Supplement: shear strength of continuous reinforced and prestressed concrete beams

IVa5

Supplement - Complément - Ergänzung

Shear Strength of Continuous Reinforced and Prestressed Concrete Beams[1])

Résistance au cisaillement des poutres continues en béton armé et précontraint

Die Schubfestigkeit kontinuierlicher Stahlbeton- und vorgespannter Balken

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Since the paper was written, further tests have been made in order to expand the scope of the investigation to beams with deformed bar reinforcement. Such reinforcement is extensively used in many parts of the world, and an understanding of the behaviour of beams with steel of high bond characteristics is of considerable importance. We are thus now able to compare the behaviour of beams with deformed and plain round reinforcements and also to review the effectiveness of orthogonal web reinforcement when the main reinforcement is deformed.

Briefly, the results of our tests are as follows, the beams being of the same proportions as shown in fig. 2 of the paper.

The use of deformed bars increases the ultimate strength of the beam in shear by about 10% when stirrups only are used and by 20% when orthogonal web reinforcement is provided. This improvement is due to the better bond characteristics of the deformed bars, as is proved by the fact that when two $^5/_8''$ ⌀ bars were used instead of one 1″ ⌀ bar (both in tension and in compression) the ultimate strength in shear increased by 15% even though the main steel area was smaller; only stirrups were provided in the two types of beams being compared. The influence of bond characteristics of the main tension reinforcement on the shear resistance of a beam is important, not only because, once again, it highlights the inter-relation between shear and bending moment in the design of beams, but also because it should make us think carefully about transferring experience on shear with reinforced concrete to prestressed concrete where the bond behaviour is not the same.

Now, referring to prestressing beams, we should recall a diagram in the paper (fig. 6) showing that the plastic moment over the centre support depends on the transformation of the tendon *only* and is not influenced by the applied shear. We did some further tests in which the prestressing wire over the centre

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[1]) See "Preliminary Publication" — voir «Publication Préliminaire» — siehe «Vorbericht», IVa 3, p. 787.

support was ground to different thicknesses so that the plastic moment at that section varied. In each case the shear capacity of the beam was unaffected. This again indicates that there is no real shear-moment interaction.

As regards beams with orthogonal web reinforcement, we found that, as in the case of beams with plain round reinforcement, the addition of horizontal web steel improves the load-carrying capacity of beams when high strength concrete is used (say over 4000 psi measured on cylinders). With lower strength concrete, the provision of orthogonal reinforcement is hardly beneficial. In other words, if diagonal cracking occurs early and the deformation of concrete is large relative to the tensile stress in it, the horizontal web reinforcement is of little help. But if the steel is stressed with the concrete, it carries the horizontal component of the diagonal tension and continues to do so up to failure.

Now I would like to mention one practical application of orthogonal web reinforcement. It has been used in joists and also in some beams in a number of buildings designed by the Department of Public Works of the Province of Alberta in Canada — a government department, and therefore, one might suspect, not an unduly progressive organization. The web reinforcement is in the form of a welded wire mesh, and is therefore extremely easy to place. The mesh carries $^{1}/_{3}$ of the shear, bent-up bars resisting the remainder. Pictures of the reinforcement are shown in the photographs of Fig. A.

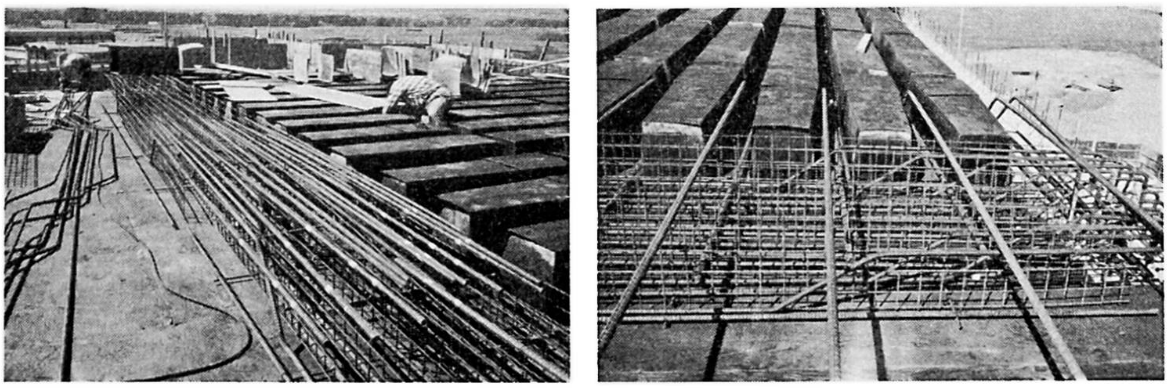

Figure A.

Without bent-up bars we would of course have the disadvantage of lack of support to the main reinforcement. In such a case I would, therefore, prefer, at least in large beams, to use a wire fabric bent into a troughlike shape which would thus provide both orthogonal reinforcement and a good support to the main reinforcement: as a result, splitting along the tension steel would be restrained and the integrity of the beam would be preserved up to a very advanced stage of overload. The same result would of course be achieved by welding the mesh to the main tension steel.

We have said that a high strength of concrete is essential for the orthogonal web reinforcement to make a good contribution to the load-carrying capacity of the beam. But with vertical stirrups only, the concrete strength (within the range of 3000 to 5000 psi determined on cylinders) does not appear significantly to improve the load-carrying capacity of beams with deformed reinforcement; we showed this to be the case with plain steel in tests reported in 1960 [2]).

The observed results were compared with the requirements of the new (1963) revision of the Building Code 318 of the American Concrete Institute. The diagonal cracking load of the beams tested exceeded the limiting shearing stress given in the Code for beams with unreinforced webs by a factor averaging 2.8. The $\varnothing$ coefficient, which provides for a chance undercapacity, was of course ignored.

One further point concerns the actual stress in concrete at diagonal tension cracking. We found an extremely good agreement between this stress and the splitting strength of concrete — the Brazilian test. The square root of the compressive cylinder strength gives equally good agreement: for our range of strengths the stress at diagonal tension cracking was $6.3\sqrt{f'_c}$. By comparison, the A.C.I. Code limits the stress in *any* beam without web reinforcement to $3.5\sqrt{f'_c}$.

The actual ultimate capacity in shear also exceeded that given in the Code by a factor of 1.55, again because the contribution of concrete up to cracking is underestimated by the Code. This excess strength is comparable to that found in 1963 by BRESLER and SCORDELIS [3]) in simple span beams.

On the other hand, the sum of the observed cracking stress and the stress carried by the stirrups according to the truss analogy accorded very well with the observed values of the ultimate shear. The mean ratio of these two quantities was 1.10, the range being 1.08 to 1.12. (The highest values were obtained with orthogonal web reinforcement.) The overestimate is due to the fact that probably not all stirrups actually yielded. It seems thus that the truss analogy has perhaps more to commend it than we thought.

Summary

An extension of tests reported in the paper to beams with deformed bar reinforcement is reported. It is shown that while the requirements of the new A.C.I. Code are in many cases unduly conservative the truss analogy seems essentially valid. Further tests on beams with orthogonal web reinforcement are reported, and the use of this type of shear reinforcement in the form of welded wire mesh in actual buildings in Alberta is described.

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[2]) J. TAUB and A. M. NEVILLE: "Resistance to Shear of Reinforced Concrete Beams". J. of American Concrete Institute, August 1960, Proc. V. 57, pp. 193—220.

[3]) B. BRESLER and A. C. SCORDELIS: "Shear Strength of Reinforced Concrete Beams". J. of American Concrete Institute, January 1963, Proc. V. 60, pp. 51—74.

Résumé

Il est rendu compte de l'extension, au cas des poutres comportant des armatures à empreintes, des essais qui ont été décrits dans le mémoire original. Si les spécifications du nouveau Code A.C.I. apparaissent exagérément prudentes en de nombreux cas, il est également montré que l'analogie du treillis est tout à fait valable. On décrit de nouveaux essais exécutés sur des poutres comportant des armatures de cisaillement orthogonales ainsi que l'emploi de ce type particulier d'armature de cisaillement sous forme de grillage soudé qu'on utilise actuellement à Alberta.

Zusammenfassung

Als Ergänzung zum Vorbericht werden weitere Ergebnisse über das Verhalten von Stahlbetonträgern mit gerippten Armierungsstählen untersucht. Dabei zeigt sich, daß, obwohl die Forderungen des neuen A.C.I. Code in vielen Fällen zu konservativ sind, die Fachwerkanalogie in der Hauptsache als richtig angenommen werden kann. Weitere Versuche an orthogonal bewehrten Trägern werden beschrieben, sowie die besondere Anwendung von geschweißten Netzarmierungen als Schubbewehrung bei einigen Bauten in Alberta.