Numerical Analysis and Experimental Studies on Welded Joint for Buildings

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Abstract: - In the last period the interest for multi-storey buildings increased due to the development of cities around the world. In fact the price of land increased so much as the investitors want to build tall buildings in a small areas. The general behaviour of the tall buildings is analysed using dedicated software but many times the particular elements must be studied in experimental laboratories.

At the „Politehnica" University of Timisoara, it was developed a theoretical and an experimental program for a specific steel and composite (steel-concrete) joint, used for the administrative building with basement, ground floor and 12 stories. Special testing specimens were designed both for the structural steel and the composite joint. The calibration of the experimental specimens was performed in the elastic and post-elastic range using numerical analysis. The main objective of the studies was to observe and evaluate the behaviour and the failure mode for steel and composite joint. Two load hypotheses on the joint were considered: symmetrical and asymmetrical.

The paper contains a comparative study between the theoretical and experimental results obtained on the behaviour of the structural steel and steel-concrete composite joint.

Key-Words: - numerical analysis, composite joint, post elastic behaviour, experimental tests

1 Introduction

One of the most representative steel – composite constructions built up in Timisoara is an administrative building assembly. The area of Timisoara is a seismic zone of Romania with a_g=0.16. It consists of three main buildings each of them having a different number of storeys. The functional requirements to have wide spaces at each level, led to a skeletal frame system for each building. All these buildings are provided with basement but different number of storeys. The highest (Fig. 1) has 12 levels. For each building, from the assembly, the basement level consists of a stiff reinforced concrete box, composed by structural walls and columns together with floors. The suprastructure are a space frame structure consisted of plane frames arranged in two orthogonal directions, connected through the reinforced concrete floor slabs. The beams are steel welded members and the columns are steel-concrete composite elements.

The structural solution is justified by the span width with unexaggerated cross sectional dimensions for the columns, adequate lateral stiffness and cost effective fire protection due to the presence of the concrete. Complete prefabrication in the workshop, followed by the transportation of the structural elements and their erection in the final position assured a high construction rhythm.

Fig. 1 Main façade of the administrative building

The composite system has the desired characteristics of the conventional systems, such as strength, stiffness and ductility. Also it represents a performant system as a seismic resistant system for buildings. An experimental test program for the specific steel-concrete composite joint, used at construction work of the administrative building, was developed at the ”Politehnica” University of Timisoara. Starting with the joint type used, eight joints were considered as experimental specimens.

As is known in reality the plasting hinges must appear outside of the joints into the beams. The aim of the study was to obtain the collapse in the joint panel rather than outside the joint, in order to compare the bending moment resistant of steel joint with the bending moment resistant of composite joint. The joints were initially analysed together with their connections – the beams and the columns in order to determine the dimensions of the joint components, thus satisfying the desired collapse mechanism at the joint zone. Were studied also the failure mechanism of the steel joint and compared with the composite one. A numerical study was performed in the elastic and post elastic range and after calibration of experimental joint the experiments were performed by using special testing equipment, and the international recommended testing procedures.

2 Structural Joint Type

Due to the technological process, a composite structure is initially a steel structure. After placing the reinforcement and the concrete casting the structure becomes a composite one. The general view of the structural composite joint is represented in figure 2.

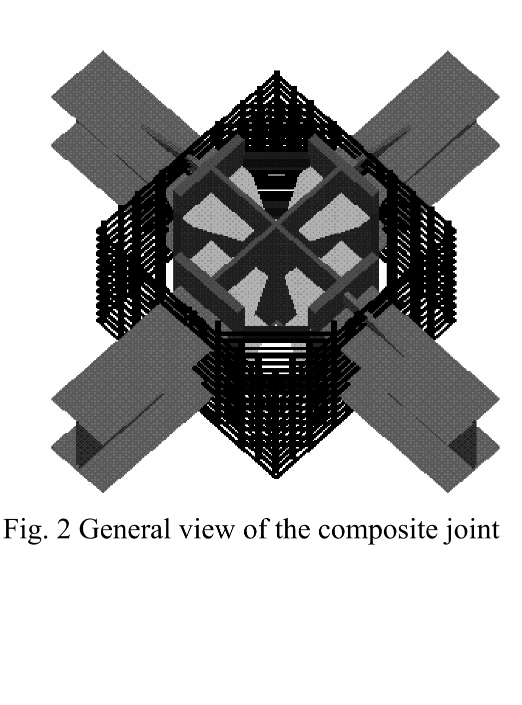


Fig. 2 General view of the composite joint

Some aspects concerning the details of structural steel joint for composite joint during the constructional work is presented in figure 3.

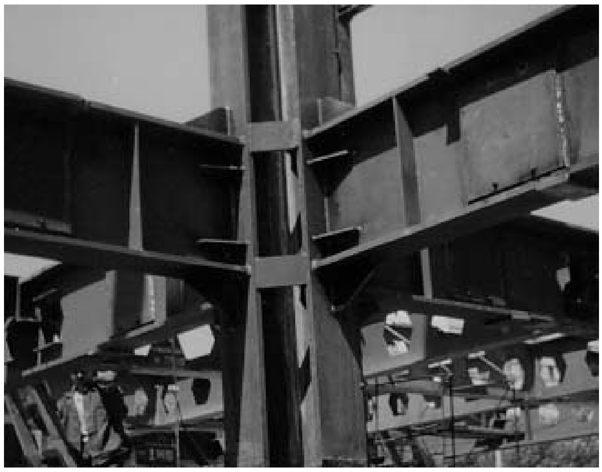


Fig. 3 Structural steel for the composite joint

2.1 Numerical analysis of steel and steel-concrete composite joint

In order to evaluate the stress state in the joint and the behaviour study of the dimensioning element, on the geometrical dimensions basis, some numerical analyses have been done using the finite element method. In the first stage the SAP 2000 numerical analysis programme was used, the modelling been done by type SHELL finite elements, for the structural steel in the joint.

To have a clearer view of the stress state in the joint, the model analysed was done according to the testing mode. Taking into consideration the possibility of making an experimental test, we drew the conclusion that for the symmetrical load the instruments that we had at our disposal allow the loading of the column and the mounting of some joint supports at the extremity of the beams that concur in the structural joint. In fact this loading type simulates the real situation when the loading is actually on the beams.

The purpose of the testing being to obtain information on the stress state inside the joint and thus to cause the failure in the joint, the decision was to eliminate the vertical stiffeners, which became useless in this case.

The vertical stiffeners are useful in real structures because they increase the bearing capacity in the joint zone, the plastic hinge taking place in the beam and not in the joint [3].

In figure 4 is presented the issostresses, obtained for the proposed experimental specimen (symmetrical load).

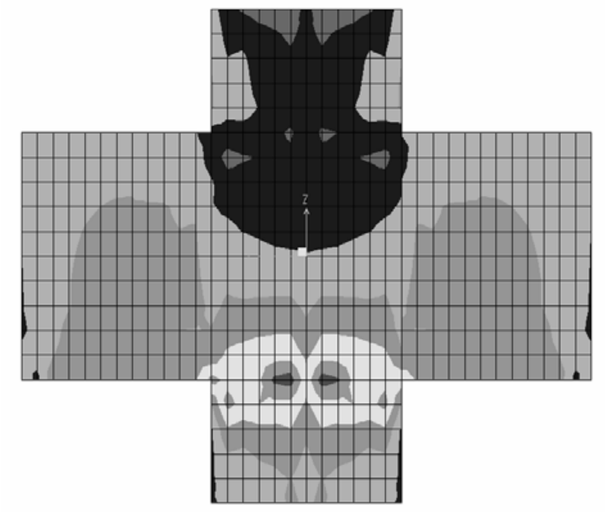


Fig. 4 Isostresses σ_{max} for the structural steel joint symmetrical loads

Starting with the geometrical dimensions obtained at the previous analysis for asymmetrical load cases the new numerical analysis on the structural steel of the experimental element was performed. The results obtained are presented in the figure 5.

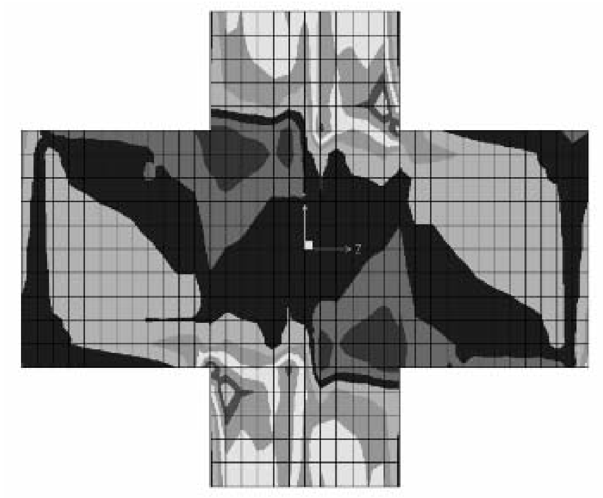


Fig. 5 Isostresses σ_{max} for the steel joint asymmetrical load (mid-plane view)

The evaluation of the stress state in the composite joint elements has been done after several numerical analyses in the post elastic range using nonlinear analysis software.

A vertical section was considered in the mid-plane of the joint, practically in the middle of the joint panel axis. In this case it was assumed that the joint is in a plane stress state (fig. 6).

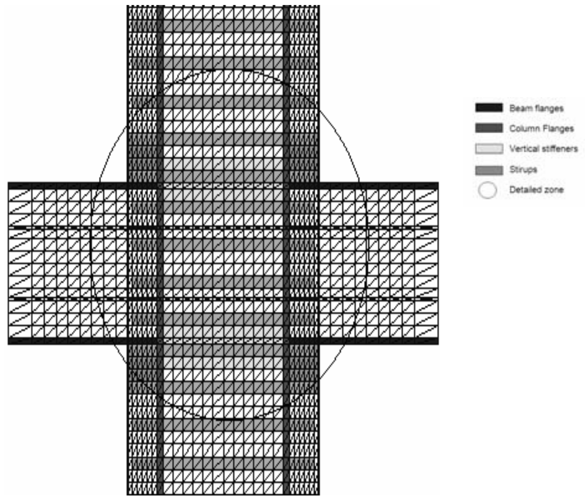


Fig. 6 Finite element mesh of the composite joint

The finite element mesh of composite steel concrete joint was done at the level of mid-plane of joint in vertical direction. All the constitutive elements (structural steel, longitudinal reinforcements, stirrups, stiffeners etc) were considered in this analysis.

The analyses made on the composite joint showed a similar state of distribution of the efforts inside the joint, as the distribution obtained for steel joint, but the stress values in composite being slightly lower. This can be explained if we take into account the fact that at the analysis of the composite joint all the components were considered [5].

The load cases and the distribution of cracks at the failure are presented in the figure 7.

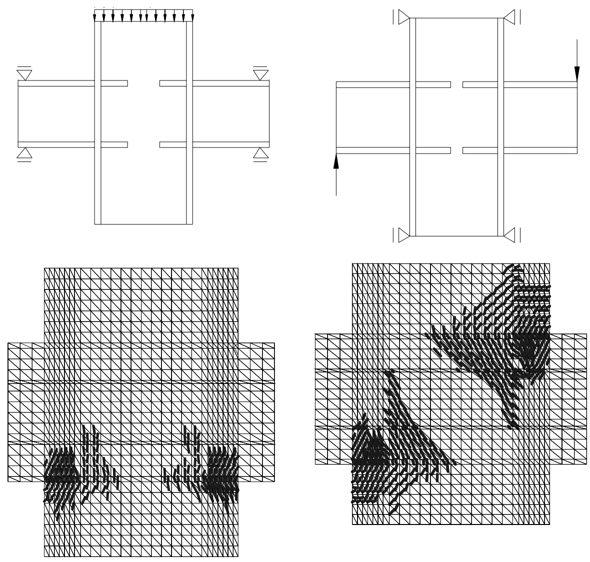


Fig. 7 Distribution of cracks at failure symmetrical and asymmetrical load

3 Monotonic and cyclic experimental tests

All the experimental tests were performed using the procedure indicated by ECCS [2].

For the symmetrical load case the load was applied at the top of column for each tested element.

For the asymmetrical load case the load was applied at the top and at the bottom of beams flanges of tested element. The tests were controlled using displacements devices of the hydraulic jacks. In order to record the behaviour of the tested joints a basic instrumentation was used for both elements.

The instrumentation consisted in displacement transducers, inclinometers and strain gauges (Fig. 8). Using recorded data from the monotonic displacement increase tests made on the steel joint (SJ1) and the composite joint (CJ1) there were evaluated the limit of the elastic range F(kN) and the corresponding displacement e_y (mm).

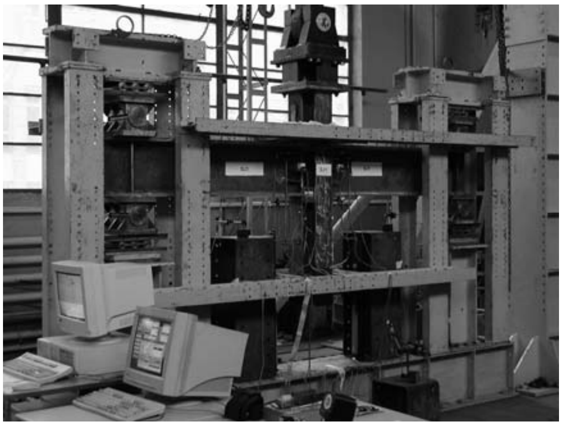


Fig. 8 General view of testing equipment symmetrical load

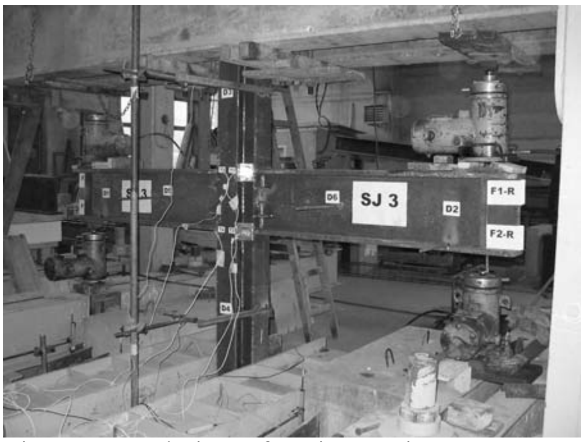


Fig. 9 General view of testing equipment asymmetrical load

The history of the cyclic tests was established using the elastic limit obtained in the monotonic tests, and the ECCS procedure [2].

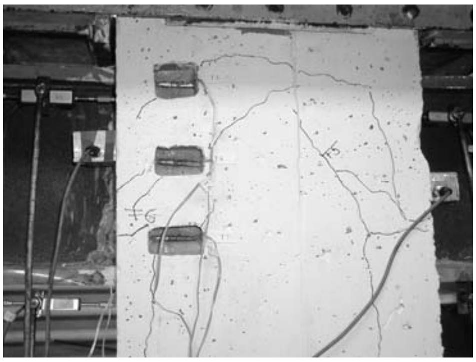
In the photos represented in figures 10 ÷ 12 can be observed a comparative study between the failure mechanism of steel joints and steel-concrete composite joints [6].

a. Front view of steel joint after test

b. Tearing of vertical stiffener

c. Large crack inside the joint panel

Fig. 10 Failure mechanism of steel joint symmetrical joint

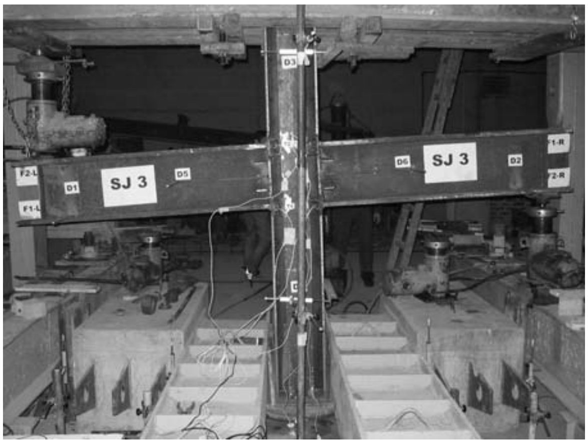


a. Distribution of cracks at the composite steel concrete joint at failure

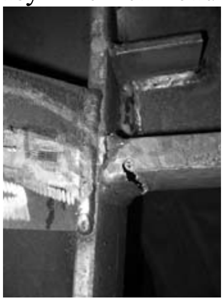
b. Tearing of vertical stiffener

c. Small crack in the joint panel

Fig. 11 Failure mechanism of steel-concrete composite joint, symmetrical load



a. General view of steel joint – asymmetrical load



b. Tearing of vertical stiffener

c. Failure of the welding from beam to column

Fig. 12 Failure mechanism of the steel joint asymmetrical load

The comparative study between the experimental elements is based on moment rotation characteristic diagram recorded at the lateral face of joints [4]. In the figure 13 is represented the moment rotation diagram for the steel and steel concrete composite joint under symmetrical load.

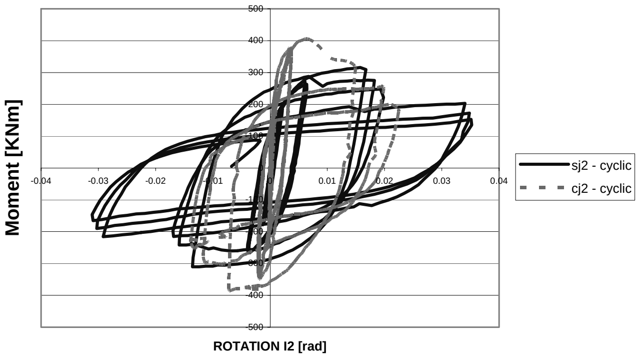


Fig. 13 Moment – rotation diagram for steel and composite joints

The comparative diagrams represented in figure 13 shows a similar behaviour of the joint under symmetrical load but with different initial value of the stiffness.

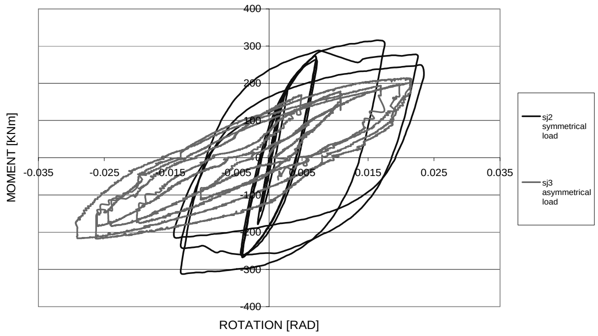


Fig. 14 Moment – rotation diagram for steel joints under symmetrical and asymmetrical load

The comparative study between the behaviour of the steel joint under monotonic SJ1 and cyclic loads SJ2 (symmetrical case load) was performed using the diagrams presented in the figure 15.

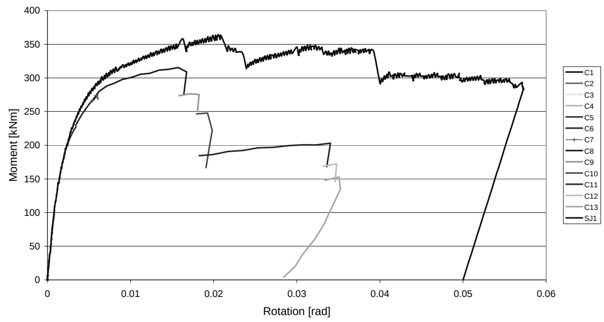


Fig. 15 Comparative study between the monotonic and cyclic tests (envelope curve) – steel joint symmetrical load

The degradation of the secant stiffness function of the cycles for the steel joint SJ2 is presented in the figure 16. If the initial stiffness is considered as 100%, at the last cycle performed the value of stiffness decrease until 8% from the initial.

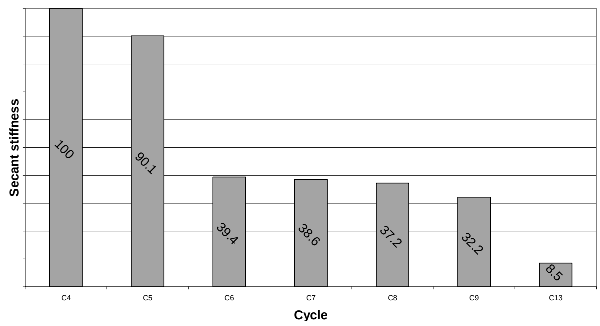


Fig. 16 Degradation of stiffness during cycles steel joint SJ2

A similar comparative study was performed for the composite joint (figure 17).

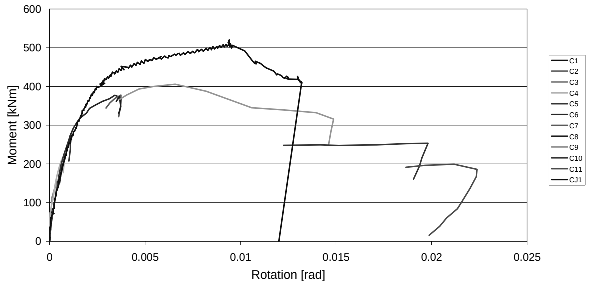


Fig. 17 – Comparative study between the monotonic and cyclic tests (envelope curve) – steel concrete composite joint symmetrical load

The degradation of the secant stiffness function of the cycles for the steel concrete composite joint CJ2 is presented in the figure 18. If the initial stiffness is considered as 100%, at the last cycle performed the value of stiffens decrease until 5.3% from the initial.

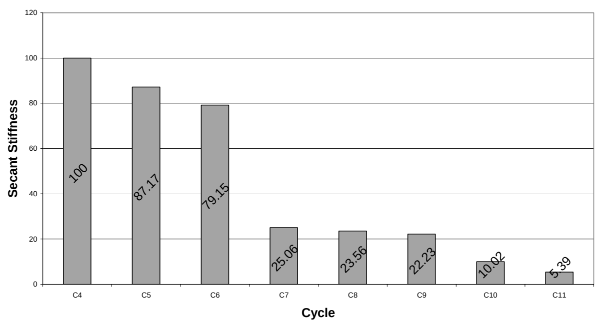


Fig. 18 Degradation of stiffness during cycles steel concrete composite joint CJ2

The presented diagrams indicate the dissipative behaviour of the tested joints.

4 Conclusions

Using the results from the theoretical study and experimental tests the following conclusions were formulated for the specific steel concrete joint:
- the results of numerical analysis were confirmed during the testing process;
- the tested joints are dissipative;
- due to the technology of welding the vertical stiffeners cannot be weld by complete penetration; it is considered that the vertical stiffeners play a significant part to the increase of the joint bearing capacity, the weak point being the welding at the column flanges;
- the behaviour of steel joint under symmetrical and asymmetrical load is different;
- the behaviour of steel and composite joint under symmetrical loads is similar;
- the cracks distributions on numerical analysis are similar with the experimental distribution of cracks;
- the concrete inside the composite joint after testing is crushed although at the exterior face the concrete has only smeared cracks;
- for the composite joint the crack distribution of concrete is similar to those of a typical reinforced concrete joint;
- the failure mechanism for symmetrical loads consisting in tearing of vertical stiffeners between column and beam flanges, buckling of compressed vertical stiffeners and tearing of joint panel;
- for the tested elements the stiffness of composite joint increase with 30% due to presence of concrete;
- the presence of the concrete in the joint has the effect of increasing the load bearing capacity of the joint;
- the tested joints are dissipative, with similar values of energy dissipation.

The experimental program concerning the behaviour of composite joints under asymmetrical loads is in progress further activities are planed until the end of the year.

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