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CONSTRUCŢII. ARHITECTURĂ

EXPERIMENTAL TESTS CONCERNING THE BEHAVIOUR OF THE STEEL–CONCRETE COMPOSITE JOINTS

BY

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The design of the building structures situated in a seismic area deals with some special provisions in order to satisfy the design concept for earthquake loads. Thus, some inelastic deformations must be concentrated in predefined zones for seismic energy dissipation. Therefore, it is important to evaluate correctly the load bearing capacity of each basic structural element, such as beams, columns and joints too. At the "Politehnica" University of Timişoara, it was developed an experimental test program for a specific steel and composite (steel–concrete) joint. Two load hypotheses were considered in order to simulate the permanent loads and the horizontal (seismic) loads, respectively, acting on the structure and the corresponding joints. Two series of joints were tested in laboratory for monotonous and cyclic behaviour. Both the steel and the steel–concrete joints were studied. A comparative study between the steel and the steel–concrete composite joints is presented.

1. Introduction

In the case of the steel and the steel–concrete composite structures the designer must conceive special details in accordance with the specific codes: EC3 and EC4.

Actually, in the joint design, the steel–concrete composite case is rather deficient than complete. Therefore, an experimental test programme for a specific steel–concrete composite joint was developed at the „Politehnica" University of Timişoara. The test specimens – 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.

Because the purpose of the experimental test was to control the design formula, the aim of this study was to obtain the collapse in the joint panel rather than outside the joint. Initially, the joint was designed by using the EC4 code. Then a numerical study was performed in the elastic and post-elastic range. Finally the experiment was performed by using special testing equipment, and the international recommended testing procedures.

The conclusions of the experimental tests may offer information for designers in order to evaluate more accurately the load bearing capacity of the joint and to avoid the development of the plastic hinge into the joints.

2. The Design of the Composite Joints

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 detail of the structural steel for composite joint, during erection, is represented in Fig. 1. The specific detailed composite joint was used in Timişoara at one building for offices.

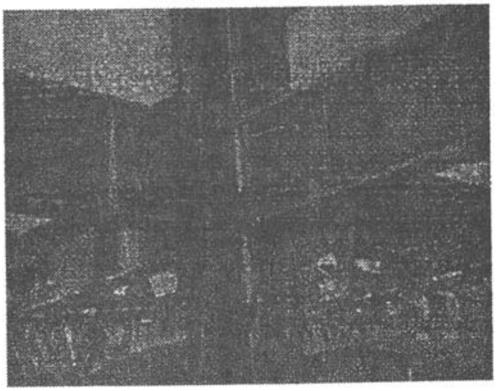

Fig. 1.– Details of the structural steel for composite joint.

Designing a composite element in accordance with EC4 means to respect the EC3 prevision. The effective relationships used in the composite joint design was indicated in the Annex J of EC4.

As it is stated at point J.3.6.5. the design moment resistance, $M_{j,Rd}$, into a composite joint with welded structural steelwork, may be determined with relation

$$M_{j,Rd} = \sum h_r F_{tr,Rd} + zF_{rd}, \quad (1)$$

where: $F_{tr,Rd}$ is the effective design tension resistance of row r of the reinforcing bars, h_r – the distance from row r of the reinforcing bars to the centre of compression, r – the number of a particular row of reinforcing bars, F_{rd} – the effective design tension resistance of the welded steelwork connection, z – the lever arm defined for welded joints.

In this case the calculus of the experimental model was made for all the components. Thus the design moment was evaluated for the beam, the column and the joint. It was important to evaluate the design capacity of the column and of the beam because the aim of experimental program was to study the behaviour of the joint and the failure mode.

The details of the composite joint designed on these assumptions are presented in Fig. 2.

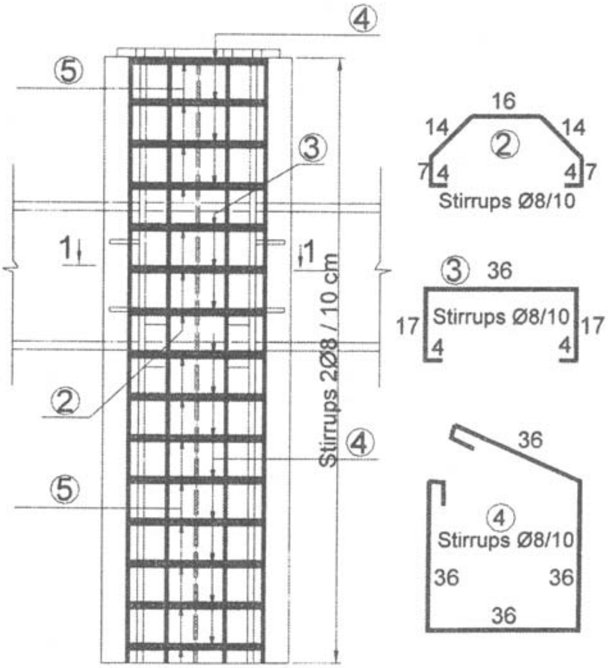

Fig. 2.- Details of the composite joint.

The reason for which the joints as composite element were studied was based on the following aspects. related into the design process:

a) the contribution of the reinforced concrete floor slab to the cross section of the beams was neglected into the overall stiffness evaluation of the space frame;

b) the cross section of the composite beam is composed by a reinforced concrete precast slab and a steel I profile; the connectors were provided only along the steel beam, but not into the joint zone;

c) in the joint zone, the continuity of the reinforced concrete slab was interrupted due to the technological process, thus the reinforced concrete precast slab, as part of the floor system, was not provided as a continuous reinforced concrete element over the joint zone, and therefore was not considered as part of the composite joint.

3. Experimental Tests

All the experimental tests were performed using the procedure indicated by ECCS. The load was applied at the top of column for each tested element. The tests were controlled using a displacement device of a hydraulic actuator. Four specimens were tested in the research program. Two of the specimens were steel joints (structural steel) and the others two were composite steel–concrete joints. Two tests were performed as classical displacement increase tests in order to evaluate the conventional limit for steel joint, respectively for composite joint. The other two tests were cyclic, with increase displacement.

3.1. Monotonous Displacement Increase Test

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. 3).

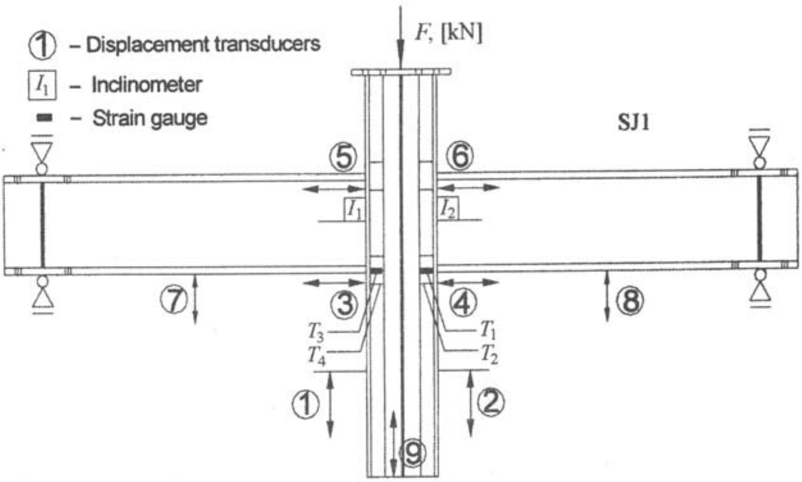

Fig. 3.- Basic instrumentation used in monotonous test of the steel joint (SJ1).

Using recorded data from the monotonous 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]. The elastic limit was calculated using the push over-load – displacement diagram (Fig. 4).

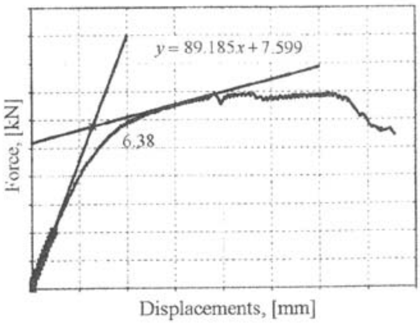

Fig. 4.- Load *vs.* displacement diagram (SJ1).

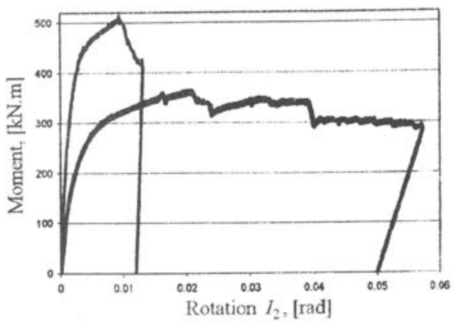

Fig. 5.- Moment *vs.* rotation diagram (SJ1/CJ1).

The behaviour of the joints was analysed by comparing the characteristic diagram moment *vs.* rotation recorded at the exterior face of the joint (Fig. 5).

In the Table 1 a comparison between the basic parameters, which characterize the joints behaviour, is presented.

Table 1
Basic Parameters Monotonous Test

	Steel joint (SJ1)/Monotonous test	Composite joint (CJ1)/Monotonous test
Maximum bending moment, [kN.m]	364	523
Maximum displacement mm	70.2	37.8
Ultimate rotation m.rad	50.7	14.37
Elastic limit, e_y mm	6.18	6.38
Experimental bending moment elastic limit kN.m	281.2	352.4

The maximum value of the bending moment for composite joint (CJ1) overpass with 43.7% the corresponding value for steel joint (SJ1). The initial stiffness of composite joint overpasses with 51% the stiffness of the steel joint. The ultimate rotation of CJ1 is only 28.3% of ultimate rotation of the SJ1. The values of the elastic limits (displacements) are very close for both tested elements. The experimental bending moment at S.L.S.. corresponding to the elastic limit, is 77% of the maximum moment for SJ1 and 67% of the CJ1. The experimental bending moments at S.L.S. for CJ1 is greater with 25.3% than those of the SJ1. The design bending moment for SJ1 is 190.6 kN.m and for the CJ1 is 206.9 kN.m. If, in the calculus of bending moment (simplified method) the vertical stiffeners are neglected, the bending moment is only 80 kN.m. This value represents 30% of the experimental bending moment. It demonstrates that this hypothesis is inadequate.

The failure mechanism for both elements is similar. In the case of the CJ1, the buckling of panel joint and vertical stiffeners did not occurs due to the confinement effect of the reinforced concrete. It demonstrates the role of the reinforced concrete in the section. The overall behaviour of the composite joint is characteristic to a stiffened joint.

3.2. Cyclic Tests

Using the elastic limit obtained by the monotonous tests for both elements, the history of cyclic tests was established. The photos represented in Figs. 6 and 7 show some aspects of the steel and composite joints *prior* testing.

The photos represented in Figs. 8 and 9 show some details of the failure mechanism for the SJ1.

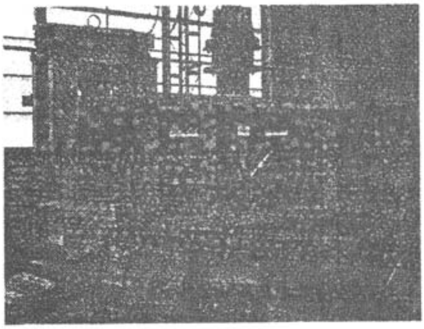

Fig. 6.– The steel joint (structural steel).

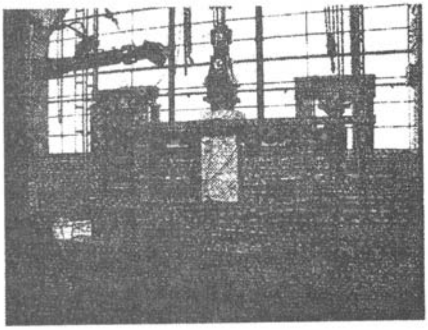

Fig. 7.– The composite steel-concrete joint.

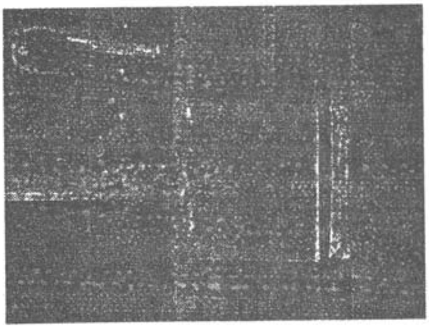

Fig. 8.– The steel joint failure – tearing of vertical stiffeners.

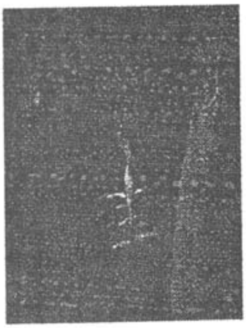

Fig. 9.– The steel joint failure – vertical crack in joint panel near horizontal stiffener.

In the photos represented in Figs. 10 and 11 some details of failure mechanism of the CJ2 are presented.

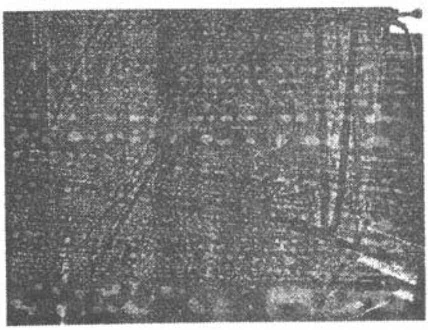

Fig. 10.– Concrete cracking in composite joint.

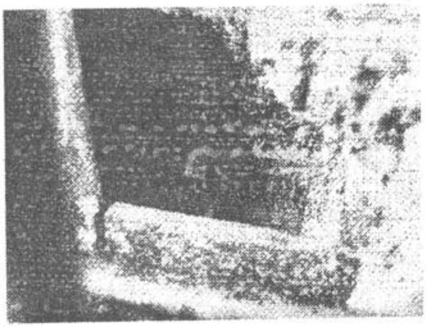

Fig. 11.– Structural steel and reinforcement in composite joint after testing.

The comparative study between the experimental elements is based on moment rotation characteristic diagram recorded at the lateral face of joints, represented in Fig. 12. The behaviour parameters are presented in Table 2.

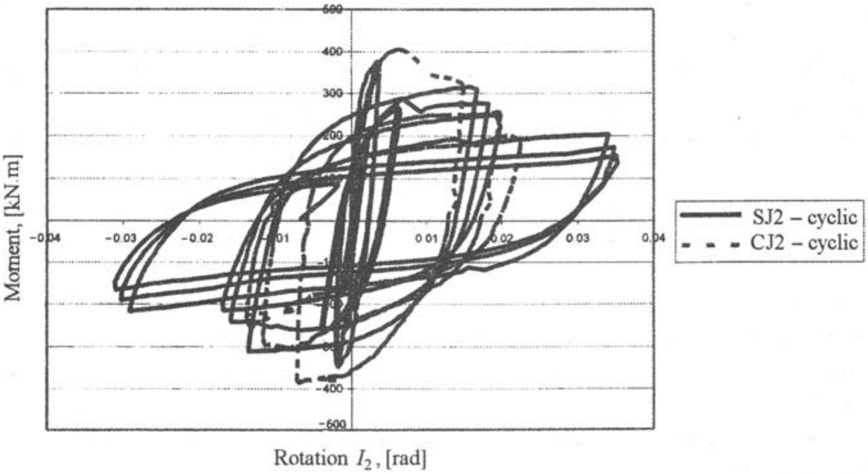

Fig. 12.- Moment *vs.* rotation diagram for steel and composite joints.

Table 2
Basic Parameters for Cyclic Test

	Steel joint (SJ2)/Cyclic test		Composite joint (CJ2)/Cyclic test	
Maximum bending moment kN.m	+315.5	–310.39	+405.6	–382.8
Maximum displacement mm	+41.17	–36.8	+27.36	–25.51
Ultimate rotation m.rad	+35.2	–29.3	+22.3	–13.8
Elastic limit, ϵ_y mm	6.18		6.38	
Experimental bending moment (elastic limit) kN.m	+201.4	–215.8	+273.4	–284.9

The diagram represented in Fig. 12 shows a symmetrical behaviour of both elements under cyclic loads. An elastic behaviour can be observed at the initial cycles after which a degradation of initial stiffness occurs. In the negative cyclic zone there were recorded small differences from the positive cycles, differences that can be explained due to the testing procedure which start with the positive cycle. Also the differences were generated by the absence of monotonic load in the negative zone in order to establish the negative elastic limit, affected of course by the behaviour of the experimental frame

4. Conclusions

By using the obtained results from the experimental tests the following conclusions were formulated for the composite joints:

a) the simplified tendency to take into account only the structural steel is inadequate;

b) if the vertical stiffeners are neglected in the evaluation of load bearing capacity, only 33% of the experimental value will be obtained;

c) in the composite joint a redistribution of the stresses occurs between the concrete, reinforcement and structural steel;

d) the connection between the structural steel flanges and the web is situated in a zone where the stress distribution must take into account the presence of the reinforcement and the concrete and therefore the stress state is far from a pure steel stress state;

e) the buckling of joint panel and vertical stiffeners in compression zone at the composite joint is avoided due to presence of concrete and transversal reinforcement (stirrups) in the joint;

f) the presence of the concrete in the joint has the effect of increasing the load bearing capacity of the joint;

g) the design formula (1) must be refined in order to cover more accurately the experimental values.

Based on the obtained experimental results we can say that the determination of the bending moment of the joint under study, with the help of the formula presented in EC 4, leads to the identification of certain values which underevaluate the joint bearing capacity. The observations made during the tests and the joint failure mode lead to certain considerations which can improve the joint simplified calculus mode.

It is considered that the vertical stiffeners play a significant role in the increase of the joint bearing capacity, the weak point being the welding at the column flange. The connection by welding of the vertical stiffeners cannot be made by complete penetration due to technical considerations. The recording of the strain gauges placed on the vertical stiffeners indicate that at the breaking point of the welding, the unit stress in stiffness reaches the value of $\sim$200 N/mm^2. In these conditions, the effect of the stiffness can be evaluated by the introduction in the calculus of the bending capacity of a safety coefficient equal to 0.6 and by taking into account the stiffeners orientation function of the column flange.

The bending moment at the elastic limit experimentally obtained for the composite joint has the value of $M_{j,\exp} = 273.4$ kN.m.

The recordings of the strain gauges from the stirrups placed at the joint level indicate that their effect is reduced, the maximum stress during the experiment being under 20 N/mm^2.

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CERCETĂRI EXPERIMENTALE PRIVIND COMPORTAREA ÎMBINĂRILOR STRUCTURILOR COMPOZITE OŢEL–BETON

(Rezumat)

În cazul structurilor compuse oţel–beton dimensionarea nodurilor este deficitară neexistând cercetări suficient de aprofundate care să permită stabilirea unei metode de dimensionare în care să fie luate în considerare toate elementele constitutive ale nodului: oţelul structural, armătura şi betonul. Se prezintă rezultatele unui studiu comparativ între metodele simplificate de determinare a capacităţii portante a unui nod compus şi rezultatele unor încercări experimentale monotone şi ciclice.