points A and B on the attached beams. The distance from these points and the column flanges is exactly 1000 mm. Table 1 shows the beams and column sizes in both tests, and Fig. 2 depicts a picture of the experimental setup.

The top horizontal and the inclined stiffeners were welded as depicted in Figs. 1 and 2 to avoid, as mentioned above, any type of failure other than that produced by shear. The stiffeners were 15 mm thick and in all cases were rigid enough to provide the necessary resistance to

Table 1
Characteristics of the tests: beam and column configurations.

Test	Column	Deep beam	Shallow beam	Depth ratio	Loading point	Type of loading
E1A	HEA 240	HEB 300	HEB 160	1.88	A	Elastic
E1B	HEA 240	HEB 300	HEB 160	1.88	B	Failure
E2A	HEA 240	HEB 300	HEB 180	1.67	A	Elastic
E2B	HEA 240	HEB 300	HEB 180	1.67	B	Failure