Numerical evaluation of the monotonic and cyclic behavior of a welded beam-to-column joint

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Summary

A numerical model of a welded beam-to-column joint subjected to both monotonic and cyclic loading is presented. Experimental results from a test on a similar joint are used for the purpose of validation and calibration of the numerical model. Results are discussed within the framework of the component method.

Introduction

The study of the seismic performance of steel joints received increased attention following the Northridge and Kobe earthquakes. The seismic events highlighted the poor performance of some connection details, long established as standard practice in the US and Japan and that lead to some catastrophic failures.

Historically, the first large experimental campaign on the monotonic and cyclic behavior of steel connections took place in the US in the sixties. Since then, as the outcome of thirty years of extensive research in the field, accurate prediction of initial stiffness and resistance is available within the framework of the component method.

However, the complete prediction of the moment-rotation response of steel joints until failure is still not possible [1]. Additionally, under cyclic or dynamic conditions, a consistent methodology that is not dependent on extensive experimental calibration for specific joint configurations is still not available [2].

Based on a calibration study of a welded joint tested under monotonic and cyclic conditions [3], illustrated in fig. 1, it is the objective of the present paper to identify the major parameters contributing to the cyclic response of steel joints. It is expected that this might lead to the extension of the component method to be able to deal with the seismic response of steel joints

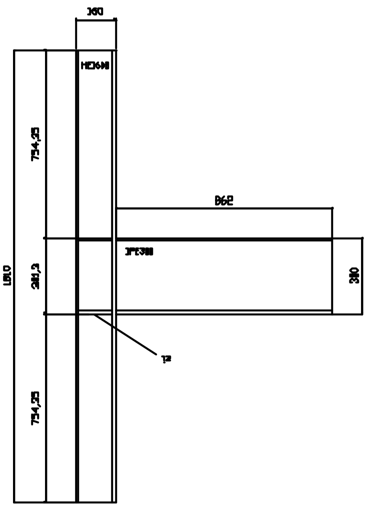

Fig. 1 – Geometry of the model

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Geometry of the model

The model of fig. 1 represents a full scale welded beam-to-column T-joint. The structural shapes are HE160B for the column and IPE300 for the beam. Full penetration groove weld is used for beam flanges, and fillet weld on both sides for the beam web. The column web panel is reinforced by 12 mm thick stiffeners. The structure has stiff supports at both ends of the column, and the load is applied at the free end of the beam. The joint was selected from an experimental programme on welded joints tested by Calado et al. [3].

Reference experimental test

The test set-up is shown in fig. 2. For the monotonic test the load was slowly increased until rupture. For the cyclic test the ECCS loading procedure was used [4] with increasing amplitudes of 0.25, 1.5, 0.75, 1, 2, 3, 4, 5 e 6 times the elastic displacement (see fig. 3).

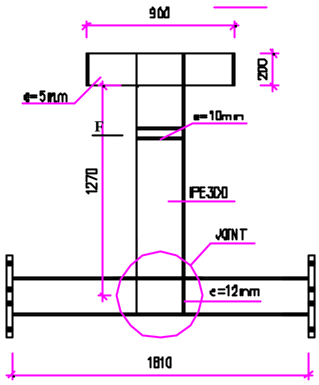


Fig. 2 – Test set-up

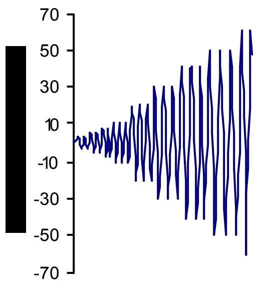


Fig. 3 – Cyclic loading

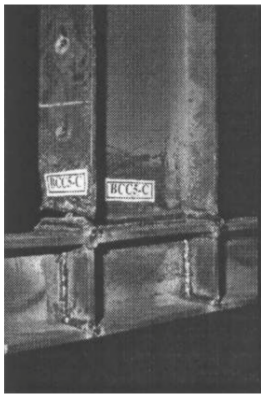


Fig. 4 – Cyclic rupture mode

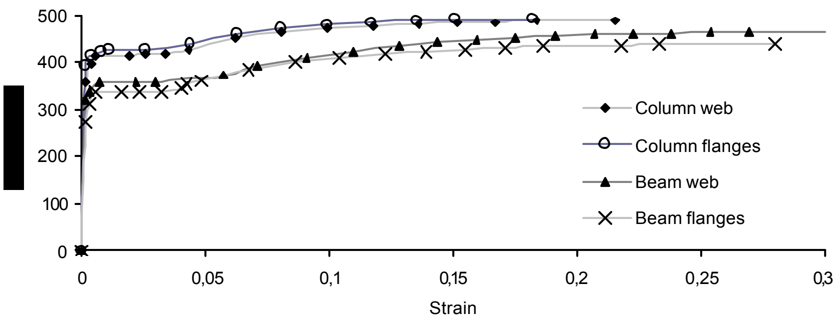


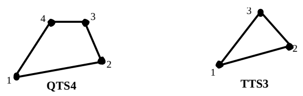
Fig. 5 – Mechanical material properties

The results of the cyclic test [3] indicate that there was not significant plastic deformation or instability in the beam, but large distortion in the column panel. Fracture begun in the bottom flange of the beam and spread to the web, as shown in fig. 4.

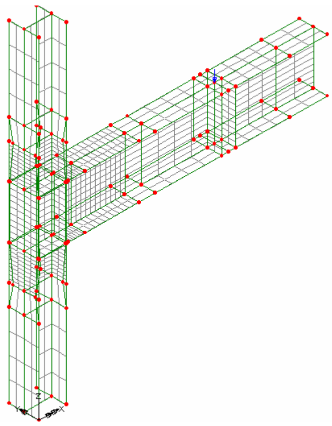
The mechanical properties were assessed by means of uniaxial coupon tests from all the parts of the structure, yielding the results of fig. 5. The steel grade is S235JR with an elastic modulus of 209 GPa and Poisson's ratio of 0.3 [3]. The curves presented correspond to engineering stress, because the dimensions of the cross section were not recorded during the test.

Numerical Model

The finite element used is thick shell type, linear, with five degrees of freedom per node (u, v, w, ?$_{a}$, ?$_{ß}$) [5] (see fig. 6a). Its formulation accounts for shear, bending and membrane internal forces. The mesh was selected following a mesh convergence study [6]. The whole model has 1312 elements and 1373 nodes (see figure 6b). In the area close to the joint the mesh is tight, to account for the high gradients in the stress field, and is slack in the rest of the structure.



a) Finite element



b) Mesh

Fig. 6 – Numerical model

To account for the material non linearity, the von Myses yield criterion with non linear isotopic hardening is used. The plasticity is associated, which means that the vector related with the flow rule used to define plastic straining is orthogonal to the yield surface [7]. The integration algorithm is implicit type (*implicit backward Euler* [5]), which ensures a quadratic convergence to the iteration procedure associated with Newton-Raphson method. For the definition of the convergence, three criteria were used [5]: i) Euclidian displacement norm (0.1); ii) Euclidian residual norm (0.1) and iii) Euclidian incremental displacement norm (1).

Monotonic results

The monotonic analysis was performed in displacement control, with automatic load incrementation guided by the nonlinearity level met in each increment. The total load considered corresponds to the displacement for rupture, in the experimental test. The results for the last load increment are presented in fig. 7, that illustrates the von Mises stress contours, and fig. 8, that depicts the deformed mesh.

Numerical and experimental monotonic results are compared in terms of force *vs* displacement at the free end of the beam and moment *vs* rotation (fig. 9), and force *vs* displacement at two specific instrumentation locations (fig.10).

These figures indicate the there is good agreement between numerical and experimental results, particularly in the elastic domain. The difference in rigidity observed in the plastic zone is due to the fact that engineering values were used instead of true values, for material mechanical properties

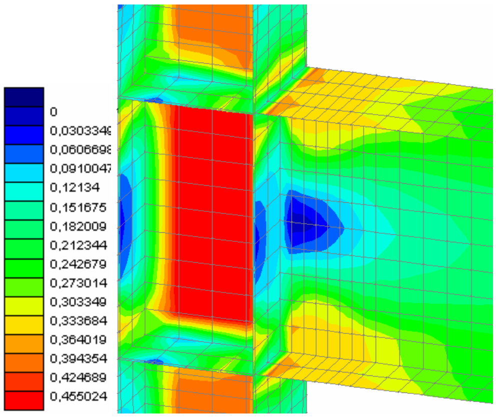


Fig. 7 – Numerical model: von Mises stresses contours

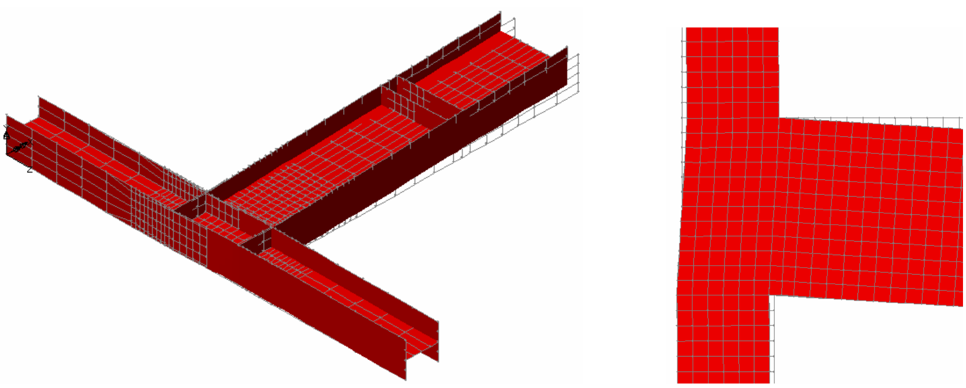


Fig. 8 – Deformed mesh

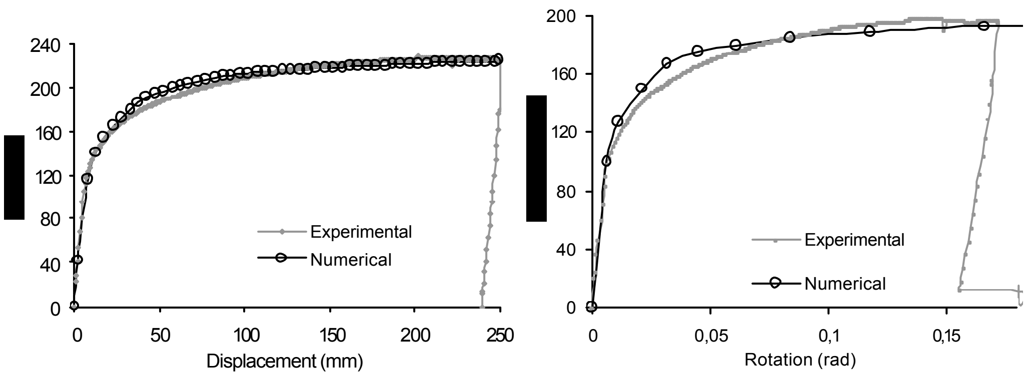


Fig. 9 – Comparison between numerical and experimental monotonic results

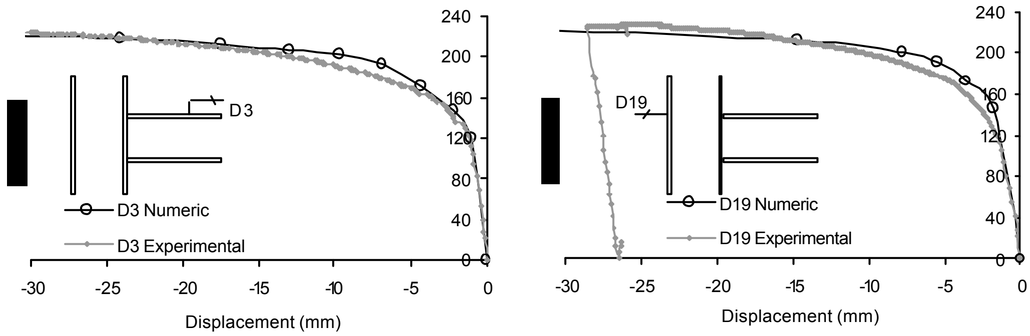


Fig. 10 – Comparison between numerical and experimental monotonic results

Cyclic results

The cyclic analysis was performed under displacement control. The load strategy was identical to that used in the experimental test, shown in fig. 3.

Fig. 11 illustrates the force *vs* displacement curves at the free end of the beam. The monotonic and cyclic curves are plotted together, so that conclusions regarding the evolution of the yield surface with cyclic straining may be drawn. Fig. 12 compares the numerical and experimental cyclic results. The comparison is established in terms of force *vs* displacement at the free end of the beam.

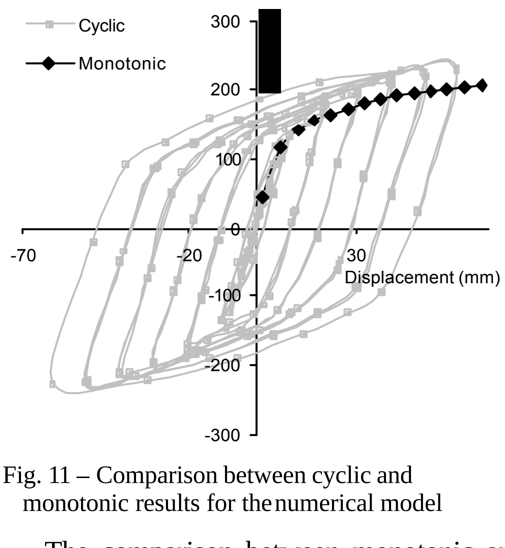


Fig. 11 – Comparison between cyclic and monotonic results for the numerical model

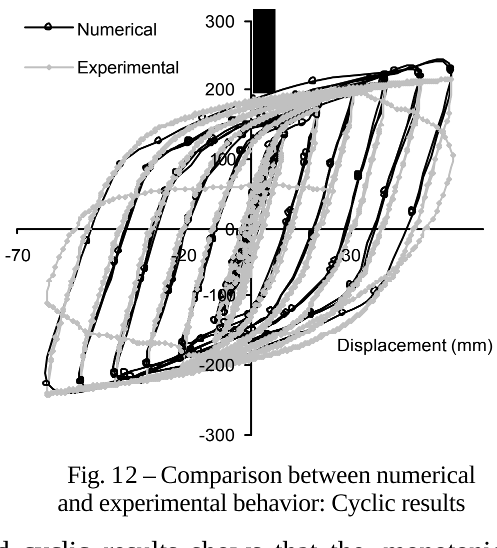


Fig. 12 – Comparison between numerical and experimental behavior: Cyclic results

The comparison between monotonic and cyclic results shows that the monotonic curve is placed beneath the line defined by the locus of maximum displacement for the cyclic curve. This fact indicates that the material endures cyclic hardening [8].

Comparison between numerical and experimental cyclic results reveals that the agreement is reasonable, except for the prediction of rupture, and for the description of the maximum positive displacement in the last cycles. The first one is related to the numerical definition of rupture under cyclic load, which is not implemented in the model, and the second one is due to the fact that the numerical material model does not account for cinematic hardening.

Conclusions

A numerical model of a T welded beam-to column joint was presented, validated with experimental results, for monotonic and cyclic loading. Given that the numerical results were able to reproduce quite accurately the experimental results (despite some uncertainties in the actual mechanical and geometrical properties of the test specimen), it is now possible to establish the monotonic and cyclic force-displacement characteristics of the various connection components, namely (i) the column web in shear, (ii) column web in compression, (iii) column web in tension, (iv) beam flange in compression, and (v) welds, thus allowing a cyclic implementation of the component method, an issue currently being actively developed.

References

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