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Tests on Reinforced Concrete Composite Girders Under Cyclic Reversed Loading

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ABSTRACT

The seismic behavior of R/C composite beam is not entirely understood. The papers present some experimental investigations aiming at clarifying the behavior of plastic-hinge zones under reversed cyclic loading, and the shear undertaking mechanism at the interface.

The tested model was extracted from a frame structure designed for high seismic activity area. The topic of interest was the influence of the amount of transverse reinforcement on the seismic behavior of the beams.

The obtained results through 9 test on beams with 3 different transverse reinforcement indicated that design regulations are now quite conservative and demonstrated the need of further investigations on composite girder, in order to improve both the analytical model and present design codes.

INTRODUCTION

Reinforced concrete composite beams (precast beams with in situ concrete topping) are widely used in frame structures in Romania, even in zones with high seismic risk. Unfortunately, the behavior of such beams is not entirely understood, and there are many different opinions among the specialists, whether or not bent-up bars are strictly needed in plastic hinge zones, to connect the negative moment reinforcement (placed in the in situ topping) to the precast beam, on the value of equivalent friction coefficients, and if the use of the shear friction concept in plastic hinge zones is realistic or not.

The paper presents a part of researches developed on the purpose of clarifying some of these aspects.

THE TESTING PROGRAM

The experimental model was extracted from a frame structure designed for a high seismic intensity area. The design average horizontal shear stress at the interface corresponding to the bending strength, was about the value of tensile strength Rt of the concrete.

The experimental specimen was a simply supported beam, loaded at mid span (fig.1). The central zone of the model represented the connection zone of the actual beam, near the beam-column joint. The load was applied in a portion with a wider cross-section, modeling the column.

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The span of the beam was so chosen that the bending moment and the shear force in the specimen were almost the same as in the real structure.

There was no bent-up bars. Nine specimens, three for each model type (G1,G2 and G3, differing by the amount of transverse reinforcement) was tested.

The reference model was G1. The ties to resist horizontal shear force was detailed according to the rules for composite elements of Romanian design code STAS (1990) (similar to ACI (1989), CAN (1984), N.Z.S. (1982) codes), based on the concept of "shear-fiction", for an equivalent friction coefficient μ=0,7. For model G3, the transverse reinforcement was reduced with 57%, being designed to resist only the vertical shear force, as in the case of an in situ cast element. Model G2 was an intermediate variant, the transverse reinforcement being reduced with 28%. All three models are detailed in fig.2.

The surface on the top of the precast element, at the interface, was not intentionally roughened and, although it was clean, it was not free of laitance. The concrete was placed against the previously hardened concrete after 14 days.

The mechanical properties of steel and concrete are presented in table 1 and 2:

Table 1. Results of Tensile Test for Steel

Reinforcement bars	Yelding strength (MPa)	Ultimate Strength (MPa)
Longitudinal reinforcement D20	402,8	622,0
Transverse reinforcement D10	284,0	370,0
Transverse reinforcement D8	330,0	433,2

Table 2 Mechanical Characteristics of Concrete

Specimen		Cubical Compressive Strength (MPa)	Young's Modulus (MPa)
G1A	p	26,2	23500
	m	29,8	24890
G1B	p	20,3	23721
	m	26,1	24042
G1C	p	27,3	24477
	m	27,3	21619
G2A	p	26,1	24776
	m	27,5	25334
G2B	p	24,3	23374
	m	30,3	27246
G2C	p	33,0	24921
	m	28,0	23146
G3A	p	29,2	23622
	m	31,0	25043
G3B	p	30,0	25795
	m	31,5	23121
G3C	p	29,5	23867
	m	30,0	25689

p - precast m - monolith

The load history adopted for the test is shown in fig.3. In the first two cycles, the specimen was loaded to a displacement representing one half from the presumed yield displacement. After that, the specimen was loaded in pairs of cycles, corresponding to displacement ductility factor $\Delta/\Delta y$, (where Δ is a curent displacement, and Δy is the displacement corresponding to bending reinforcement yielding) of 1,2,3, etc. until 8.

TEST RESULTS

The good hysteretic behavior for all three models was quite close to each other and similarly to a monolithic specimen. The hysteretic loops for type G1 and for G3 (whose transverse reinforcement was reduced with 57%) is presented, comparatively, in fig.4. One can see that for both models, the energy dissipation capacity is significant.

All nine tested elements have developed large ductility (displacement ductility factor larger than 10). Some elements, to which, after loading was completed, the loading was applied monotonously until the final yelding, the displacement ductility factor was as high as 17, without any significant loss of the undertaken loading. All specimens yielded in bending.

The specimen secant stiffness decayed rapidly in postelastic range of loading (in postelastic domain).The relationship between the stiffness reduction and the loading increase is presented in fig.5. At the loading that produced a displacement 8 times greater than the yield displacement, the remaining stiffness represented 12-14% from the initial one.

The loading values corresponding to imposed displacement cycles were very close one to another for all three different types of tested models (differences not greater than 9%).

For the case of interface in tensile zone (upwards loading) the maximum attained load exceeded with 50-64% the nominal load (Pn) corresponding to the bending capacity calculated according to code STAS (1990), and the load corresponding to the longitudinal reinforcement yielding was greater then this nominal value with 20-29%. For the case of interface in compression zone (downwards loading) the corresponding values were 78-93% for the maximum load and 17-28% for the yielding load. The main experimental values of load is present in Table 3.

Table 3 Load Values

Specimen		Py (kN)	Py/Pn	Pm(kN)	Pm/Pn
G1A	↑	275	1,25	361	1,64
	↓	142	1,17	230	1,90
G1B	↑	270	1,23	351	1,60
	↓	155	1,28	234	1,93
G1C	↑	264	1,20	341	1.55
	↓	142	1,17	221	1,82
G2A	↑	275	1,25	352	1,60
	↓	155	1,28	216	1,78
G2B	↑	275	1,25	356	1,62
	↓	142	1,17	216	1,78
G2C	↑	284	1,29	341	1,55
	↓	150	1,24	221	1,82
G3A	↑	264	1,20	330	1,50
	↓	155	1,28	234	1,93
G3B	↑	268	1,22	337	1,53
	↓	155	1,28	224	1,85
G3C	↑	271	1,23	334	1,52
	↓	152	1,25	230	1,90

↑-upwards loading; ↓-downwards loading; Py-yielding load; Pm-maximum load; Pn-nominal load
P1n=220,0 kN - nominal upward load; P2n=121,3 kN nominal downward load

The connecting ties in plastic-hinge zone attained the yielding point earlier at G2 and G3 (loading, corresponding to 4Δy) than G1 (loading corresponding to 6Δy, where Δy is the displacement corresponding to bending reinforcement yielding).The strain in ties at the loading corresponding to yield initiation in the longitudinal reinforcement did not exceed 45% from the yield value.

The large strains in the bending reinforcement, in the plastic hinge zone, lead to an increase in the beam length. The average increase in length, in the plastic hinge zone, over a distance of 20 cm was about 2 mm for the loading corresponding to a displacement of 2Δy.

The relative displacement at the interface was not significant (under 0.01 mm) for all nine elements, no matter the amount of transverse reinforcement. As a consequence, no horizontal cracks were observed at the interface (photo 1-3).

CONCLUSIONS

There was analyzed several R/C composite beams, without bent-up bar and with moderate shear stress at an interface not intentionally roughened.

Three different amounts of transverse reinforcement were taken into consideration.

All three models (nine elements) had a similar, favorable behavior under cyclic reversed loading (hysteretical behavior, displacement ductility, cracking pattern and the loading values corresponding to the imposed displacement). All specimens yielded in bending.

No significant relative displacement, neither any horizontal crack was recorded at the interface even in plastic-hinge zones. It is worth to mention that, because of lack of horizontal cracks at the interface, the so called "shear friction" was not mobilized.

The transverse reinforcement reduction (compared to present design regulations) did not influence the general good behavior and the undertaking of the horizontal shear at the interface.

The investigations revealed the need for further research (for beam with greater shear stress at the interface) on composite girders, in order to improve both, analytical model and the present design regulation.

REFERENCES

ACI 318-89 Building Code Requirements for Reinforced Concrete, American Concrete Institute, Detroit, Michigan

CAN 3-A 23.3- M84. Dec.1984 Canadian Concrete Design Handbook.

N.Z.S. 3101:82. "Code of Practice for the Design of concrete Structures", Standards Association of New Zealand

STAS 10107/0-90 Romanian Code for Civil and Industrial Buildings Design and Detailing of Concrete, Reinforced Concrete and Prestressed Concrete Structural Members

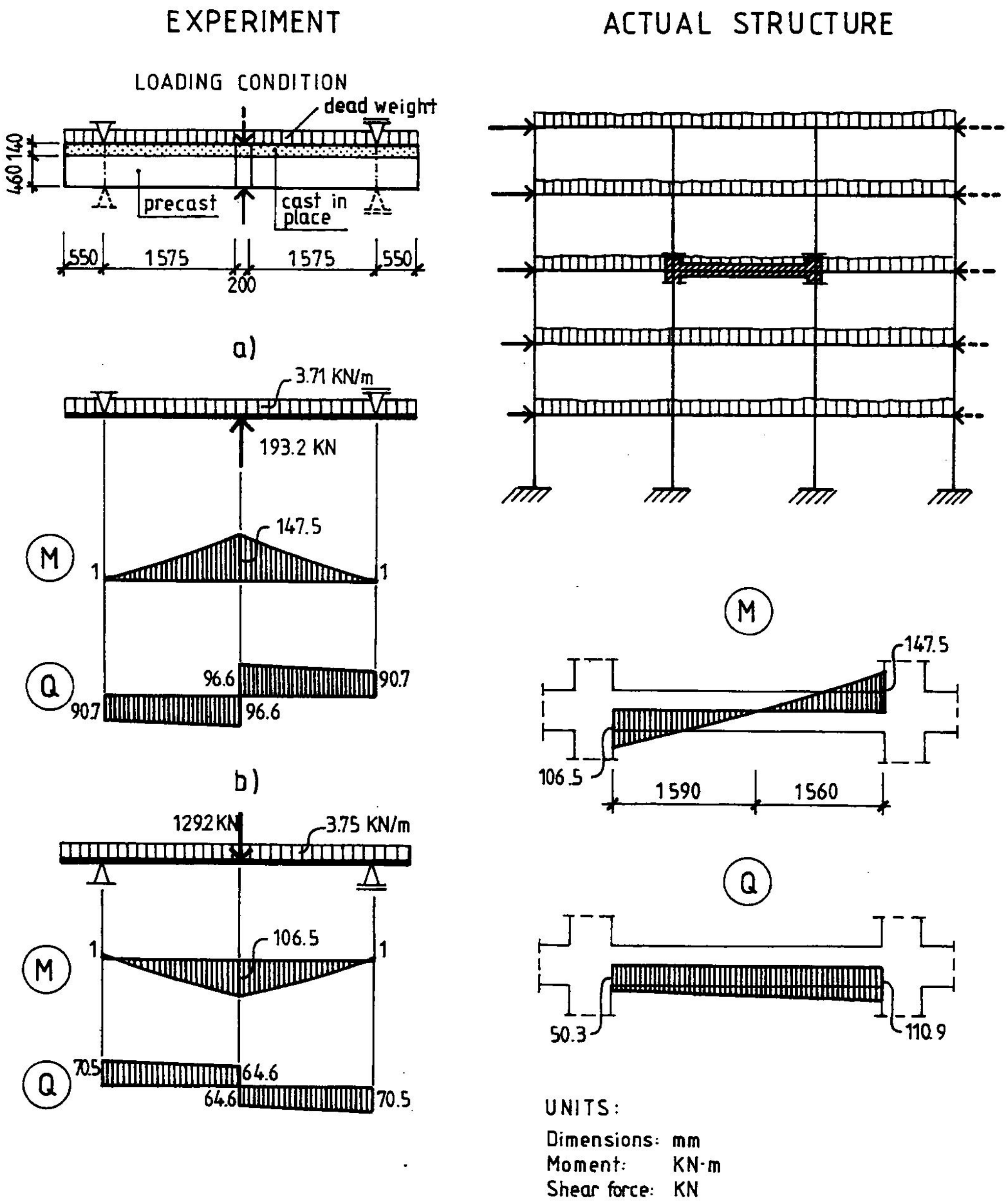

Fig. 1 MODELING FOR EXPERIMENT

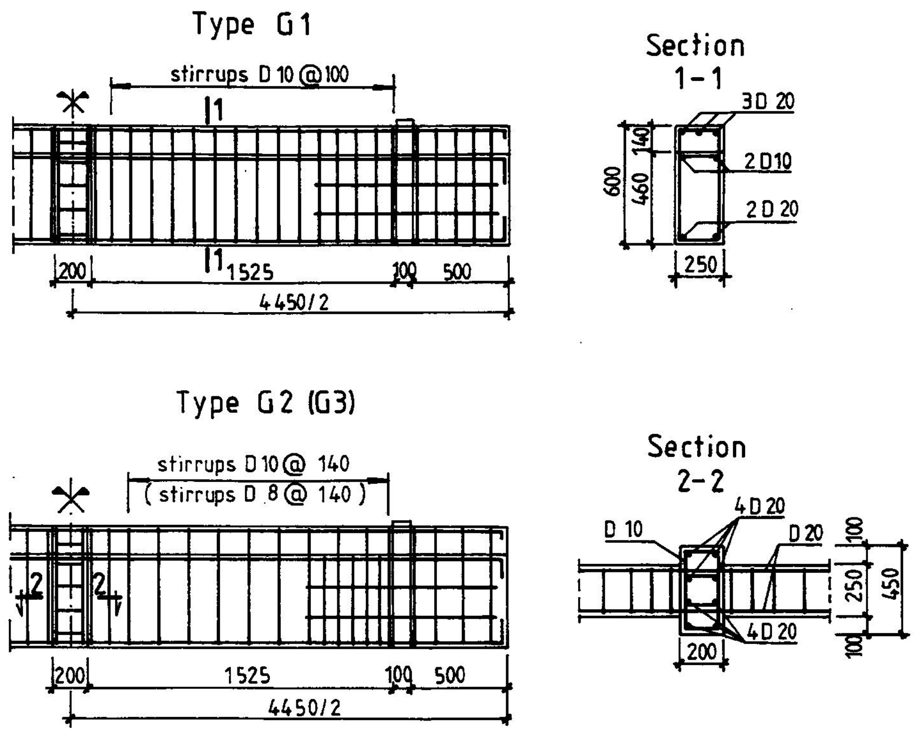

Fig. 2 TEST SPECIMENS

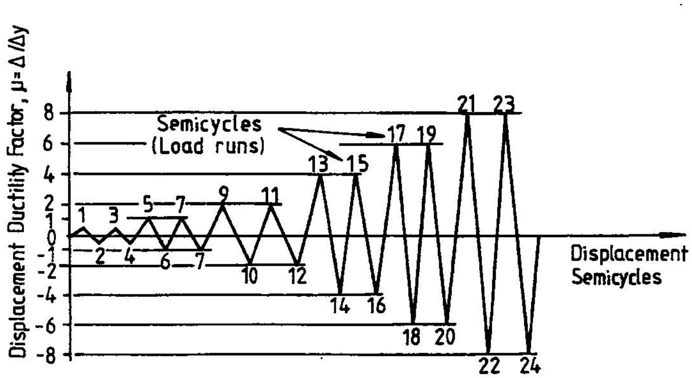

Fig. 3 LOAD HISTORY

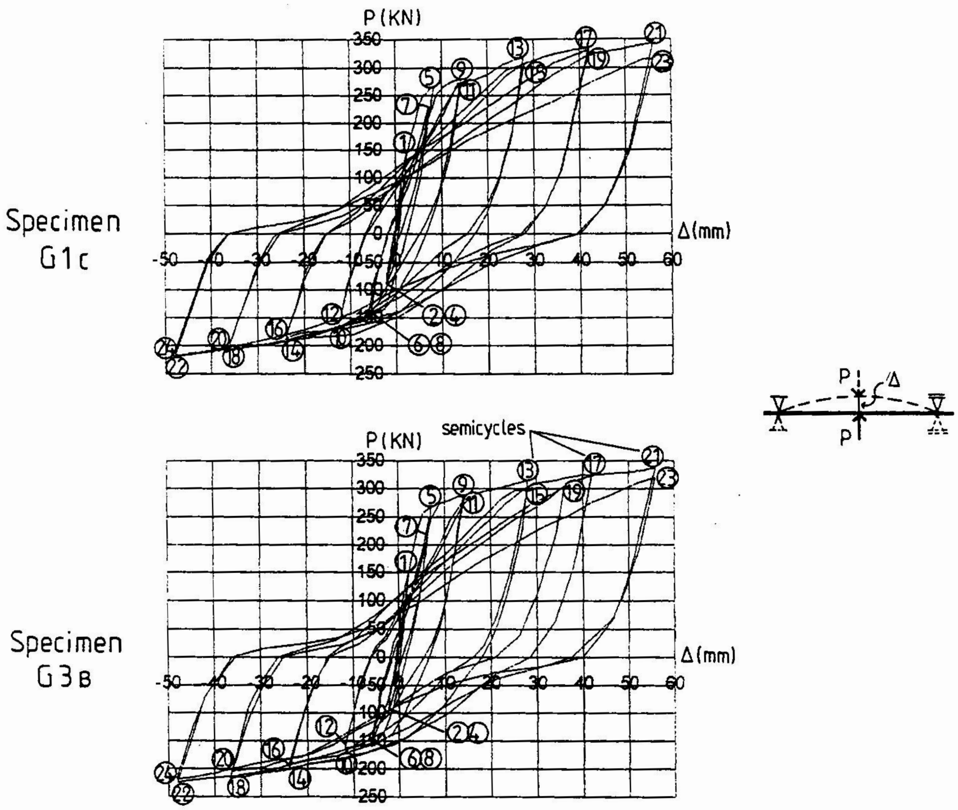

Fig. 4 LOAD-DISPLACEMENT RESPONSE

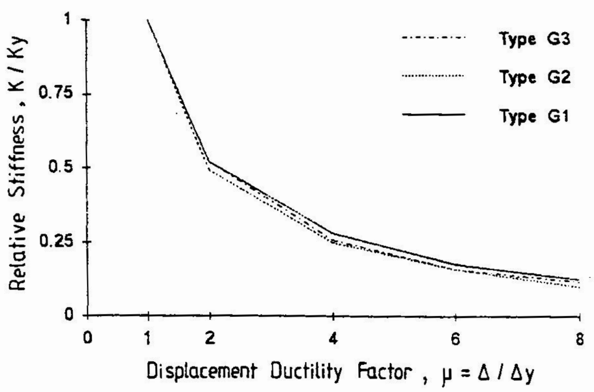

Fig. 5 STIFFNESS REDUCTION– INELASTIC CYCLES

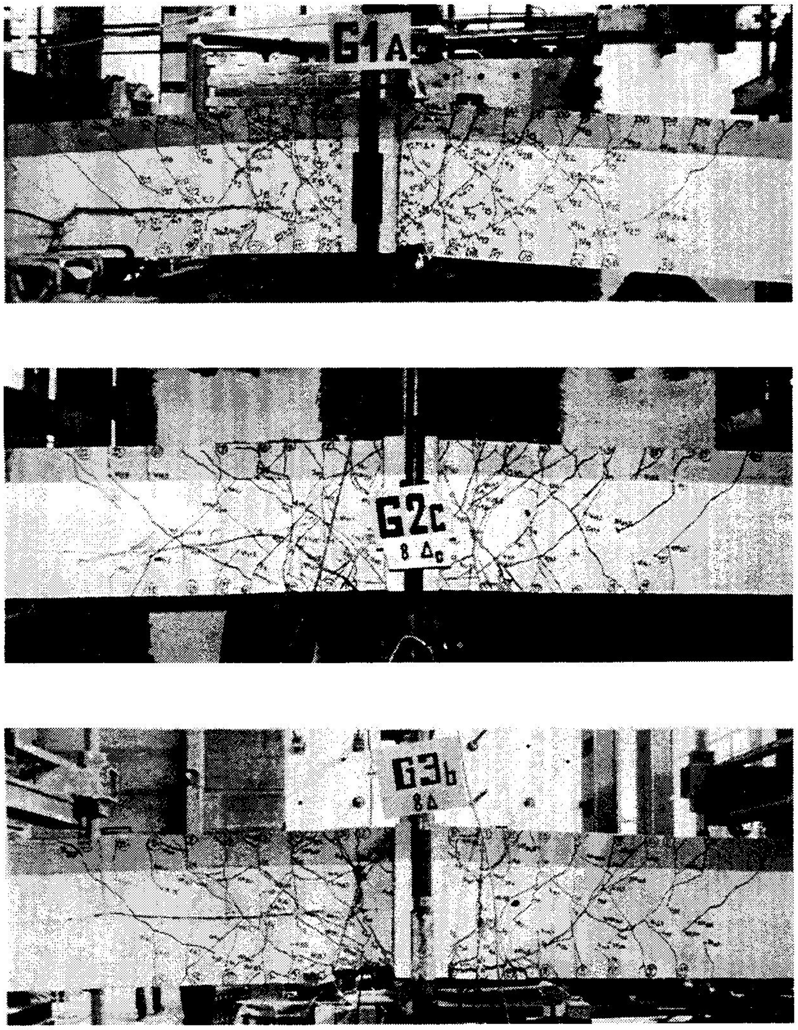

PHOTO 1-3
POST TEST SPECIMENS