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DESIGN AND VERIFICATION OF A TESTING INTERFACE FOR AXIAL AND BENDING LOADING OF THE STRUCTURAL *T* JOINTS

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Abstract: *The plane welded T joints validation is made by axial and in plane bending loading, both of them requiring dedicated test rigs. The article presents the development of a device consisting in an interface that allows both types of loadings, on a common testing machine. The numerical calculations of stresses and displacements are presented. The behaviour of the testing interface within the experimental testing program is assessed, together with design recommendations and conclusions.*

Key words: *welded steel structures, T joint, experimental testing, test rig*

1. Introduction

The experimental testing of structural joints requires dedicated test rigs to provide apropriate fixture, rigidity, load introduction and specific measurements. Because every joint has specific load cases, most of the time, dedicated test rigs are needed for every load case or at least customised modules of the test rig.

Test rigs are fitted with axial or bending actuators, measurement data being collected with strain gauges or with alternate systems (like photogrammetry) [1], [2] and [3]. For complex joints, test rigs may be fitted with multiple loading systems as presented in [4], [5], [6] and [7]. For simple bending loads, a simpler solution is presented in reference [8], by inserting fittings in the junction's tubes ends. This last application allows only bending testing.

Article presents a testing interface that permits two different kinds of fixture for the *T* joints within a bigger range of member's dimensions. This interface allows the testing of joints using an universal testing machine. The interface consists in a welded subassembly, without needing actuators or bolted clamps.

Thus, using a single interface, dedicated test rigs are not needed any more, saving time and money for experimental testing.

2. The Tubular *T* Joints

The most usual structural hollow sections (HS) from civil and mining engineering are circular (CHS) and rectangular (RHS). The civil engineering (steel constructions) dedicated many studies and research programs to *T*, *Y*, *K* and *X* connections under different types of loading conditions [15], [22], [19], [21]

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and [20]. The studied connections are planar or multiplanar, under axial loading, in plane bending or out of plane bending.

According reference [14], the use of circular section structures against open profiles is justified by higher overall buckling strength, higher radius of gyration depending of the cross sectional area and smaller effective buckling length than that of angle profiles. For the same compression capacity, the hollow structures (CHS & RHS) weight section is almost 60% from the *H* section [15]. Circular hollow structures present also the lowest aerodynamic drag, for this reason being extensively used in aircraft industry.

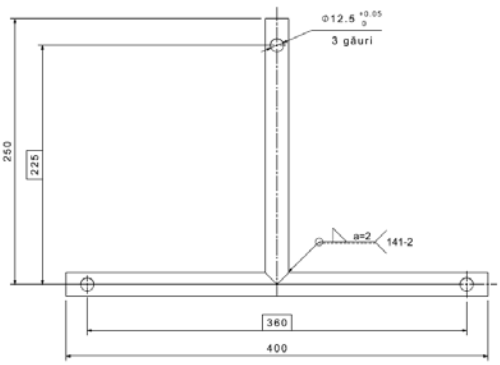
In civil steel constructions, offshore platforms and other heavy structures, gussets (longitudinal plates) are used for beam to column or column to ground plate connections [16], [13], [9]. They are used as well to facilitate bracing or other attachments to RHS [10], [15].

To improve the *T* joints fatigue behaviour, base plates (chord doublers) are employed according ref. [17], [19] and [18], or outer collar [9]. For lightweight structures, gussets are used to improve the dynamic and fatigue behaviour, being met in a big variety of shapes, placements and dimensions [11], [12].

In lightweight structures, the weight saving problem deals also with the type of gusset. An appropriate kind of gusset will decrease the stress level leading to a smaller tube section, thus the structure becoming lighter.

3. The Testing Interface Requirements

The interface has to allow testing of both simple *T* joint samples (Fig. 1 a) and gusset reinforced joints (Fig. 1 b). Samples will have different wall thickness for tubes and gussets, in a range of 0.8 ÷ 2.0 *mm*. The gussets will have different dimensions and shapes. The experimental program was planned to test 100 samples, most of them up to the limit of elasticity. Samples were manufactured from OL37, STAS 530/1, being welded with Tungsten Inert Gas method, according aircraft standard ASN 430.04.



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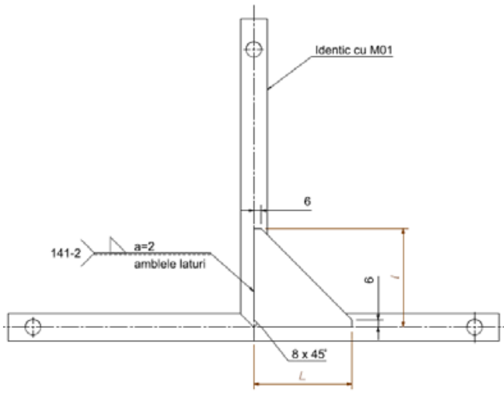

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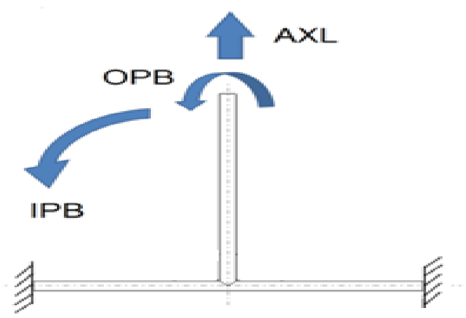


c)

Fig. 1. *a) T joint sample; b) T joint with gusset sample; c) T joint load cases*

Joints will be subjected to axial load (AXL) and in plane bending (IPB) load cases (Fig. 1 c). Out of plane bending (OPB) was considered not mandatory for the *T* joint, being a planar joint.

The testing machine was Lloyd's LS100 Plus, allowing static and cyclic loading for tensile, compression and bending testing, with the maximum load of 100 *kN*.

The design requirements were as follows:

- Safety and simplicity of operation;
- Allowing both AXL and IPB testing;
- Easy acces for inspection of cracks and remanent deformation measurement;
- Easy to mount and to remove the samples, even after deformation;
- The possibility to test the sample joints up to the total failure;
- Robustness;
- Low - cost raw materials.

4. The Testing Interface Design

For the testing interface, an OL 37 steel angle was used, having the dimensions of 40x40x5 *mm*, SR EN 10056-1:2000. The welds were executed according EN ISO 5817/2007. All dimensions are shown in figure 2.

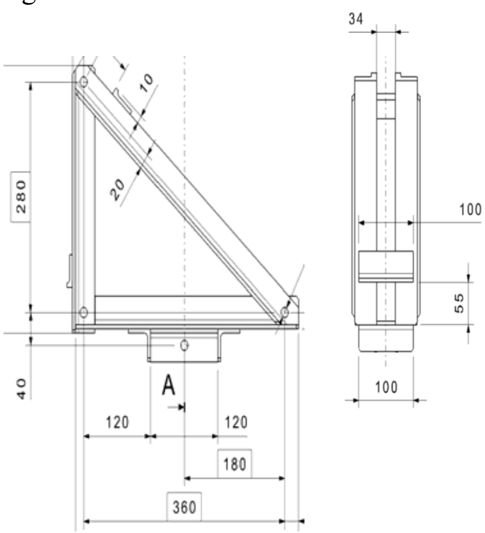
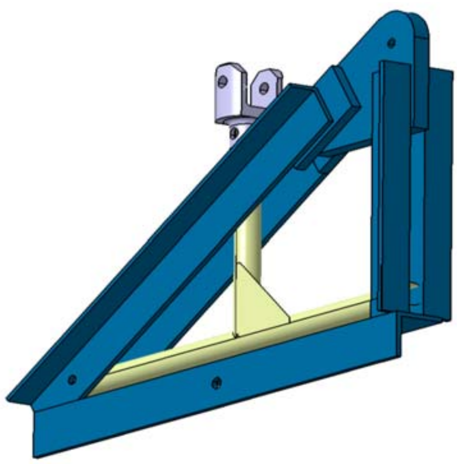
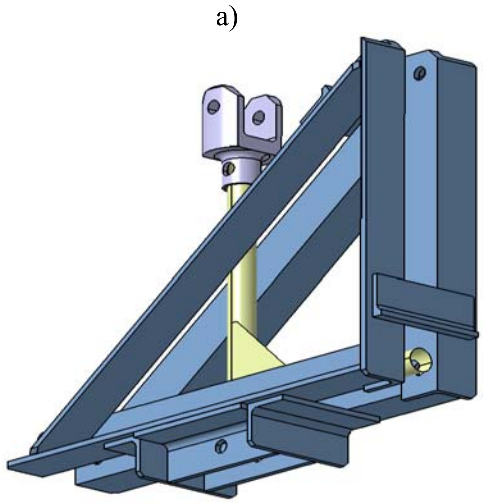


Fig. 2. *Dimensions of the testing interface*

Within the initial design, the interface was fitted with eyelets (Fig. 3 a). In order to have only symmetrical loading of the interface (to avoid eccentric loads), an improved design was elaborated. Thus, two triangles were joined with welded brackets, to provide room for sample mounting and also a robust fork attachment on the testing machine eyelets (Fig. 3 b). The sample is mounted inside the testing interface using two pins, with conical head. The vertical member of joint is fitted with a fork to allow the mounting in the mobile eyelet of the testing machine.



a)



b)

Fig. 3. *Variants of the testing interface: a) initial design; b) improved design*

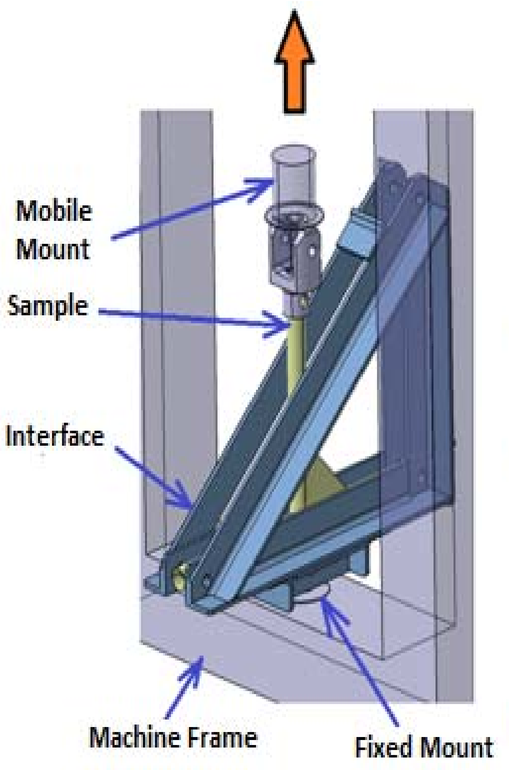
In figure 4, one may see the installation of the testing interface on the universal testing machine for both load cases. The testing machine eyelet is moving only in vertical direction. By the different orientations and mounting points of the testing interface relative to the testing machine, the sample may be loaded in two different ways. Thus, with a single one capability, the samples can be tested both under AXL and IPB loading, using only an universal testing machine.

5. The FE Study of the Testing Interface

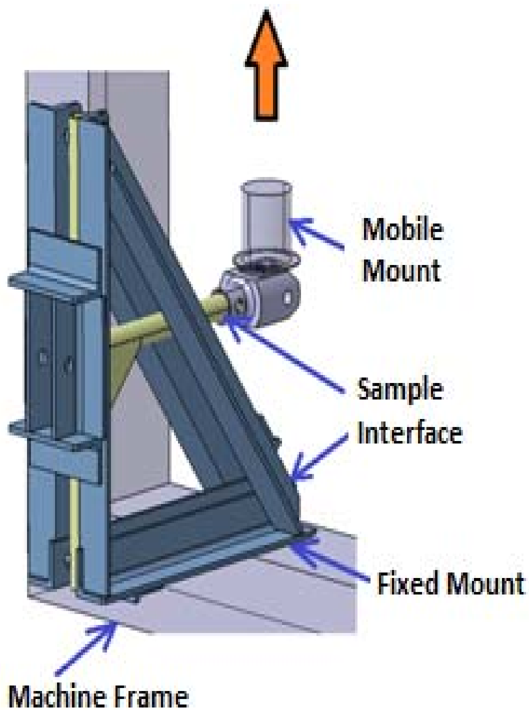
The two major conditions to be fulfilled by the testing interface are the maximum rigidity and the stress level below the material's yield stress. Being and elastic structure, infinite rigidity is not attainable, therefore the acceptance criteria is the rigidity of the interface to be much bigger than the rigidity of the sample.

The finite elements model (FEM) was meshed with 3D tetrahedral elements with median node (TET10), while the sample was modeled with 2D shell elements (Fig. 5). Between the interface and sample, RBE2 constraints were added to model the assembly with cylindrical pins.

The loads were introduced by the meaning of the sample. The boundary conditions and the loading diagram are shown in figure 6, for both load cases. The lower attachment corresponds to the fixed eyelet of the testing machine. The load is applied on the vertical member of the sample by attaching it to the mobile eyelet of the testing machine. In order to prevent rotation in bending loading, the load is applied through an intermediate fork fitting.



a)



b)

Fig. 4. *The testing interface mount: a) axial load; b) in plane bending*

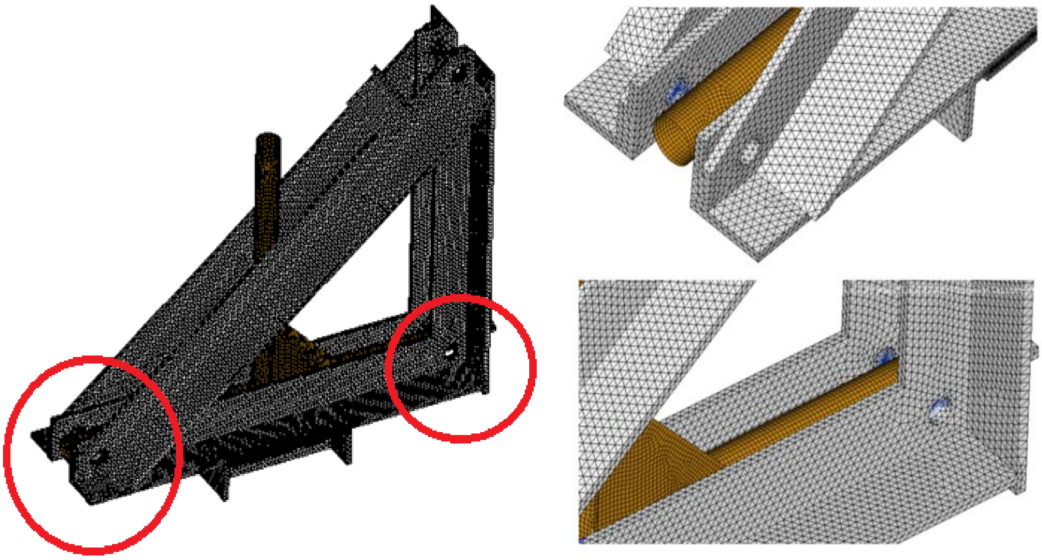


Fig. 5. *The FE model for the interface and sample assembly*

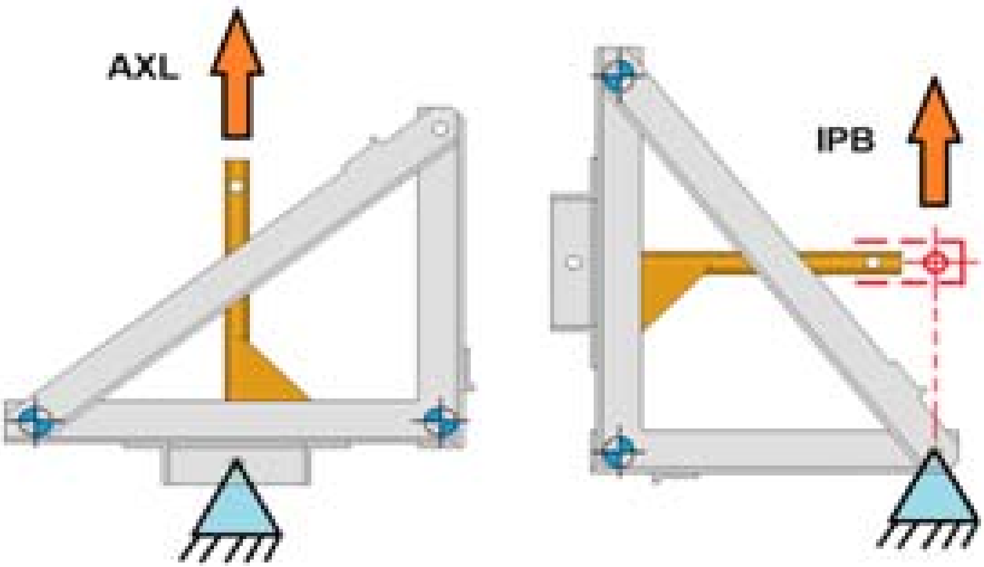


Fig. 6. *The loading diagram and the boundary conditions of the interface/ sample assembly*

Using the FE analysis, it was determined the ultimate yield load of the samples of 2 *kN* of axial load and 1.5 *kN* for in plane bending load. For rigidity checking, some conservative values of 20 *kN* for AXL and 5 *kN* for IBP were considered.

For the axial loading, the maximum displacements of the testing interface were of 0.04 *mm* for the sample yield limit and 0.37 *mm* for sample failure (Fig. 7). The von Misses stress level is 34 *MPa* for sample yield limit and below 200 *MPa* for the sample yield limit (Fig. 8).

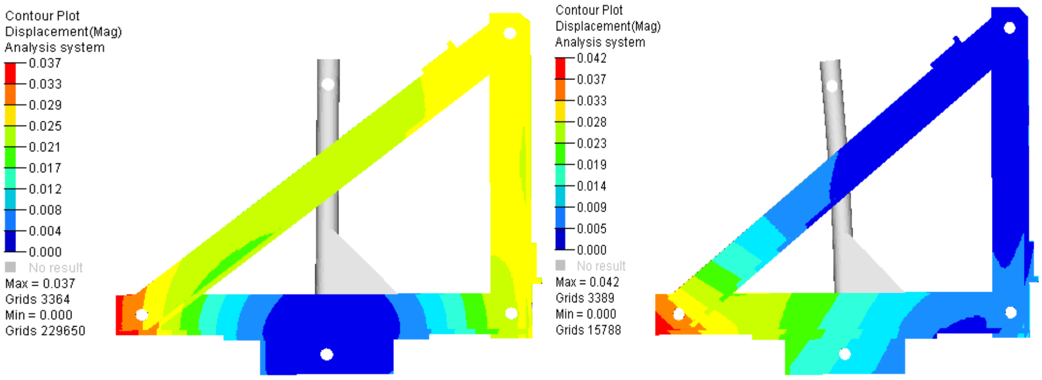


Fig. 7. *The testing interface displacements for the yield limit of the sample (AXL/ IPB)*

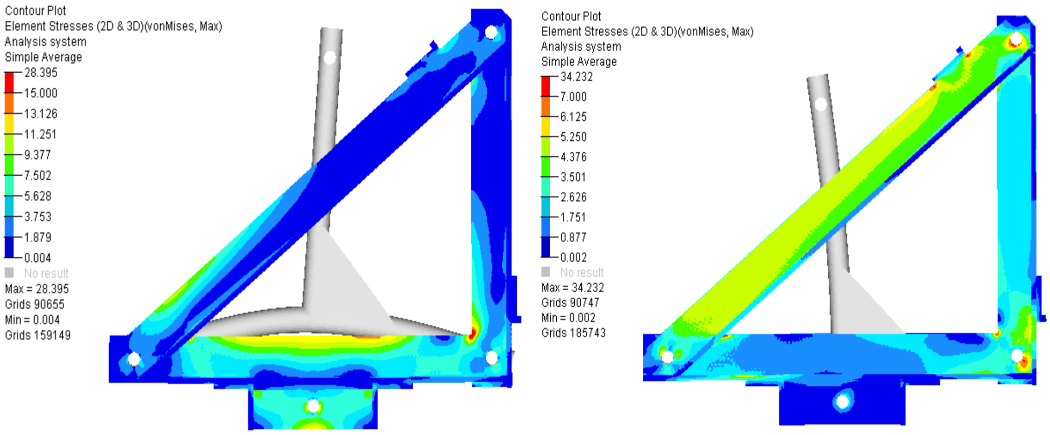


Fig. 8. *The von Misses stress of the interface for the yield limit of the sample (AXL/ IPB)*

Fig. 9. *The testing interface installed on the LS100Plus testing machine (AXL/ IPB)*

6. Conclusions

Article presented the development and numerical testing of a testing interface for *T* joints experimental study. The following conclusions may be formulated:

- The testing interface allows testing of joints with and without gussets in a range of 15 ÷ 40 mm diameters, with corresponding wall thickness;
- The testing interface allows the testing of samples for both AXL and IPB loading conditions, using a common testing machine, without any modifications or customisations;
- The testing interface fulfilled all design requirements, the manufacturing costs being much lower than a dedicated test rig;
- The FE analysis revealed deformations of the interface of 2% from the sample's deformations; therefore the testing interface is robust enough to carry on the experimental testing loads.
- The von Misses stresses are below the yield stress limit of the OL37 steel (240 MPa), therefore the testing interface will not suffer remanent deformations along the experimental testing.

The ergonomic analysis was confirmed by real tests, the interface being easy to use, allowing the inspection of areas of interest, saving also time for testing. The testing interface complied with operational requirements, after preliminary tests no adjustments being needed. The interface behaved well through the whole experimental program (100 samples), for this reason, a patent application being made.

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