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BEHAVIOR OF INNO3D JOINTS UNDER MONOTONIC AND CYCLIC LOADING

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Abstract

Hybrid structures are highly efficient and economical. In particular, modular solutions with tubular columns combined with horizontal light-weight girders made of cold-formed steel sections may provide a cheap and efficient system. In order to simplify the on-site erection phases, a novel plug and play joint has been proposed within the RFCS INNO3D joints project to enable industrialized and modular solutions that ensure fast-track construction and increase the quality of the finished product. The aim of this paper is the investigation of both the monotonic and cyclic behavior of this type of joint by finite element analyses. Thus, an advanced numerical model was developed and validated against experimental results performed within the INNO3D research project. The results show for a large rotational value and increase of the joint stiffness due by the contact between the joint components.

Keywords: INNO3D joints, Finite element model, Abaqus, Plug and play joint

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1 INTRODUCTION

Nowadays increasing attention is given in the design of steel structures located seismic area to avoid brittle failure concentrating all the plastic deformation within the ductile elements [1-17]. In particular, in steel market there is a growing interest in developing new design and construction approaches that could results more efficient, safer, environmentally friendly, less labor-intensive, and can lead to buildings that are of higher standards and can be constructed in a compressed schedule [17-22]. Shortage of skilled workers, low productivity, and increasingly stringent client requirements are the incentives behind developing innovative approaches. The construction industry has been dominated by conventional construction practices which are less efficient and economical. Modular constructions provide several advantages. The economy of modular systems depends on several variables, namely: resistance to lateral load and the type of connections which plays a major role in stability and robustness of the system.

To meet the needs of clients and communities of the future it is required to rethink the design and construction processes and develop appropriate responsive strategies. A few modular construction systems are available using light-weight steel solutions, which are easily assembled in panels and delivered on site. The European project DRYCONDIS summarizes the capabilities of light-weight steel dry construction building systems [23]. Several research projects have dealt with light-weight steel systems for prefabricated steel buildings and their integration with the steel skeletal system (e.g. ETHICS; InFaSo; FrameUp; PRECASTEEL, [24-27]). However, in only a few of them, the execution phase was a main parameter considered in the development and optimization of the system.

In the light of these considerations, innovative modular constructions with hybrid systems made of lightweight steel truss girders connected to tubular columns by means of plug-and-play joints have been developed within the recent INNO3DJOINTS (acronym of "Innovative 3D joints for robust and economical hybrid tubular construction") project in order to ensure fast-track construction and increase the quality of the finished product. This paper aims to provide a preliminary investigation of the joint under monotonic loading.

2 DEFENITION OF THE INNO3DJOINTS

Figure 1 (a) illustrates the main elements of the system and the details of the plug-and-play connection (b). Columns could have cold-formed rectangular, square, or circular hollow structural section, while the beams are truss girders composed of light-gauge cold-formed profiles which provides the main lateral resistance of the system. The joint is a plug and play joint which guarantee a fast and safe on-site execution. As showed in Figure 1b, the joint is connected to the column at two different levels. It is noteworthy to mention that, due to the cold-formed characteristics of the cross section, the joint is connected to the column at the end of the corner radius; these details improve the connectivity of the joint to the column, since the welding procedure of this this type of profiles could show some local imperfections. The main components are the socket and the plug: the former is made of two S-shape plates that are welded to the column's face at one end, while serves as a host for the plug on the other end. The plug is made of a T-shape and U-shape plates, and it is reinforced by stiffeners at both sides. In addition, the plug is connected to the truss on one end, and it will be locked in the socket on the other side. During fabrication of the structure in a steel workshop, the T-plug with Y-fork are assembled to the truss girder and the socket is welded to column.

The slab in this system is constructed using CLT panels, providing both the necessary gravity load-bearing capacity and enough in plane rigidity to act as a rigid plane diaphragm.

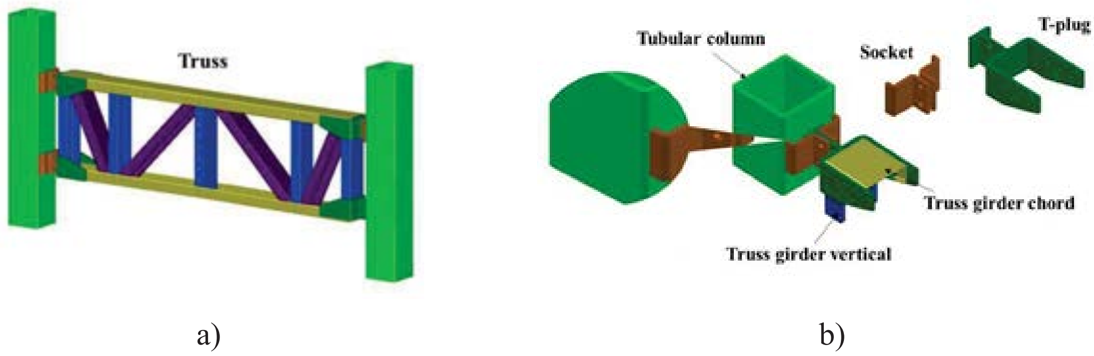


Figure 1 Structural system (a); Details of the plug-and-play connection (b)

3 FINITE ELEMENT MODELING OF THE JOINT

A 3D model of the test specimens was developed based on the experimental set-up as shown in Figure 2. The model was developed by means of Abaqus software [28] and all the main modelling assumptions are in line with the models developed by Tartaglia et al. [29-34]. Due to the large number of contacts, the bolts and the material nonlinearity, the full 3D model is difficult to construct and is computationally intensive. Thus, considering some simplification is necessary for the model; in this case proper boundary condition were introduced to reproduce the symmetry of the connection. A mesh transition technique is used to mesh the model. The fine mesh was used in a critical area or anywhere that the behavior of the model is important. A coarser mesh is used in areas further away from the critical zones by using a wedge element between two zones. A general contact is defined for the model. For general contact interactions, the discretization, tracking approach, and surface role assignments are selected automatically by Abaqus/Standard. A contact property that has tangential and normal behavior is assigned to the contact. The penalty method is selected for enforcing the contract. It enforces the contact by use of springs without adding a degree of freedom to the matrix structure.

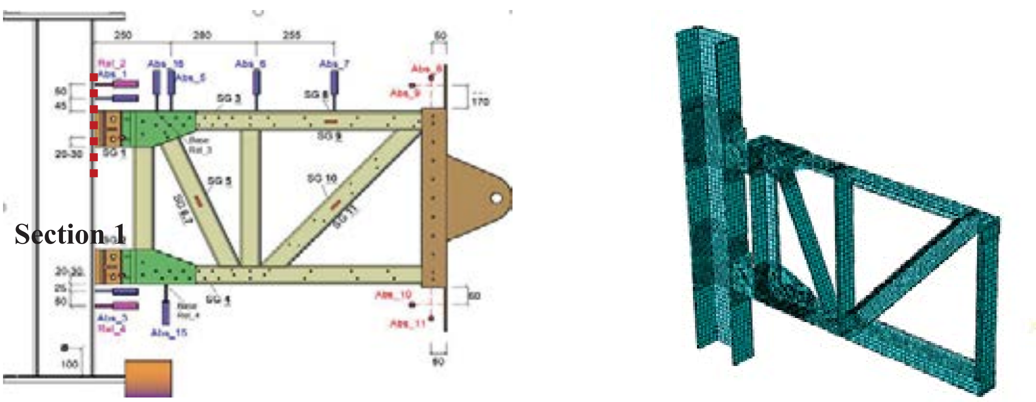
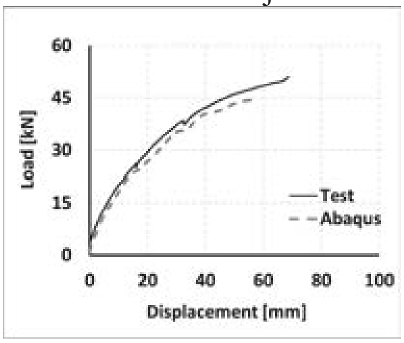
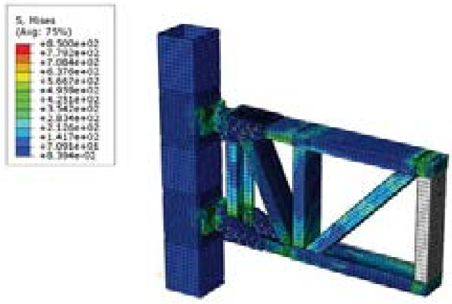


Figure 2 Left: the test set-up Right: the FEM

Figure 3a shows the comparison between the numerical simulation and the experimental test in terms of force versus the displacement curve. The force is measured by the load cell while the vertical displacement is extracted from the LDTV ABS_11 (see Figure 2). After an initial decrease, the joint shows an increase of stiffness. This additional source of stiffness is due to the contact between the T-plug and the socket.

The Von-mises stress are also depicted in Figure 3b where a large concentration of tensions can be observed at the join location.



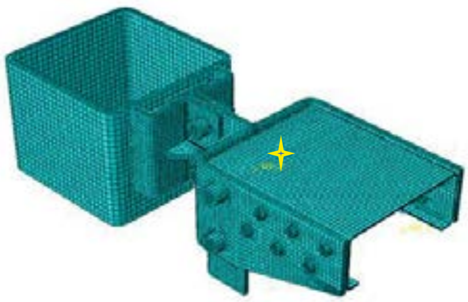


a) b)

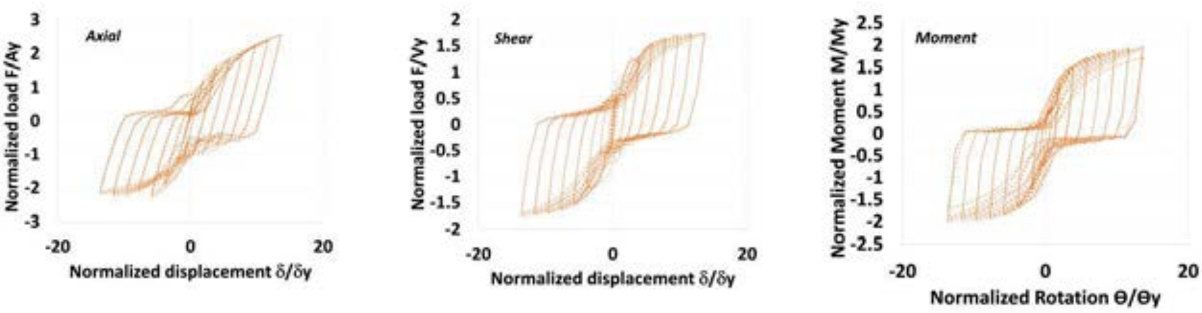
Figure 3 Force-displacement from the FEM and available experimental data.

The top joint is isolated from the system to investigate the cyclic response of the joint as shown in Figure 4a. The cyclic behavior of the joint is investigated under the ECCS loading protocol. First, a monotonically increasing displacement load (rotation) was applied to the reference point that is highlighted in yellow. From the recorded force (moment) – displacement (rotation) curve, the conventional limit of the elastic range and the corresponding displacement (rotation) were deduced based on ECCS prescriptions. The reaction forces and moments are extracted from section-1 (see Figure 2).

The cyclic behavior of the joint is evaluated and shown in Figure 4 in terms of bending moment, shear and axial force. The curves are normalized with respect to the axial, shear and bending yielding resistance evaluated from the monotonic response. The hysteretic behavior shows a fair amount of pinching which is mainly due to the opening and closing of the bolts or contact and separation of different plates in the joint.



a)



b) c) d)

Figure 4: The cyclic behavior of the inno3Djoint

4 SUMMARY AND CONCLUSIONS

INNO3DJOINTS joint is an innovative plug-and-play joint for hybrid tubular construction, whereby tubular columns are combined with cold-formed lightweight steel profiles to provide a highly efficient structural system. A finite element model of the joint was developed based and validated against the experimental test. Under monotonic loads an initial loss of stiffness due to contact between the T-plug and the socket can be observed; contrariwise for increasing value of rotation an increase of stiffness was observed. This discontinuity can be observed also when the joint is subjected to cyclic action; indeed, as observed the joint cyclic behavior is characterized by a pinching behavior.

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