Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 55 (1987)

Artikel: Axial shear connectors for wide span prefabricated structures

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DOI: https://doi.org/10.5169/seals-42767

Axial Shear Connectors for Wide Span Prefabricated Structures

Goujons axiaux pour structures préfabriquées de grande portée

Axiale Schubdübel für vorfabrizierte Balken mit grosser Spannweite

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Carlo Marioni, born in 1939, graduated in civil engineering from Milan Polytechnicum in 1964. From 1974 through 1977 he lectured at Rome University. He has been responsible for a number of prefabricated and/or prestressed structures projects ranging from multi-storey buildings to highway bridges and nuclear power plants, partly based on his own patents.

SUMMARY
The purpose of achieving spans for bridges of up to 90 meters by means of prestressed simply supported structures adopting light composite truss beams supporting cast in situ floor decks is getting nearer and of real economical interest. Coupling of steel diagonals and struts to prefabricated prestressed concrete chords is facilitated by flexible-type shear connectors. The paper describes tests carried out during ten years and first realizations by the author.

RÉSUMÉ
Le franchissement de portées de 90 m, par des poutres librement appuyées, précontraintes, est devenu intéressant par l'utilisation de poutres-treillis légères en construction mixte acier-béton précontraint, soutenant des prédalles complétées in situ. Le couplage entre les barres métalliques du treillis et les éléments préfabriqués est obtenu au moyen de goujons flexibles. L'étude donne une description des expériences conduites pendant dix ans par l'auteur, et les premières réalisations.

ZUSAMMENFASSUNG
Die Möglichkeit Brückenspannweiten bis 90 m mit Hilfe frei aufgelagerter, vorgespannter Balken zu erreichen kommt näher und wird wirtschaftlich interessant, wenn vorgespannte Fachwerk-Verbundträger verwendet werden, welche mit einem an Ort gegossenen Ueberbeton zu ergänzen sind. Die Verbindung der Fachwerkstäbe aus Stahl mit den vorfabrizierten Betonelementen wird mit Hilfe flexibler Schubdübel erreicht. Der Beitrag beschreibt Versuchsergebnisse und erste Anwendungen.

1. FOREWORD

A careful investigation on shear connectors particularly fit to prefabricated structures and aimed at reaching wide spans, using composite truss beams completed by cast-in-situ floor decks, was conducted by the author during ten years. First realizations in Italy, ranging from highway bridges to floor decks for nuclear plants, display an ingrowing interest for this type of structural solution.

2. EXPERIMENTAL INVESTIGATION

2.1. Statical Tests (Asymmetric Specimens)

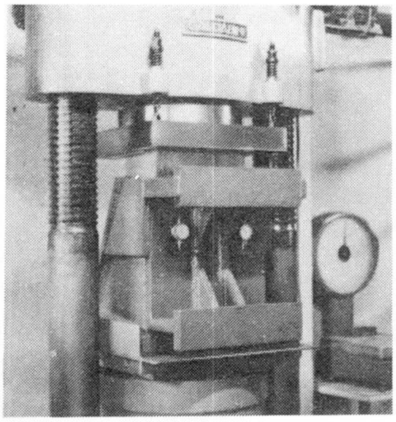

Fig.1 Tests on asymmetrical shear connector specimens

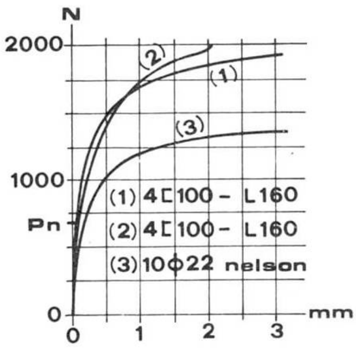

Fig.2 Relative displacement vs. load for different types of shear connectors

Early tests at the Laboratory of the Istituto di Scienza delle Costruzioni at Turin Polytecnicum during 1978 on four shear connectors specimens (2 specimens with channel and 2 specimens with Nelson headed stud connectors) persuaded the author to choose the light channel type connector, so much that he stopped testing the forth specimen equipped with Nelson-type connectors (curve three of Fig.2). Intensive and more carefully conducted tests by other authors (1),(2),(3), explain in detail the soft behaviour of the Nelson type,(4) compared with the rigid behaviour of the channel-type connector (curves 1 and 2 of Fig.2).

A second serial of tests was conducted in 1979 at the same Laboratory of Turin Polytechnicum upon 2 real scale specimens of truss beams spanning 6.36 meters (5). Location of the 149 measurement bases on two beams are shown in Fig.3 and the quite low relative displacements between steel plates and concrete are illustrated in Fig. 4, giving good accordance with early results.

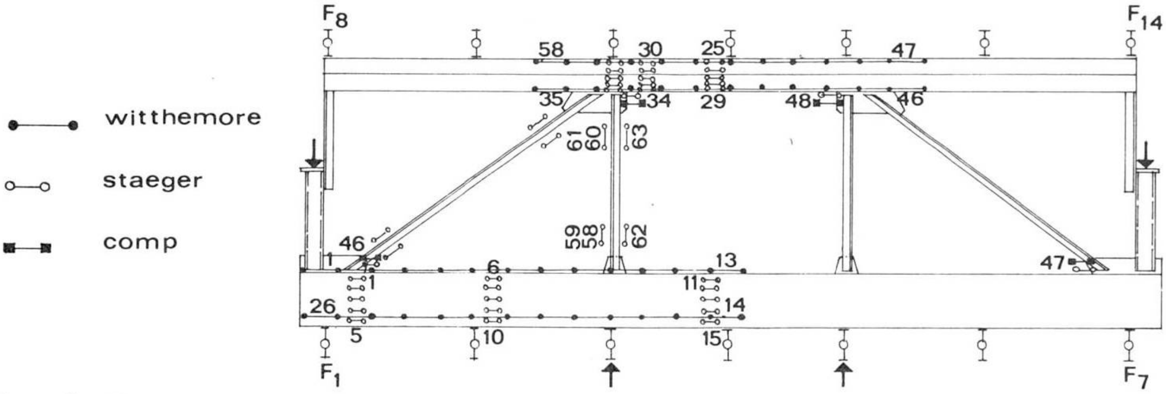

Fig. 3 Measurement location for the 2 beams tested at Turin Polytechnicum

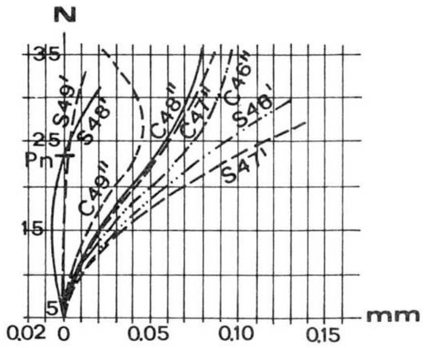

Fig. 4 Relative displ./load for Fig.3 beams

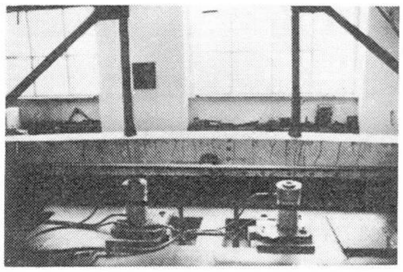

Fig.5 The limit state for one of the tested beams of Fig.3

Both beams were tested by means of two hydraulic jacks of 1000 kN and behaved almost elastically up to working conditions; the second beam (Fig.5) showed a permanent deflection of about 0,20 mt. after a loading range totalling 2.3 times the working load; the whole beam revealed full exploitation of all structural elements (p.c. and r.c. chords, steel diagonals and sruts, shear connectors and gusset plates).

2.2. Tests - (Symmetric Specimens)

Push-out tests on 3 double specimens (A Serie) equipped with (80x45x6)mm. channels and measuring (160x120x200)mm. (dimensions are slightly different from the standard AIPC-CEB-CECM-FIP ones) in 1983 at Milan Polytechnicum, revealed the intrinsec sensitivity of the proof to arch effects related to lateral thrust at the base of specimens. The third test with reduced distance for the two lower hinges, showed however lower rotations of twin specimens up to ultimate load, and an almost tangential working for the shear connectors in the elastic range: this effect caracterizes axial shear connection for truss beams.

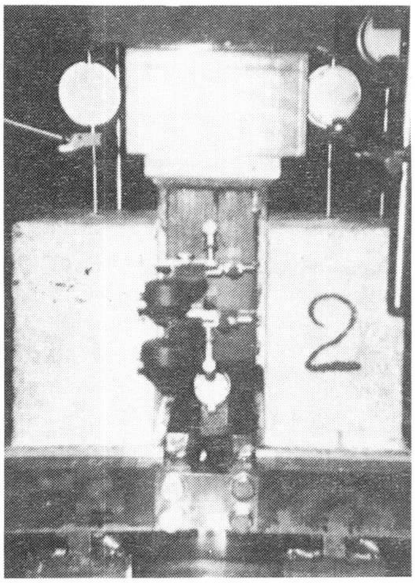

Fig. 6 Statical tests of symmetric specimens

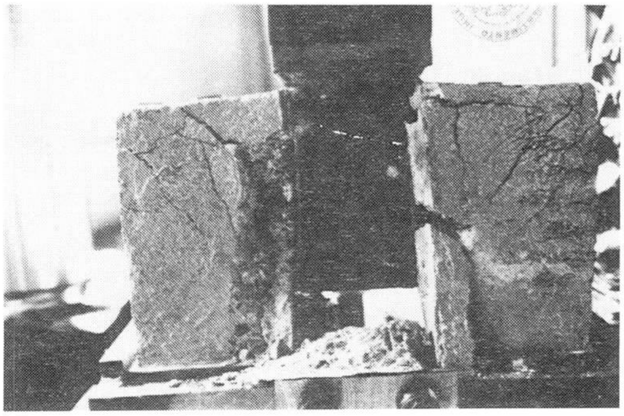

Fig. 7 Failure of specimen B5 under static load

2.3. Dynamic Tests - (Symmetric Specimens)

Dynamic pulsating tests on 7 double specimens (B Serie) same as the static tested ones, were carried out also in 1983 at Milan Polytechnicum. The pulsating force was held between 40 and 150 kN, by a frequence of 9.9 Hz. Each sample underwent 2.E6 loading cicles without visible cracking effects. Seven stops during tests made it possible to perform a statical test under a load of about 40 kN. The measurements showed a longitudinal adaptation less than 0,1 mm. of the tested specimens for the first 10000 cicles, slightly increasing for 2.E6 cycles, and an angular rotation of the head of the specimen held constant. Another result of the tests, which will be illustrated more in detail in a next publication, was the tendance of tested specimens to raise internal states of self-stressing related to cracking, under localized shrinkage effects. Three specimens were also statically tested up to failure as shown in Fig. 8 averaging an ultimate load not lower than that reached by the same specimens not prooved by dinamic tests. Failure was given by crashing of concrete, and almost simultaneously reached excessive elongation of connectors web. Fig.7 shows a characteristic failure crack pattern for specimen B2 which permits to "read" the real path of compressive struts through concrete. The steel connector was a St 430 MPa, weld was magnetically inspected, and a preliminar chemical investigation was made for mill steel. Concrete reached a characteristic R'bk = 50MPa cubic strength at 28 days.

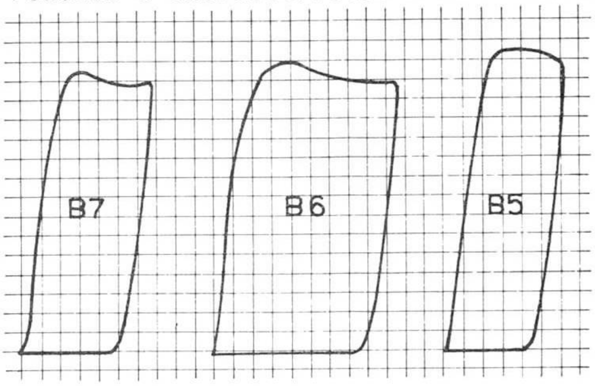

Fig. 8 F-ε diagram for static loading to failure, of 3 dynamic tested specimens.

3. APPROACH WITH F. E. METHOD.

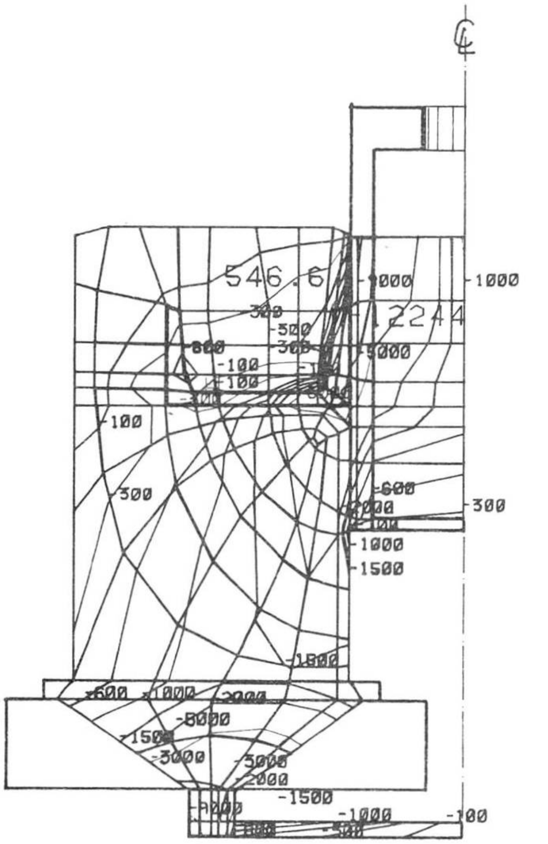

Fig. 9 Stress level plot after elastic analysis with a F.E.M. mesh of 151/2-D elements.

An analysis conducted with 2-D quadrilateral strain F.E. confirmed high stress concentrations at the fore toe of the channel;after inibition of some F.E. at the interface with the steel pipe. Though quite inadequate, the elastic analysis showed that real behaviour of this type of connection is far from being well understood and needs for more intensive and widespread ascertainement in the future. This gap of our knowledge has been recently remembered by other investigators (6).

4. UP TO DAY REALIZATIONS.

The first realizations include 2 bridges over the river Melezzo built during 1982 in the high Vigezzo Valley, about 30 Km. far from Locarno. The Mugnago bridge spans 3x40 and the Meis bridge 30 -45- 30 meters. Both are pedestrian bridges designed for a 270 kN truck. The bridge deck was entirely prefabricated in a plant 300km. away, and assembled within 2,5 months/bridge. Each 1/3 span single beam segment was assembled during a workday by 4 workmen,and raised on provisional piers by a little self-moving crane: maximum load of one segment was 170 kN. Two days after sealing of 60 mm.thick chord joints by means of high strength cement mortar; tensioning of the (2x2) lower chord 1200 kN/each prestressing tendons produced self-raising of both main beams. Another group of realizations still under construction comprises the aseismic floor decks of 4 major buildings of the nuclear plant ENEL (general designer ANSALDO) near Rome. The flat deck of the Turbina building for ex. measures

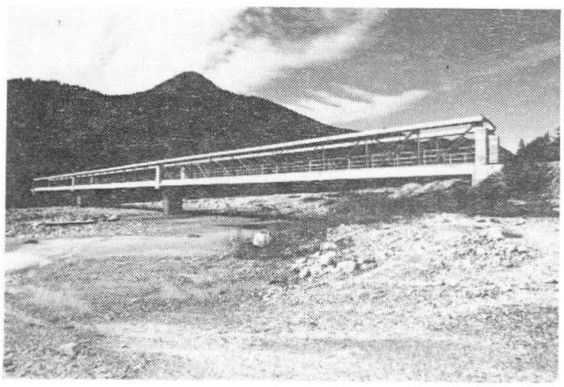

Fig.10 The Mugnago Bridge spanning (3 x 40,0 meters)

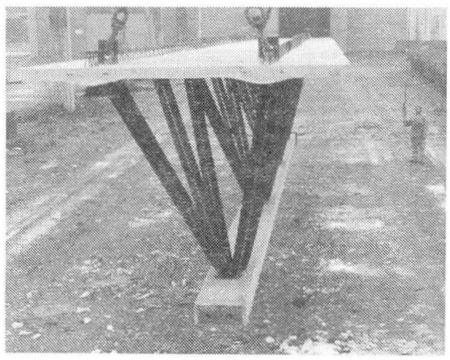

Fig. 11 Assembler beam for nuclear plant near Rome

(115,0x35,0)m. and is a completely isolated plate 0,40 m. thick, supported by 48 adjacent Assembler-type truss beams and post-tensioned by 46 cables; linked to the exterior wall of the 35,0 m. high structure by means of some 38 hydraulic shock-absorbers and 4 neoprene/teflon bearings of 6000 kN (7). The last realization is the Plusc bridge of Verbania on the boarder of the Maggiore Lake in North Italy, spanning 70,0 m., also under construction. The bridge deck is designed for highway loads and is supported by 3 Assembler-type beams weighing 2100 kN spaced at 3,75m.

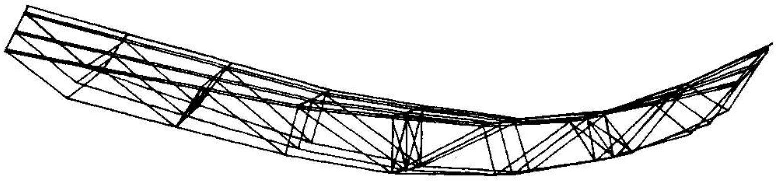

Fig. 12 Elastic deformed structure of the 70,0 m. span of Plusc Bridge of Verbania

5. THE ECONOMICAL SIDE.

Computations of designed works give (Table I) the following values for building materials. Table II gives extrapolated items for a 90 m. span.

Concrete of the plate-deck	$0{,}24 m^3/m^2$	$0{,}24\ m^3/m^2$
Concrete of pref. beams	$0{,}32 m^3/m^2$	$0{,}65\ m^3/m^2$
Structural steel	$1{,}05\ kN/m^2$	$1{,}33\ kN/m^2$ *
Prestressing steel	$0{,}17\ kN/m^2$	$0{,}34\ kN/m^2$
High-bond steel pref. beams	$0{,}19\ kN/m^2$	$0{,}40\ kN/m^2$
Table I Materials for a 70,0m. h.-bridge		Table II Materials for a 90,0 m. h.-bridge
* adopting for diagonals and struts circular seamless pipes.		

Further savings will be obtained by utilization of high strength concrete so to reduce the weight of the prefabricated truss beams.

6. CONCLUDING REMARKS.

This new type of structure permits to improve the range of spans for prefabricated structures, eliminating the heavy webs of traditional prestressed beams. Contemporary use of prestressing steel and structural steel for the beams, and r.c. in the upper zone of the deck, avoids provisional windbracing of steel beams during erection and gives best behaviour under impact and dynamic loading.

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