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Autor: Bergvall, Bengt / Wästlund, Georg

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Fatigue Tests on Composite Beams

Essais de fatigue sur poutres mixtes

Ermüdungsversuche an Verbundträgern

BENGT BERGVALL
Assistant at the Division of Structural Engineering and Bridge Building, Royal Institute of Technology, Stockholm

GEORG WÄSTLUND
Dr. Dr. h. c., Professor of Structural Engineering and Bridge Building, Royal Institute of Technology, Stockholm

At the International Bridge Congress in Cambridge, 1952, a paper on "Studies of composite beams" was published by L. ÖSTLUND and G. WÄSTLUND [1]). This paper reviewed some results of *statical* tests on composite beams, i. e. a steel beam in composite action with a concrete slab.

To begin with, different types of shear connectors had been investigated in small "push-out" tests. A type of connector consisting of a round steel bar, 12 mm, 16 mm, or 20 mm in diameter, bow-shaped and welded to the steel beam, had been found to be the best.

Then this type of connector had been specially investigated on real composite beams. Some of them were subjected to positive moments, others to negative moments. The steel in the connectors 1952 had a yield point stress of 3.500 kg/cm^2 (50.000 psi).

The test results indicated an allowable transferred load of about 9 metric tons on each connector consisting of a 16 mm round steel bar and a somewhat higher allowable load for a 20 mm round steel bar connector.

In the general report, Preliminary Publication, 1952, which reviewed that paper, among others, and at the congress itself, the question was raised how those connectors behaved under *repeated loadings* or fatigue.

Until recently such tests could not be performed owing to lack of suitable equipment. Since the Division of Structural Engineering and Bridge Building has now got installations for repeated loadings, some complementary tests on

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[1]) "Preliminary Publication" (1952), p. 557. Final Publication (1953), Discussions, p. 277.

composite beams have been made by the Authors. This time, the investigation comprised statical tests and repeated loadings. The composite beams were similar to those used in 1952, Fig. 1.

The connectors were of the same type as those mentioned above. They consisted of 19 mm round steel bars. The "allowable load" on each connector was assumed to be about 11 metric tons, and corresponded to a nominal safety factor of 1,6 referred to the yield point stress. See Fig. 2.

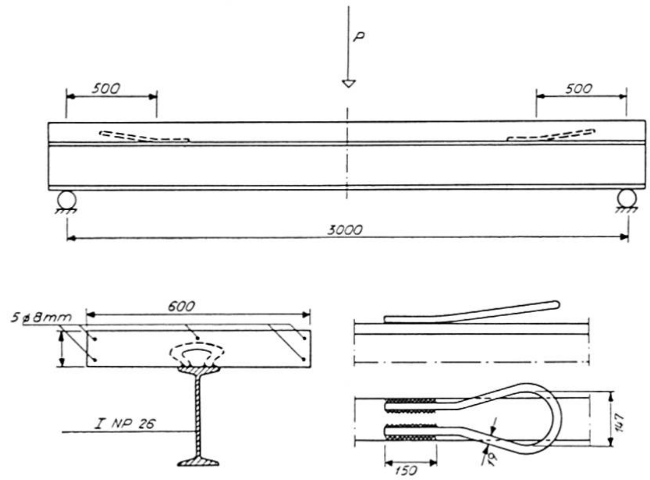


Fig. 1. Test Beams No. 1 and 2, Subjected to Positive Moment. Dimensions in mm.

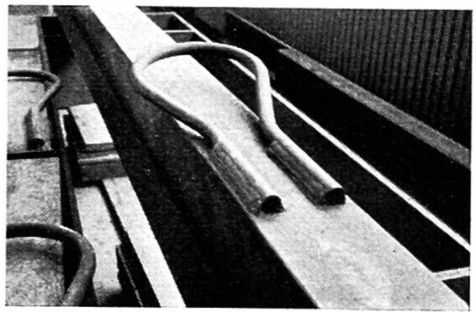


Fig. 2. The Connector, Welded to the Steel Beam Flange.

Each test beam was built up of an INP 26 steel beam and a concrete slab, 10×60 cm, cast on, and connected to, the top flange. The length of the test beam was somewhat more than 300 cm. On each half of the beam there was only one shear connector. The beams were supported at the ends and loaded with one concentrated load at the middle section, two beams, Nos. 1 and 2, with positive moments (concrete slab compressed) and the other two, Nos. 3 and 4, with negative moments. On all beams the connectors were orientated so as to be in tension.

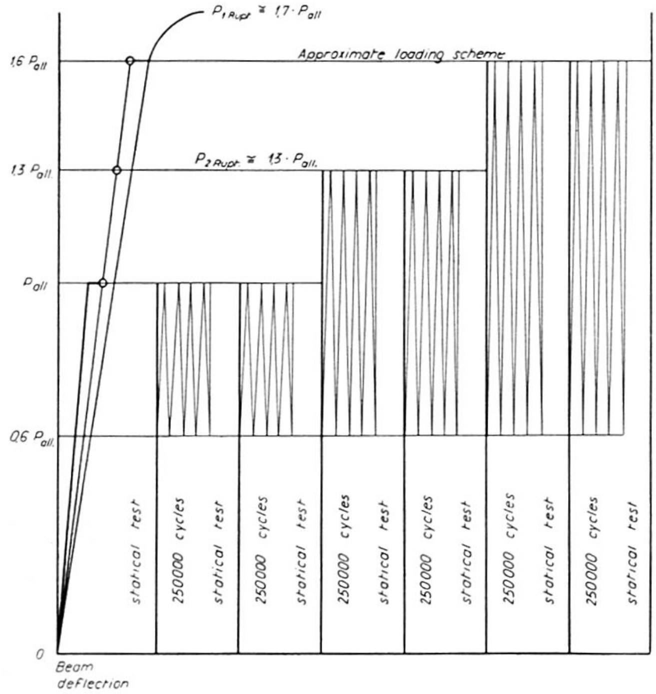
The properties of the materials were as follows:

Yield point stress of the 19 mm round steel bars 3.180 kg/cm^2 (45.000 psi), ultimate strength 5.070 kg/cm^2.

Cube strength of the concrete in the beams Nos. 1 and 2, 422 and 413 kg/cm^2, respectively. Bending strength 36,1 and 36,6 kg/cm^2 respectively. These strength values were obtained from tests on samples of the same age at testing as the large beams.

Fig. 3 shows quite schematically the loading programme. First a normal statical test was performed up to a load giving a force in the connector = $P_{allowable}$, i.e. 11 metric tons. Then followed a period of repeated loadings, which comprised 250.000 cycles, up to the same load. The whole procedure was then carried out once again, i.e. the same statical test and the same 250.000 cycles. Then a third statical test was performed up to a load corresponding to a force in the connectors = $1{,}3 \cdot P_{allowable}$, and was followed by 250.000 cycles of repeated loadings. A fourth statical test was made up to $1{,}3 \cdot P_{allowable}$, and was followed by 250.000 cycles. After that a fifth statical test was performed up to a load corresponding to $1{,}6 \cdot P_{allowable}$, followed by 250.000 cycles, and so forth.

The force in the shear connector was calculated on the assumption of no bond, elastic behaviour of the connector, and $n = E_{steel}/E_{concrete} = 15$.



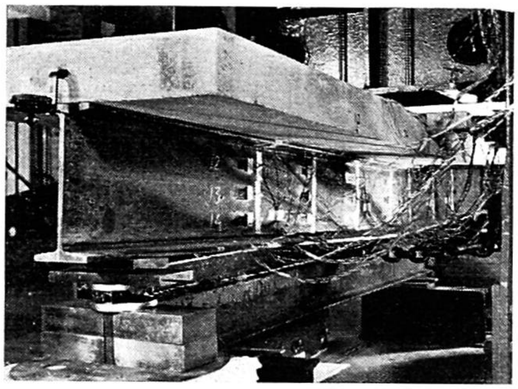


Fig. 4. The Test Beam No. 1 After Failure.

Fig. 3. The Loading Program, Schematically Shown. The Relation Between Load and Beam Deflection Schematically Shown.

During each statical test measurements were made at different load levels. The measurements were as follows: beam deflection, steel strain in the connectors, strain distribution over several beam sections comprising steel and concrete members, and slip between steel and concrete members at the beam ends. The strains were measured by means of strain gauges. During the statical tests and the repeated loadings the forces were measured by special force indicators. The frequency of repeated loadings was 200 cycles per minute. See Fig. 4.

This combination of statical tests and repeated loadings proved to give ample information about the structural body under investigation. The periods of repeated loadings unveil clearly all beginning defects of the structure. We can hear crackling sounds, notice falling flakes, feel opening joints with the fingers, etc. Statical tests after such cycles reveal permanent deflections and possible changes in structural behaviour.

Fig. 3 also shows schematically the relation between load and beam deflection. This relation indicates three stages in structural behaviour.

The *stage 1* is characterized by undestroyed bond between the steel beam and the concrete slab. Thus the composite action is complete.

The *stage 2* is characterized by destroyed bond but elastic action of the connectors. During this stage the elastic behaviour of the whole composite body is good.

In the *stage 3* this elastic behaviour does not exist, the structural body begins to be worn out. This ends in collapse.

The test results showed a marked influence of the repeated loadings in comparison with the results of statical tests, yet the allowable load per connector proposed in 1952 seems to be well founded.

In the 1952 tests the bond or friction between steel beam and concrete slab considerably contributed to an increase of the ultimate load, in fact to such an extent that if all the shear was assumed to be taken by the connectors, one connector should have taken up to about 44 metric tons, or about 5 times the allowable connector force.

Fig. 5. The Fatigue Rupture of the Connector. The Picture Shows the Concrete Slab, Upside Down, with the Connector Ends, After Failure.

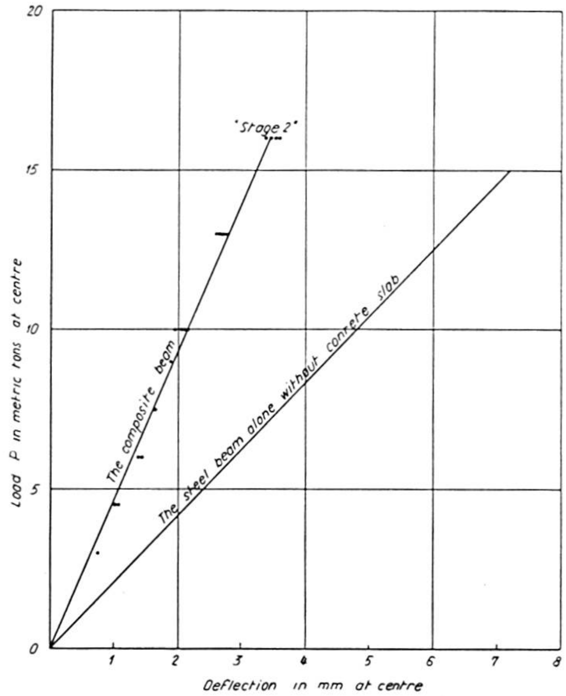


Fig. 6. The Deflection Measurements Made at All Statical Tests on the Beam No. 1 During its "Stage 2".

The new tests gave results which were in certain respects similar to those obtained in 1952. However, the repeated loadings destroyed very soon the bond and decreased the friction between steel beam and concrete slab. Thus the shear had mainly to be taken by the connectors, and therefore, in both beams Nos. 1 and 2 the ultimate load was determined by a *fatigue failure* in the connectors near the weld, see Fig. 5.

The three stages in the action of the beams were noticed in several ways.

Fig. 6 shows the deflection measurements made in all statical tests on the beam No. 1. As has been said, the statical tests were all interfoliated with a period of 250.000 loadings. It is obvious that the structure has behaved elastically, and has been intact after all repeated loadings. In this case the stage 1 fell out, see below. The curves thus show the stage 2, when the composite action is ensured only by means of the shear connectors. The deflection of the steel beam alone is about 2,4 times as great.

Fig. 7 shows the deflection measurements made on the same beam, now in stage 3. The beam does not behave elastically any longer, the composite action has been destroyed.

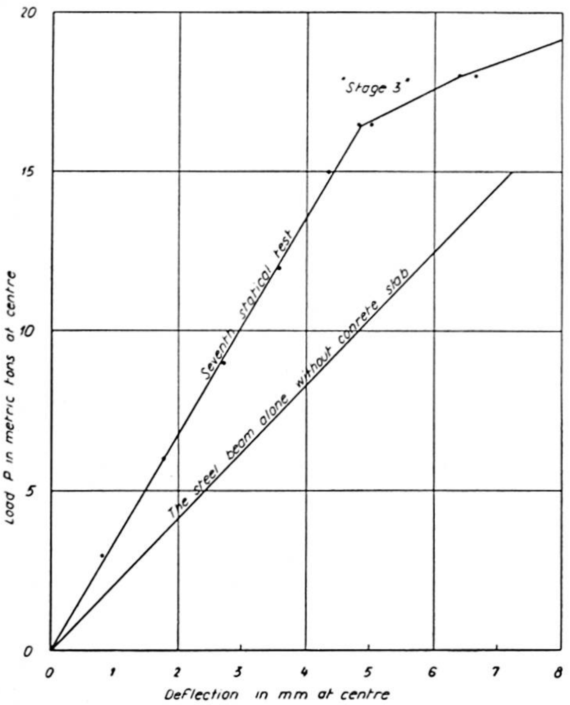


Fig. 7. The Deflections of Beam No. 1 During its "Stage 3".

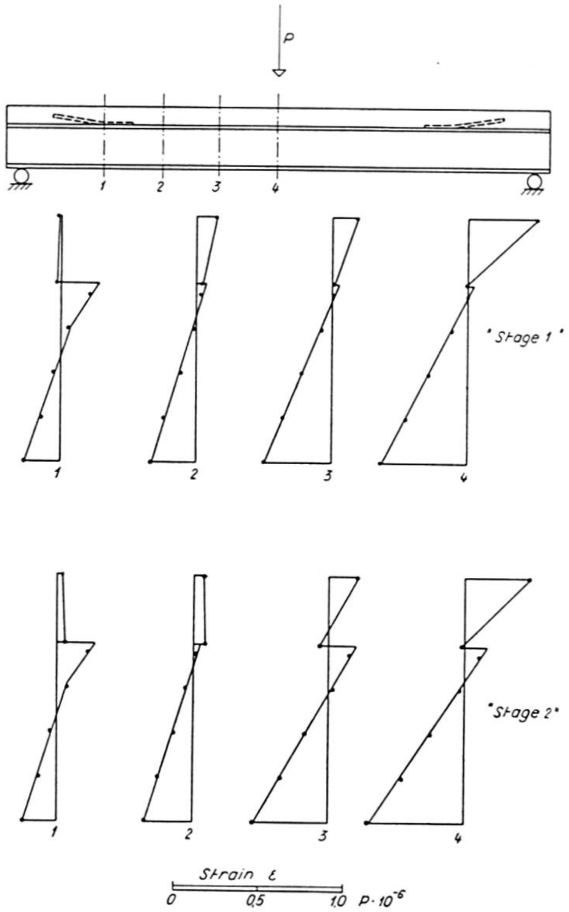


Fig. 8. The Strain Distributions Over Four Sections of Beam No. 2.

Fig. 8 shows the strain distributions over four sections of the beam No. 2. The first row represents the stage 1, when there is still bond between steel beam and concrete slab. The second row represents the stage 2, when the bond has been destroyed. The neutral axis of the steel beam has moved down a little in the second row in comparison with the first row, and there is a more marked jump in the strain diagrams in the second row.

The beam No. 1 acted elastically and remained intact up to a load corresponding to a force in the connectors 60 % higher than allowed after a total number of 1.500.000 repeated loadings. The beam No. 2 remained intact up to a load corresponding to a connector force 30 % higher than the allowed after a total number of 1.300.000 repeated loadings. These results seem to be quite satisfactory.

The beam No. 1 was about 90 days at testing, and after such a long time the shrinkage of the concrete had been great enough to destroy the bond without any loading. In the beam No. 2 the bond was destroyed during the first period of repeated loadings.

More than one million of loadings up to, and slightly more than that which corresponds to the allowable connector force does not change the elastic behaviour of the beam during the stage 2.

In the 1952 statical tests only the first and third stages were clearly to be observed.

The results relating to the beams subjected *to negative moments* showed, among other things that the concrete slab did not take any tension stresses. This confirmed the results obtained in 1952.

Summary

Composite beams with connectors consisting of round steel bars, which were bow-shaped and welded to the steel beam, had earlier been statically investigated, and were found to be better than several other types. A new investigation of similar composite beams has been performed, with a loading program comprising a series of statical tests and periods of about 250.000 repeated loadings each. The test results showed a marked influence of the repeated loadings, yet the allowable load per connector proposed in the earlier publication seems to be well founded.

Résumé

Des poutres mixtes, munies de chevilles formées de fers ronds recourbés en boucle et soudés à la poutre métalliques, avaient été soumises précédemment à des essais statiques. Ces essais ont montré que la liaison acier-béton ainsi réalisée est supérieure à plusieurs autres types. De nouvelles recherches sur des poutres mixtes semblables ont été effectuées suivant un programme de mise en charge qui comprenait une série d'essais statiques et des phases de sollicitations pulsatoires d'environ 250 000 cycles chacune. Les résultats de ces essais ont montré une influence marquée des mises en charge répétées; la charge admissible par cheville, qui a été proposée dans une publication antérieure, paraît cependant justifiée.

Zusammenfassung

An Verbundträgern mit Dübeln, die aus bogenförmigen, an den Stahlträger angeschweißten Rundeisen bestanden, waren früher statische Versuche ausgeführt worden, bei denen diese Träger sich mehreren anderen Verbundlösungen überlegen erwiesen. Eine neue Untersuchung wurde an ähnlichen Verbundträgern ausgeführt, und zwar bei einer Belastungsfolge, die eine Reihe von statischen Belastungen sowie Perioden von je etwa 250 000 Lastwechseln umfaßte. Die Versuchsergebnisse zeigten einen ausgeprägten Einfluß der wiederholten Belastungen, aber die zulässige Last je Dübel, die in einer früheren Veröffentlichung vorgeschlagen wurde, scheint gut begründet zu sein.