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Numerical based performance of UK industry standard simple and/or semi-rigid steel connections subjected to rapid rotations.

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Abstract

The majority of multistory steel framed buildings in the UK are designed such that the connections between the frame elements can be classified as 'simple' or 'semi-rigid'. Current UK design provisions relating to structural integrity and robustness for these types of connections do not currently incorporate dynamic effects such as inertia or strain rate sensitivity. A numerical study has been carried out on a typical UK beam-column simple connection, in which the supported beam connects into the web of the supporting column. The connection has been subjected to a rapid rotation using the finite element software package LS-DYNA. Results and discussion of the numerical study are presented herein; experimental validation of these results is currently being carried out.

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1. Introduction

Highly transient loading conditions, such as blast and impact, are now a very real and necessary design consideration for the structural engineering community. The two topics, in the context of building engineering, have been highly active research areas for a number of years and steel-to-steel connections have been a key focus for many academics and engineers in the field of resilience in the built environment. In the UK, it is common practice for the connections between primary structural elements in a steel framed building (excluding portal frames) to be designed to resist only shear forces in the normal design situation with their ultimate tensile capacity assessed to

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satisfy any progressive collapse requirements in the accidental design situation. Such design methods consider only quasi-static loading conditions and neglect the dynamic nature of a collapse, blast or impact scenario. The American based design code UFC 3-340-02: *Structures to resist the effects of accidental explosions* [1] proposes a limiting rotation of 2° at the supports of a steel beam, or a maximum ductility ratio, μ, of 10 (whichever governs) to ensure safety of personnel or equipment, where the ductility ratio is defined as the ratio of maximum dynamic response to the equivalent elastic response of the beam. This rotational limit, when applied to connections typically used for simple braced-frame construction in the UK (such as those in SCI P358 [2]) could likely result in the need to re-design the frame as a continuous frame, adding extra cost to a project not only in design fees but in construction costs also.

Progress has been made to understand the true capabilities of such connections when subjected to transient loading mechanisms. Tyas and Stoddart et al. [3-5] subjected typical UK style simple beam-column connections to rapid rotations in a purpose made test rig, and observed increases in peak resistance when compared to quasi-static resistance. Rahbari et al. [6] utilised the same experimental test rig to study angle cleat connections (a form of connection omitted from SCI P358) and observed rotational capabilities of the order 12-14°. There have also been a number of studies [7-10] that have considered UK style connections under sudden column loss scenarios and found it unsafe to rely on static force based catenary action as a mechanism that will arrest the onset of collapse. More recent studies [11,12] that investigate connection behaviour when subjected to impact loading, seek to characterise connections by their energy dissipation capabilities. This falls in line nicely with a preceding study carried out by Szyniszewski and Krauthammer [13] in which the energy flow of a progressive collapse was studied and it was concluded that the ability of any structure to arrest a collapse hinges on its capacity to dissipate kinetic energy, going on to say that future studies may need to focus on energy dissipation.

2. Simple and/or semi-rigid connections typically used in the UK

Existing studies on the topic tend to look at beam-column connections in which the beam connects to the flange of a column square on, as well as this, the majority of studies assume the same grade of steel (S355) is used in practice for the connecting members as for the plate elements of a connection. In the UK, it is almost always the case that the main structural elements (beams and columns) on a project are comprised of grade S355 steel, while any plate material components (flat bracing & plates within connections) are comprised of S275 steel. Bolts within the superstructure connections are usually fully threaded M20 (8.8) bolts and welds are typically 6 or 8mm fillet welds. This is most likely to ensure a connection is classified as 'simple' and does not attract any unwanted fixity. SCI P358 recommends any plate elements of a connection be a maximum of 12mm in thickness, bolts be M20 in size and welds be a maximum of 8mm fillet welds. Standard bolt pitch (vertical spacing) is 70mm and the gauge (cross centres) is set at 90mm for connections where the connecting beam depth is up to 533mm, and set at 140mm beyond that, assuming M20 bolts are used. If a connection is specified beyond these recommendations, then it is more likely to be classified as 'semi-rigid' than 'simple' in accordance with EN1993-1-8 [14]. The additional rotational stiffness properties that semi-rigid connections possess are seldom utilised in the design of structures in the UK. A survey conducted on the UK steel construction industry [15] indicated the most preferred form of simple and/or semi rigid connections to be full depth end plates followed by partial depth end plates and then fin plates. The connection studied here-in examines the numerical based performance of a partial depth end plate connecting into the web of a supporting column.

3. Numerical Model

A numerical model has been built of a partial depth end plate connection between a 305x127x37 UB and a 203x203x46 UC using the LS-DYNA finite element code. The end plate was 150mm wide, 220mm deep and 10mm thick, it was welded to the 305x127x37 UB section with a 6mm fillet weld. The plate then connected to the web of the 203x203x46 UC section, along centre lines, with 6No M20 bolts in two lines at 90mm gauge and positioned with 70mm pitch emanating from the centre of the end plate. The grade of steel of the two open sections was treated as S355, the grade of the end plate treated as S275 and the grade of the bolts treated as grade 8.8. It was assumed the weld inherited the same material properties as the end plate. The numerical model resembled a drop hammer test which is to be conducted on the specimen at a later date. An engineering drawing of the drop hammer test is shown in Fig. 1.