Fatigue behaviour of orthotropic steel bridge decks

Fatigue Behaviour of Orthotropic Steel Bridge Decks

Comportement à la fatigue des dalles orthotropes de ponts en acier

Ermüdungsverhalten orthotroper Platten in Stahlbrücken

Stefano CARAMELLI
Prof. of Struct. Eng.
University of Pisa
Pisa, Italy

Maurizio FROLI
Researcher of Struct. Eng.
University of Pisa
Pisa, Italy

Pietro CROCE
Dr. Eng.
University of Pisa
Pisa, Italy

Luca SANPAOLESI
Prof. of Struct. Eng.
University of Pisa
Pisa, Italy

SUMMARY
Recently, some orthotropic steel bridge decks have suffered fatigue cracks. For a better knowledge of this problem, the European Community promoted and financed collective research work in which seven laboratories in six European countries participated. The Italian contribution to this research, deals with the experimental determination, on full scale specimens, of the fatigue behaviour of two types of welded connections of longitudinal stiffeners.

RÉSUMÉ
Récemment, quelques dalles orthotropes de ponts en acier ont montré des fissures de fatigue. Afin d'améliorer la connaissance de ce problème, la Communauté Européenne a encouragé et financé un programme de recherche auquel ont participé sept laboratoires de six pays européens. La contribution italienne, avait pour but de déterminer, de façon expérimentale et sur des éprouvettes en vraie grandeur, la résistance à la fatigue de deux types d'assemblages soudés de raidisseurs longitudinaux.

ZUSAMMENFASSUNG
In letzter Zeit wurden in den orthotropen Platten einzelner Stahlbrücken Rissbildungen infolge Ermüdung beobachtet. Um die Ursachen dieses Problems zu ergründen, wurde unter dem Patronat der Europäischen Gemeinschaft ein Forschungsprogramm zusammengestellt, an dem sieben Laboratorien aus sechs verschiedenen europäischen Ländern beteiligt waren. Der italienische Beitrag behandelt die an Bauteilen durchgeführte experimentelle Bestimmung des Ermüdungsverhaltens zweier verschiedener Schweissverbindungen von Längsrippen.

1. INTRODUCTION

The fatigue cracks appeared on some orthotropic decks of steel bridges after nearly twenty years of service life [1] showed that steel orthotropic decks are sensitive to fatigue problems and that their fatigue strength may not be directly estimated by means of the S-N curves proposed by the European codes which concern simple details used in steel constructions instead of the complex shaped connections of the orthotropic decks.

Beside that, the codified S-N curves are based on experimental results of little size specimens generally free from residual stresses patterns due to the welding procedures and probably less affected than the real scale complex shaped connections by local in the welds. But, as noticed by FISHER [2] and confirmated recently by YAMADA, KENDO, AOKI and KIKUCHI [3], CUNNINGHAME [4], AGERSKOV, BJØRNABAK-HANSEN [5] and others, lack of penetration, residual stresses and dimensions of the connected pieces are the factors that mostly influence the fatigue resistance of the joints.

In order to aquire a deeper knowledge on the static and fatigue behaviour of steel orthotropic decks, the ECSC promoted and financed the collective research programme: "Fatigue strength of orthotropic decks of steel bridges", third phase of the general programme: "Measures and interpretations of dynamical loads on bridges".

The research programme, concluded in 1989, was carried out by seven laboratories of six European countries among those, for Italy, the Istituto di Scienza delle Costruzioni of the University of Pisa.

The Italian programme foresaw the theoretical and experimental determination of the nominal stresses in those points of a real scale orthotropic deck more sensitive to a fatigue cracking risk and the execution of constant amplitude fatigue tests of stiffener to stiffener connections performed both on real scale ribs samples (type B specimens) and on the orthotropic deck panel previously used for the static test (type A specimen) [6].

This paper illustrates that part of the research dealing with the fatigue experiences.

2. FATIGUE TESTS ON TYPE B SPECIMENS

2.1 Description of the specimens and test modalities

The Fe 510C steel specimens, 200 mm long, consist of triangular cross section ribs built by welding a cold formed 6 mm thick steel plate to a top plate 600 mm wide and 12 mm thick. At middle span of each specimen, a type I or type II joint was shop executed reproducing the same working modalities provided for field execution. In figure 1 both type I joint and type II joint are illustrated, while in figure 2 the welding geometries S1÷S4 are shown.

In type I joints, the ribs are interrupted at a distance of about 200 mm astride the connection. The two limbs of the top plate - one of which has the backing strip welded to it (S1 welding) - are placed in such a way to get a root gap of about 6 mm, and thus automatically welded. The missing rib element is then inserted and manually welded in overhead position (backing strip weld S3 (fig. 3)).

In type II joints, the top plate is interrupted for about 200 mm. The stiffener webs are butt welded, with complete penetration, using S4 welding (fig. 4) which is manually executed with coated electrodes. First, the internal part of the ribs is welded in ascending vertical position, then one proceeds to the grooving of the external part and to the restarting of the weld in overhead position. The joining is completed with the insertion of the missing top plate portion, the execution of the S1 flat position welding and the manual overhead remaining welding S2 between the top plate and the ribs.

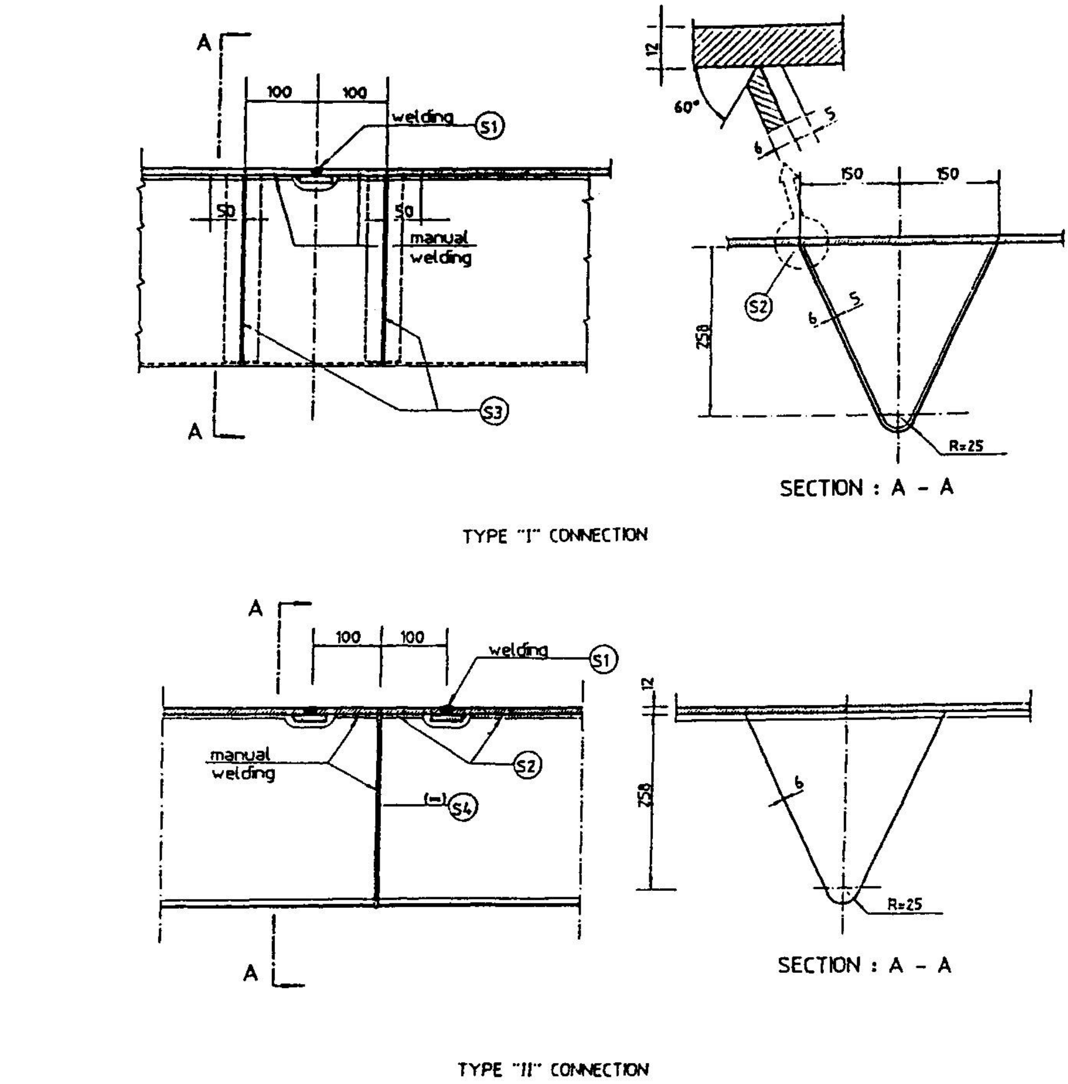

Fig. 1 Type I and type II stiffener to stiffener connections

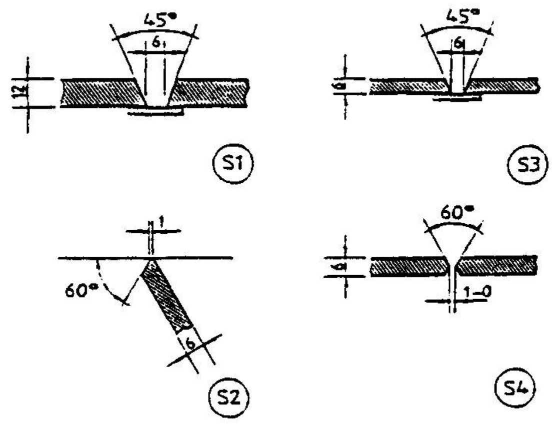

Fig. 2 Edge preparation

All the weldings have been checked by means of visual and magnetic controls. The butt weldings, moreover, have been 100 % X-raied and repaired where found (only one time) not acceptable according to the UNI 7278 Italian Standard.

The fatigue tests at constant stress amplitude, were carried out on nine type I joint specimens and on eight type II joint specimens.

The static test scheme is that of a simply supported beam, 2400 mm spanned, with the fatigue load applied at middle span by a pulsating hydraulic jack acting with a frequency of 4 Hz.

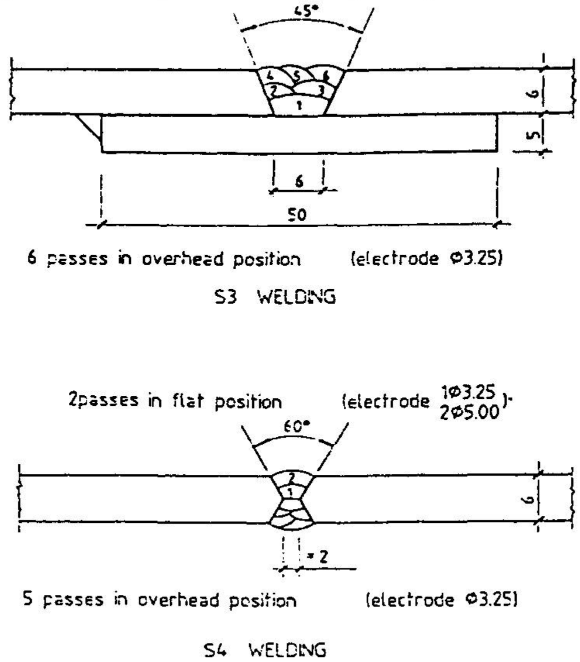

Fig. 3 S3 and S4 weldings

The load was applied on a rectangular neoprene strip 50 mm wide, 600 mm long and 10 mm thick, put between the moving jack and the top plate.

The stresses at the apex of the ribs were measured using electrical strain gauges, placed in a way that allowed the determination of the nominal stress amplitude excluding local peaks.

During the tests, the minimum nominal stress has been kept constantly at 1.5 KN/cm² for all the specimens.

Each test was interrupted at failure, recognized by the specimen's loss of stiffness (an increase of one centimeter of the maximum deflection under load), or when 8,000,000 cycles had been performed without any breaking.

2.2 Experimental results

The experimental results obtained on B specimens with type I joints and type II joints are respectively reported on the bilogarithmic S-N diagrams of figure 4 and 5 together with their mean life curves.

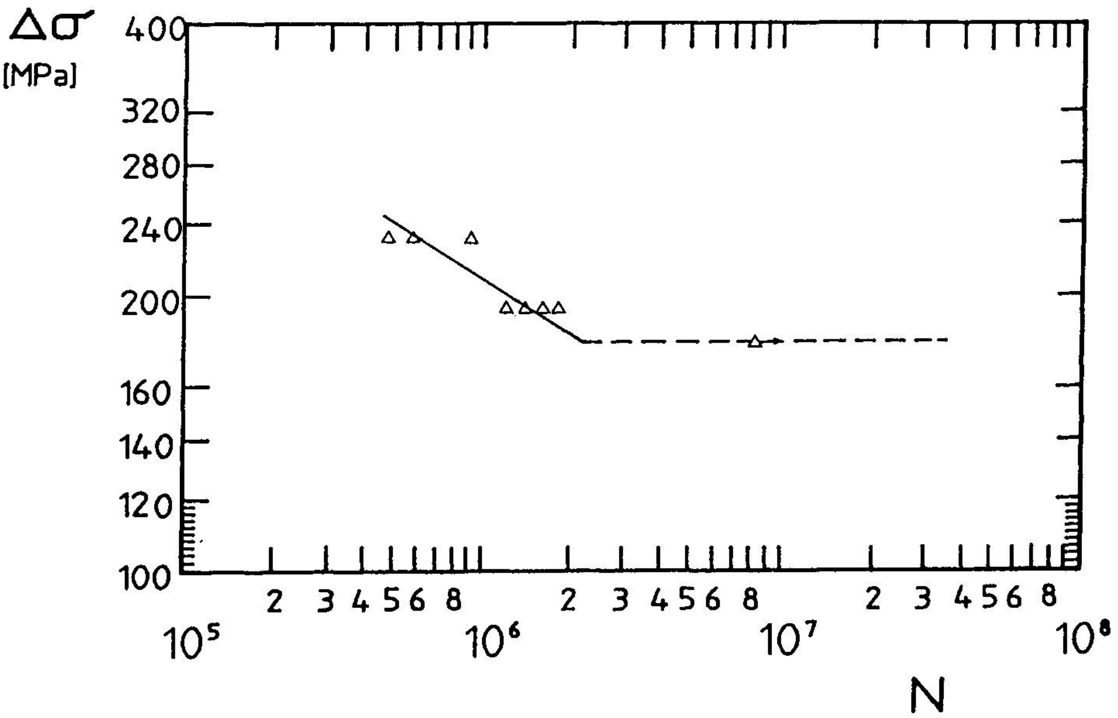

Fig. 4 Fatigue test results of type B specimens with type I joints

The two groups of results are then compared in the diagram of figure 6 from which the fatigue behaviour of type I joints appears to be better than that of type II joints.

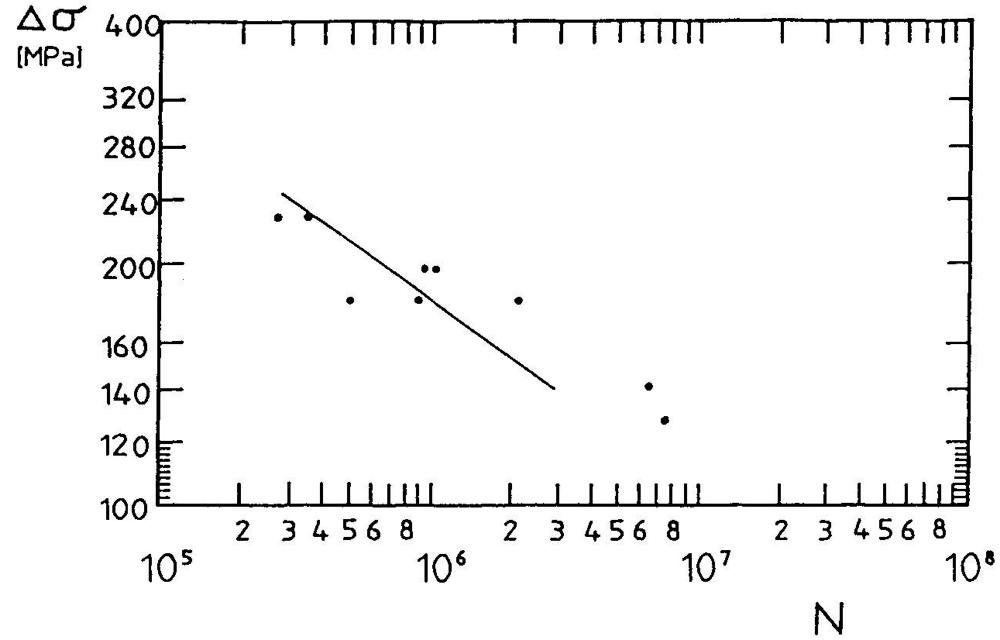

Fig. 5 Fatigue test results of type B specimens with type II joints

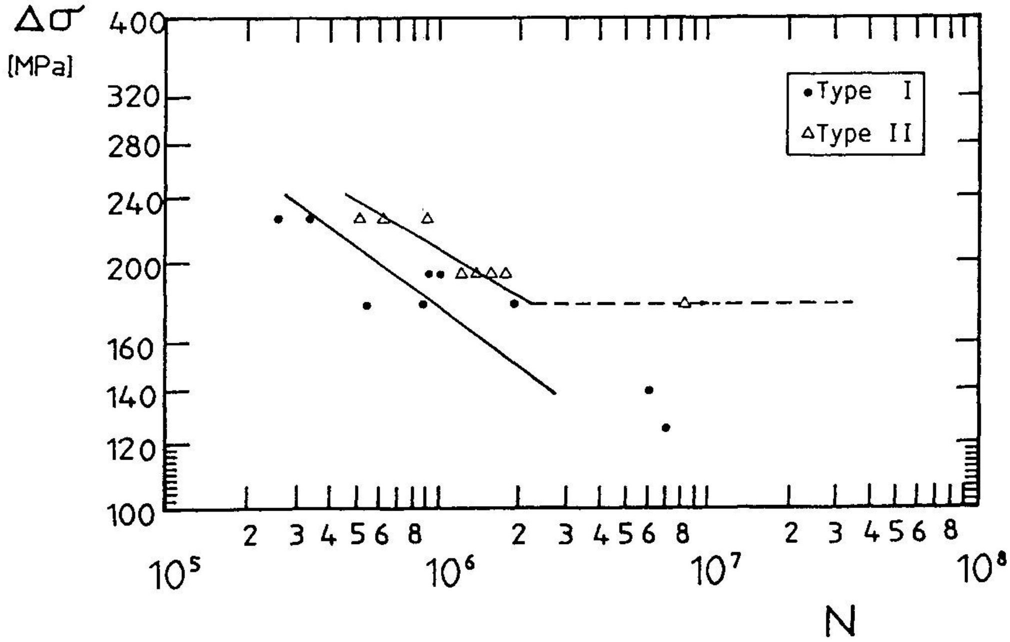

Fig. 6 Comparison between fatigue test results of type B specimens

3. COMPLEMENTARY TESTS

The previous result was rather unexpected because all the existing codes for fatigue design of steel structures classify backing strip welds in a lower position than complete penetration butt weldings (see for example [7]) and it is has also important consequences in the design practice because stiffener to stiffener connections with backing strip welds are more economic than the other welded connections.

In order to get a better understanding on the causes of the different behaviour of the two kinds of joints, it was decided to execute relaxation tests on type B specimens to control the residual stress levels and in the same time to perform a great number of fatigue tests on little size specimens provided with S3 and S4 weldings, for which residual stresses are negligible, to verify wether the different behaviour of the joints was to be attributed to the different types of weldings.

3.1 Residual stresses measurement in type B specimens

Residual stresses have been indirectly measured by means of mechanical relaxation tests executed on some type B specimens provided with type I and type II joints.

The test scheme is the same adopted for fatigue tests. During the test, some loading and unloading cycles have been performed until the steady cycle was reached. At each loading step the longitudinal strains at the lower apex of the stiffeners, close to the weld foot, have been measured.

Two typical load-strain curves related to type I joint and type II joint are reproduced in figure 7: it can be immediately noticed that residual stresses are almost absent in type I joints while one finds that they reach nearly 20 KN/cm^2 in type II joints.

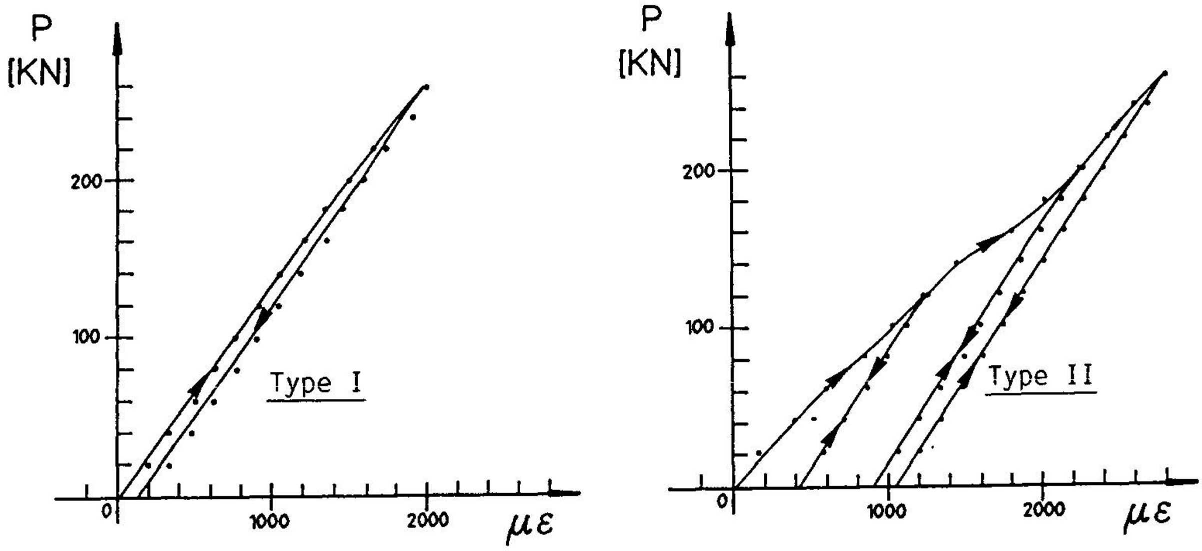

Fig. 7 Load-strain diagrams of the relaxation tests on type B specimens

3.2 Fatigue tests on welding specimens

The samples, 600 mm long, 35 mm wide and 6 mm thick, (figure 8) have been obtained by saw cutting two sheets 2000 X 300 X 6 mm of the same steel used for the stiffeners and welded together with the same modalities (operator position, number and sequence of passes, type of electrode) adopted for the S3 and S4 weldings used in type B specimens. Before cutting, the weldings have been submitted to the same checks executed for type B specimens without finding any defects.

In each specimen the surfaces of the cut have been ground to eliminate every stress concentration due to roughness and than fatigue tested under a tensile load pulsating sinusoidal with a frequency of 12 Hz, by means of a universal test machine Losenhausen UHP10. During the experience, the lowest tensile stress, kept constant for each specimen and equal to that of the type B specimens, was 1.5 KN/cm².

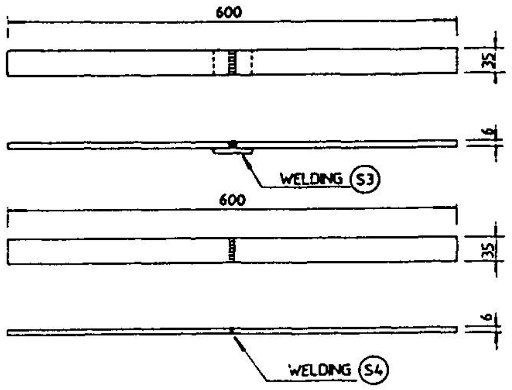

Fig. 8 Welding specimens

A number of 62 specimens have been tested: 31 with S3 weldings and 31 with S4 weldings.

The results are plotted on diagrams of figures 9 and 10, in which the mean S-N curves and the confidence band related with each group of results (fractile of 5% and of 95%), obtained following the ASTM E739-80, are reported too. It can be noticed that the two mean curves are practically coincident.

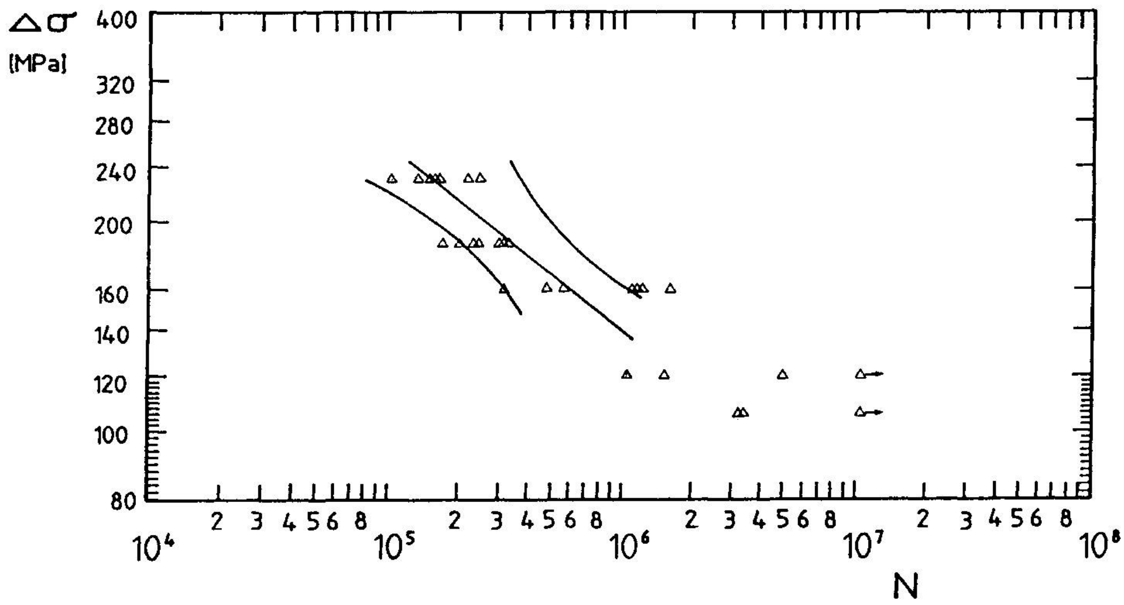

Fig. 9 Fatigue results on S3 welding specimens

4. FATIGUE TESTS ON TYPE A SPECIMENS

4.1 Description of the tests and test modalities.

In order to check the applicability of the fatigue results obtained on type B specimens to real deck joints, fatigue tests were carried out on two full scale orthotropic deck specimens provided with stiffener to stiffener type I joints which have been obtained by cutting crosswise along the central line the specimen used in the static test (type A specimen: see figure 11).

The test scheme is that of a plate with cantilever resting on two cross beams. The cantilever have been ballasted using two concrete blocks weighting totally 54 KN. The pulsating fatigue load, applied onto a 200X300 mm rectangular neoprene plate placed at middle span, induced a nominal stress delta at the lower apex of the central rib, close to the weld foot, equal to 22.5 KN/cm2 and a minimum stress of 1.5 KN/cm2, reference being the stress induced by the ballast and the self weight of the deck.

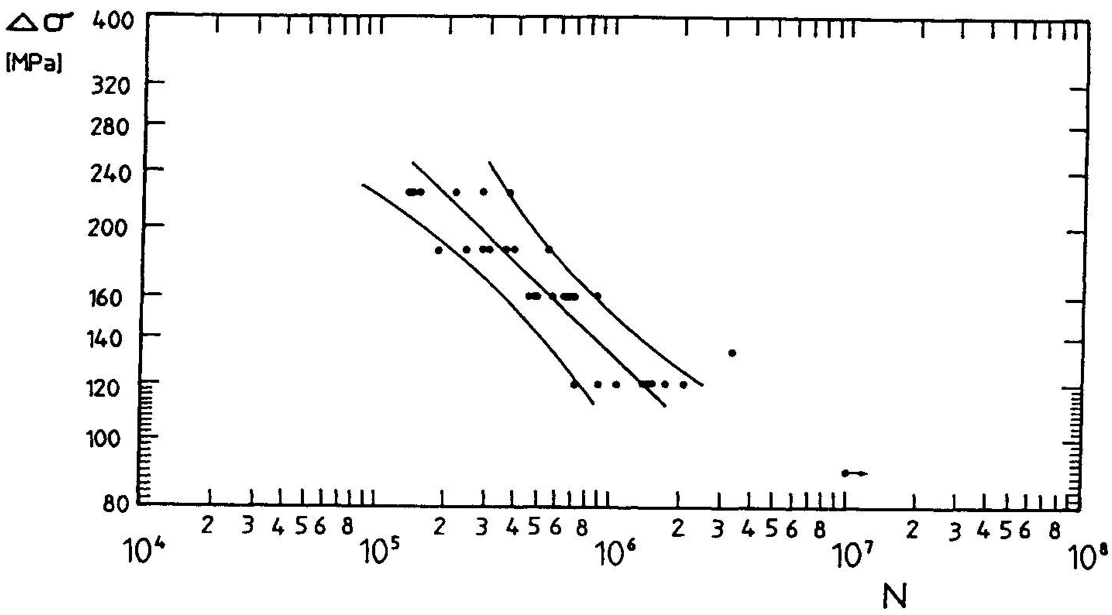

Fig. 10 Fatigue results on S4 welding specimens

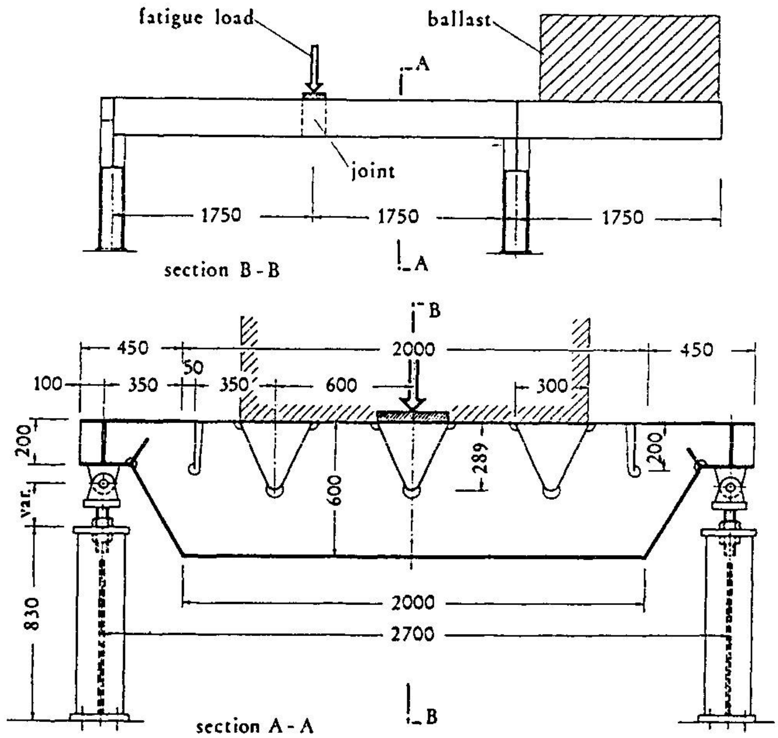

Fig. 11 Type A specimen

4.2 Experimental results

The first specimen failed after 240,000 cycles, the second one after 260,000 cycles. In both cases crack initiated in the weld at the apex of the rib and propagated in the weld too.

The comparison between the results obtained on the two types (A and B) of specimens reveals good accordance, within the normal dispersion limits. The lower fatigue strength revealed by type A specimens may be due to the residual stresses which in full scale orthotropic deck panels are to be expected higher than on simple ribs because of the greater stiffness of the deck.

5. CONCLUSIONS

The mean S-N curves of type B specimens and those regarding the welding specimens are compared in figure 12 where also the ECCS curves for backing strip weldings (class 71) and for full penetration weldings (class 80) are reported.

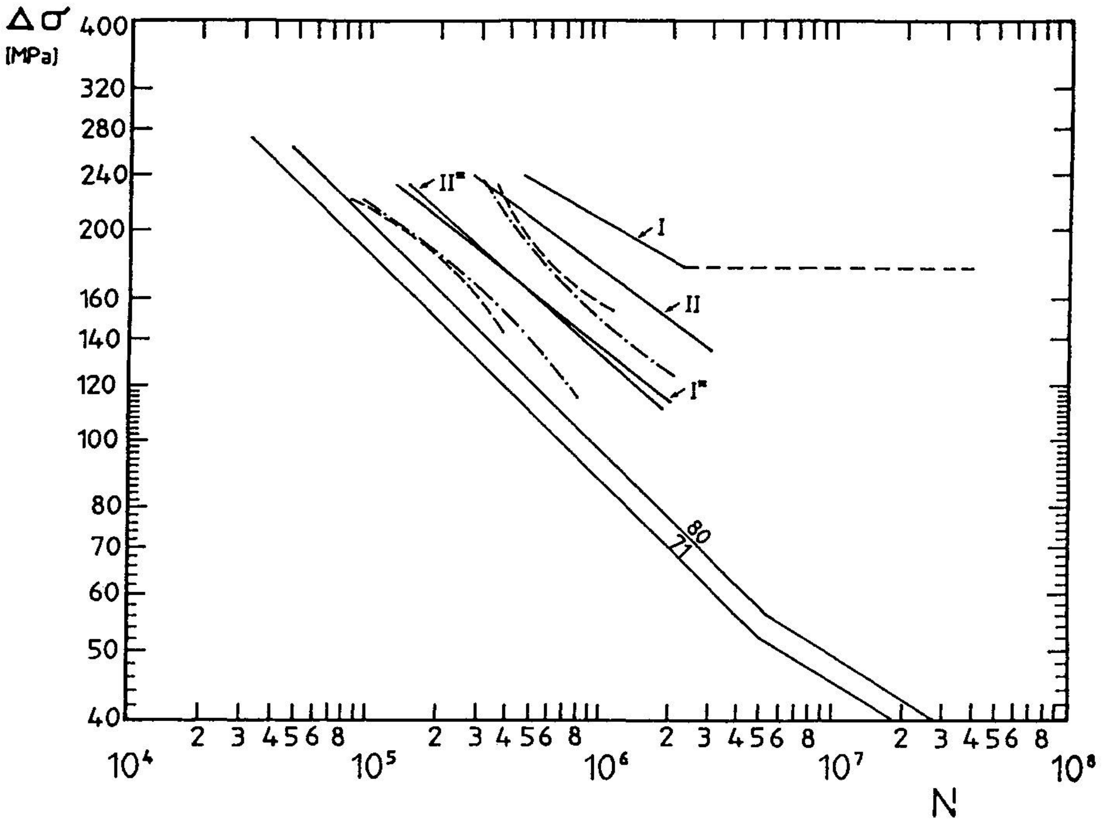

Fig. 12 Comparison between experimental results and ECCS curves

The S3 and S4 welding specimens have practically coincident fatigue strength and the 5% fractile curves of the two groups are situated both above ECCS curve 80. It can thus be concluded that the penalization of correctly designed and executed backing strip weldings, with respect to full penetration weldings, appears unjustified. On the contrary, type B specimens with type I joints have a higher fatigue life than that exhibited by type B specimens with type II joints (higher in both cases than that of the welding specimens because of the longer crack propagation life).

It follows then also that the fatigue life of the two types of joints does not dependent from the type of weldings (S3 or S4), if correctly executed and without defects, but depends from residual stresses.

Concluding, a distinction between joints, provided with backing strip weldings or full penetration weldings, based exclusively on the typology of the weldings and not taking into account the geometric features of the weldings themselves and the execution modalities of the connections is not justified. It is moreover not possible to assert "a priori" if it is safer or not to apply the present codified curves to complex details for which, at least for those most commonly used, it would be opportune to define specific S-N curves.

In our case, the authors mean that also backing strip weldings if correctly designed and executed, could be inserted in ECCS class 80.

Some aspects of the problem, such as more precise evaluation of residual stresses, remain still not completely clarified and the authors intend to dedicate on them their future research work.

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