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Autor: Walther, René

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Discussion of Some Papers of the Preliminary Report

Remarques sur certaines contributions du Rapport Préliminaire

Diskussion verschiedener Beiträge des Vorberichtes

RENÉ WALTHER
Dr.-Ing., Basel/Stuttgart

Following a suggestion made in the General Report, the results presented in some of the papers to the Congress in Rio de Janeiro will be compared with the findings of the extensive investigation into the problem of shear recently conducted at the Otto-Graf-Institute (Technische Hochschule Stuttgart).

Dealing first with the contribution of R. WARNER and B. THÜRLIMANN, the general approach and many assumptions differ considerably from our findings, yet the final conclusions are fortunately very similar as far as the dimensioning of the web reinforcement is concerned. According to our point of view, the following objections can be made:

1. Shear-compression is not the predominant mode of failure, especially not for T-beams or box-girders, which are mostly used in practice[1]) and where the problem of shear is more important than for rectangular members.
2. Even for rectangular members the ultimate cause of failure is very often a local or over all destruction of the bond of the longitudinal reinforcement, even though the failure appearance is very similar to shear-compression. Thus the inclined cracks propagate closer to the compression fibre than vertical bending cracks, i. e. $\delta < 1$. This is especially the case for continuous beam, due to the poor bond of the longitudinal tension reinforcement over intermediate supports. Our reevaluation of early and recent test data have conclusivly shown, that the influence of bond is so important, that it should not be neglected in deriving empirical parameters.
3. The inclination φ of diagonal cracks is very often smaller than 45° and depends, among other, on the percentage of web reinforcement. Incidently this is one important reason, why the "full web reinforcement" according to the truss analogy is often not necessary, since the stirrup force Q_s (notations see WARNER and THÜRLIMANN) becomes greater with smaller values of φ.

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[1]) The vast majority of all the beams mentioned in the Separate Volume on precast concrete, for example, are of non rectangular sections.

4. The relative depth ζ_c of the compression zone is certainly a function of the web reinforcement. The ratio $\delta = \zeta_c/\zeta_0 \sim 1$ was empirically derived only from tests without web reinforcement and does not possibly hold true for beams with web reinforcement.

In spite of these objections — and similar objections can be made to any approach suggested so far — the final simplified design criterion, that the required percentage of web reinforcement be

$$\rho = \frac{Q - Q_c}{\sigma_f\, b\, h}$$

with

$$Q_c = \tfrac{1}{8}\, \sigma_u\, \zeta_0\, b\, h$$

corresponds in effect closely to the relationship which we have found from our tests,

i.e.

$$\sigma_{St} = \frac{\tau_0 - \tau_{0\,cr}}{\rho}$$

with σ_{St} = mean stress in the stirrups,

$\tau_{0\,cr}$ = shearing stress at inclined cracking load.

but we derived this relationship quite differently namely directly from stirrup stresses, which we have carefully measured in all our beam tests. As a first example we cite the results of a beam series, mentioned already in the contribution of the writer, where only the web thickness was varied. The measured load-stress curves of the stirrups, presented in fig. 1 have all about the same slope, but this slope starts from different loads P depending on the web

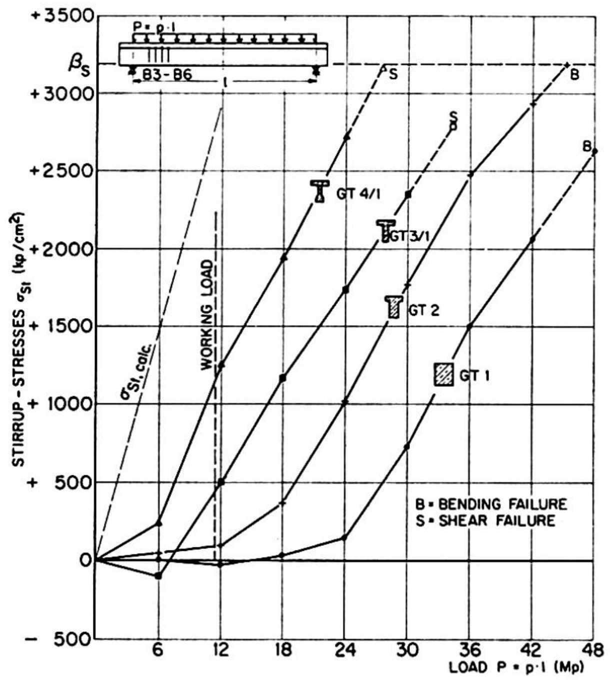

Fig. 1. Measured stirrup-stresses of a beam series, where only the web thickness was varied.

thickness. Undoubtedly this load represents the inclined cracking load P_{cr} since stirrups are only appreciably subjected to tension when inclined cracks have formed. Dividing P_{cr} by $b_0\, h$ (b_0 = web thickness) yields an approximately constant value, which can safety be defined as inclined cracking shear stress and which from many tests was found to be about a $^1/_{30}$th of the concrete strength β_p (prism-strength):

$$\tau_{0\,cr} = \frac{P_{cr}}{b_0\, h} \sim \frac{1}{30}\beta_p\,.$$

By this method the inclined cracking load can reliably be determined and is no more left to the choise of the investigator, as the authors rightly argue for visual observation of the crack propagation.

Another example is given in fig. 2 for a T-beam series where only the

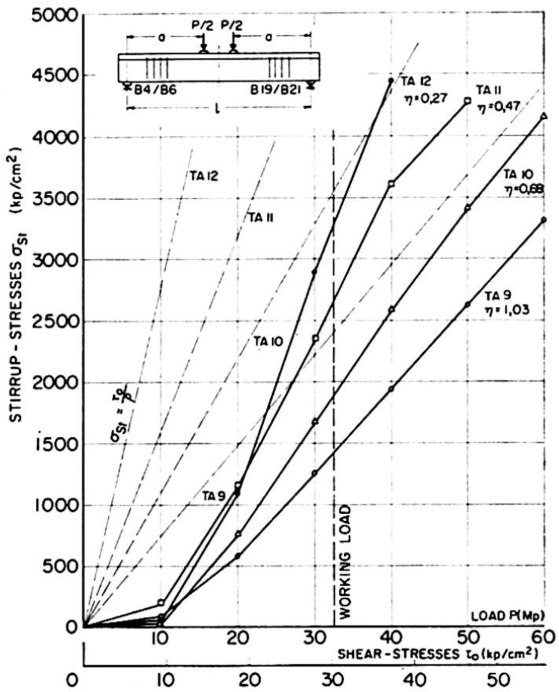

Fig. 2. Measured stirrup-stresses of a beam series, where only the relative amount η of web reinforcement was varied.

percentage of web reinforcement was varied. As expected for beams with constant cross-sections and constant concrete strength the initial cracking load is about the same for all beams. The slope of the load-stress curves depends on the relative amount η of web reinforcement [2]), which varied from

[2]) The notion "percentage ρ of web reinforcement" is not deemed to be a very practical one, since it not related to the shear force and thus does not convey a direct idea of its magnitude. $\rho = 1$ for example may be a very strong web reinforcement for rectangular beams, but a weak one for beams with thin webs. We therefore prefer the notion of "relative amount η of web reinforcement", which is the ratio of the actual web reinforcement to the one theoretically required by the truss analogy ($\eta = 1$ = "full web reinforcement").

$\eta = 1{,}03$ (beam T A 9) to $\eta = 0{,}68$ (T A 10), $\eta = 0{,}47$ (T A 11) and $\eta = 0{,}27$ (T A 12). These curves are about parallel to the theoretical ones given by the truss analogy to $\sigma_{St} = \tau_0/\rho$ or $\sigma_{e,Bü} = \tau_0/\mu_s$ in our notations.

Thus the measured stirrup stresses follow the relationship mentioned before:

$$\sigma_{St} = \frac{\tau_0 - \tau_{0cr}}{\rho}.$$

This relationship was found in all our tests for simple span and continuous beams of rectangular as well as for I-sections, T- and inverted T-sections and last not least even for prestressed box-girders which will be mentioned in the contribution of F. LEONHARDT. There are many reasons for this phenomenon such as shear resistance of the compression zone, dowel action of the longitudinal reinforcement, inclination of diagonal cracks smaller than 45°, compression and bending stiffness of the concrete compression diagonals (the actual "truss" has no hinged connections) etc.

Since the above design rule corresponds closely to the one suggested by WARNER and THÜRLIMANN and in effect also to the one proposed by the ACI-Building Code it can safely be accepted for practice without worriing about the vastly different and maybe sometimes questionable approaches. Contrary to the restriction assumed by WARNER and THÜRLIMANN, it is also valid for non rectangular beams.

This simple design rule has however to be accompanied by construction requirements especially with respect to the reinforcement (bond, anchorage, spacing, cutt-off bars etc.) and the interaction of moment and shear. Furthermore it does not dismiss the need of a satisfactory and practicable ultimate shear strength theory.

As to the contribution of ST. SORETZ we would like to make two remarks. Firstly, the failure of the continuous member shown in fig. 8 does not seem to be one of normal shear. In our opinion it was primarily due to the fact that the hooks of the bent up bars were anchored in the critical tension zone, which is contrary to generally accepted rules of reinforced concrete design. Since these bent up bars were stronger than the too widly spaced stirrups, they tended initially to carry most of the shear force in the vicinity of the intermediate support but could not transfer that force to the tension chorde.

The second remark pertains to the merits of horizontal web reinforcement. Undoubtedly such a reinforcement is beneficial to minimize the crack width, especially for relatively deep beams. The tests cited by SORETZ however disprove the claim of E. RAUSCH, that the horizontal web reinforcement has to be equally strong as the stirrups, since beam C 4, where the area of horizontal web reinforcement was only half of that of the stirrups, showed markedly smaller crack widths than beam C 3 with three times as much horizontal web reinforcement. This is not surprising, when compared with our measurements of the relative displacement of the crack borders, shown in fig. 3 for a T-beam

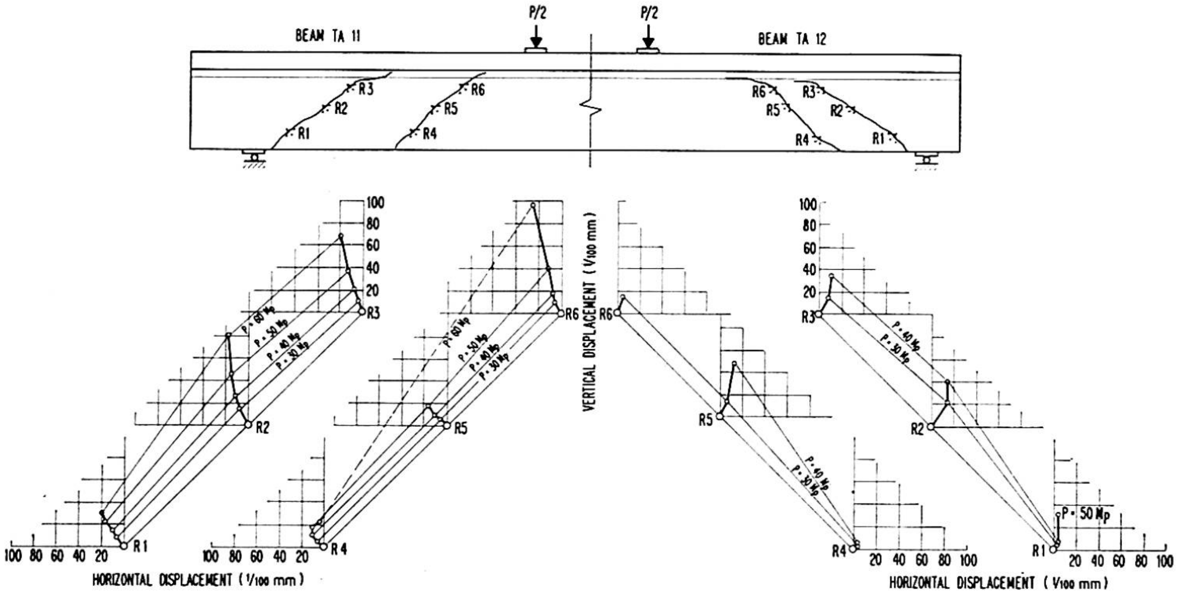

Fig. 3. Relative displacement of the crack-borders for a T-beam with vertical stirrups. Shear cracks open about twice as much in vertical direction than in horizontal.

with vertical stirrups. It follows that shear crack open about twice as much in vertical direction than in horizontal. Consequently vertical or slightly inclined stirrups are definitely the best shear reinforcement.

Summary

Some papers of the Preliminary Report are discussed and compared with the findings of investigations at the Institute of Technology Stuttgart.

It is shown, that the design rules proposed by Warner and Thürlimann correspond closely to the ones derived by Leonhardt and the writer, even though the basic approach of the problem was quite different.

Test data is presented to prove the effect of vertical and horizontal web reinforcement.

Résumé

On discute certaines contributions contenues dans le Rapport Préliminaire et on les compare avec les résultats des recherches conduites à l'Ecole Polytechnique de Stuttgart.

Il est montré que les règles proposées par Warner et Thürlimann pour le dimensionnement des armatures correspondent étroitement à celles établies par Leonhardt et l'auteur, et ce en dépit des différences fondamentales qui distinguent les deux manières selon lesquelles le problème a été abordé.

On présente les résultats de différents essais afin de mettre en évidence les effets des armatures de cisaillement verticales et horizontales.

Zusammenfassung

Es werden einige Beiträge des Vorberichts diskutiert und mit Ergebnissen der an der Technischen Hochschule Stuttgart durchgeführten Schubversuche verglichen.

Trotz der grundlegend verschiedenen Ansätze kommen Warner und Thürlimann zu ähnlichen Bemessungsregeln für die Schubbewehrung wie sie aus den Stuttgarter Schubversuchen abgeleitet wurden.

Anhand von Meßergebnissen wird die Wirksamkeit von horizontalen und vertikalen Schubzulagen aufgezeigt.