The use of high tensile steel as reinforcement of concrete

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Der hochwertige Stahl als Bewehrung des Eisenbetons

Emprego de aço de alta resistência nas armaduras para betão

Emploi de l'acier à haute résistance dans les armatures à béton

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The importance of the use of high tensile steel as reinforcement of concrete is now internationally recognised. Out of 9 papers in Section Va, 6 are devoted to this question. These 6 papers originate from 5 different countries. France is represented by 2 contributions, Austria, Great Britain, Germany, Hungary, each by one. The papers deal with a great variety of types of steel regarding both shape and quality.

I wish to refer first to the contribution by M. LAZARD who reports on comparative tests on good quality mild steel and Torsteel respectively in beams of unusually large size. His conclusions should therefore be particularly convincing. May I quote the last sentence of his summary (p. 761):

> «Use of Tor 40 reinforcement bars for working stresses of 20 kg/mm² (= 28,450 psi) seems absolutely justified for bridge beams submitted to aggressive fumes of steam railway engine smoke» [1].

This conclusion is of very great importance since there are still many engineers who believe that the best way to avoid corrosion is to use plain mild steel bars and limit the stress to 1400 kg/cm² (20,000 psi), or even less. This view is convincingly refuted in Mr. SZÉPE'S paper (p. 851):

> «It has to be stated that the older regulations which try to achieve freedom from cracks in reinforced concrete or crack control by limiting the tensile stress in the steel and in the concrete, have gone the wrong way».

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[1] In his verbal contribution at the Congress M. LAZARD has stated that the stress in Torsteel 40 actually adopted by the French Railways is now 21 kg/mm² (= 29,870 psi).

The real cause of corrosion is not the occurrence of transverse cracks but lack of cover and porosity of the concrete. The paper by Messrs. ROBINSON and PELTIER, which is the continuation of a paper submitted by M. ROBINSON in Cambridge 4 years ago, seems to go to the root of the defects commonly known in every country. It is obvious from this research that corrosion cannot be prevented by a limitation of tensile stresses and is bound to occur under certain conditions even if the stresses are nil or compressive. In his verbal contribution at the Congress M. ROBINSON has referred to tests in which corrosion occurred first as a consequence of the porosity of concrete and cracks were a secondary effect caused by corrosion.

Whilst considerable effort is being made in various countries to restrict the width of cracks, it would appear that another important aspect of the admission of high tensile stresses has not received sufficient attention.

The serviceability of a structure depends not only on cracking but probably even more on deformation. With mild steel at working stresses of the order of 1400 kg/cm^2 (20,000 psi) deformations are rarely relevant. When we come into the range of working stresses of 1800 to 2500 kg/cm^2 (25,600 to 37,000 psi) as usual with steels of what I would call medium quality i. e. with a yield point or proof stress of the order of 40 to 50 kg/mm^2 (57,000 to 71,000 psi) conditions become more critical, but in the range of working stresses of 3500 to 4500 kg/cm^2 (50,000 to 64,000 psi) as adopted in Austria for Torsteel 60 and bi-steel (p. 748) respectively, the deformation must be the primary consideration of the designer, particularly the deformation under sustained loading [1] [2]. Since the modulus of elasticity of these special steels is not higher than that of mild steel, it is obvious that the deformation of structures with working stresses of this order may be 2 to 3 times greater than the deformation of structures with mild steel. Other conditions being equal, the substitution of a great number of small size bars for a small number of large size bars improves the crack control but has very little influence on the deflection under sustained loading. Consequently such high stresses must be restricted to exceptional cases where the depth/ span ratio is very favourable. It is interesting to note that based on his tests on beams reinforced with Torsteel 60 and 80 respectively which were otherwise similar to the beams discussed on his paper (Va 4) (2). M. LAZARD has come to the conclusion that «the practical interest of the Torsteels 60 and 80 is slight».

M. SAILLARD has included in his paper two tables (pp 837-8) in which the steel stresses are set out as a function of the diameter of the bars and of the maximum crack widths which can be tolerated. I think that a similar table or graph is necessary to limit the deformation of structures so that the permissible steel stress becomes a function of the slenderness ratio of the member in which the steel is used, of the percentage of reinforcement and of the modulus of elasticity of the concrete.

It may be seen from M. SAILLARD'S table on p. 837 that the stresses in plain round bars are very much restricted by the crack widths. In order

(2) Ratio effective depth/span of the order of 1/9.

to use higher stresses, bars with protrusions must be adopted. Torsteel is one solution but according to M. SAILLARD (p. 820) the optimum crack control cannot be achieved with bars having only 2 or even 4 helical nibs. It is clear from the paper by Professor RÜSCH, Figs. 2 & 3, (pp. 795-6) that deformed bars are more efficient for controlling the crack widths. His proposition to standardize the pull-out tests is very good, but I should like to suggest two modifications:

1 – Professor RÜSCH suggests that prisms without any transverse reinforcement should be used (p. 795). From my experience, which is common with that of many other research workers, prisms without transverse reinforcement are bound to burst at a very small movement of the bar which is to be pulled out.

This tendency of bursting the concrete has also been pointed out by M. SAILLARD (p. 820). Indeed, the better the bond, i. e. the more efficient the bar, the greater is the tendency of bursting. A pull-out test which ends by the splitting of the concrete is, in my opinion, most unsatisfactory. The bar should be either pulled out or fractured but the specimen must not burst.

It is, of course, essential that the bursting of the concrete should be prevented in structures and for this reason transverse reinforcement must be provided wherever deformed bars end. Pull-out tests on prisms without transverse reinforcement would therefore not be representative of the correct use of deformed bars.

2 – My second point of disagreement with Professor RÜSCH is the magnitude of the slip at the unloaded end at which the bond stresses should be compared. Professor RÜSCH has suggested a slip of 0.1 mm (p. 796). Admittedly, the magnitude of the slip at which stresses are compared is as arbitrary as the elongation of cold worked bars to which the proof stress is related. However, since we can tolerate crack widths of even 0.3 mm in certain cases, I do not see the reason for adopting a slip of only 0.1 mm in general. I suggest that the pull-out tests should be so standardized that stresses are compared at slips of 0.1, 0.25 and 0.5 mm. This would give a much better idea of the performance of the bar since it would show to what extent the resistance of the bar against being pulled out is increased with increasing slip. With plain bars, the increase is nil, with Torsteel and square twisted bars it is very small, but with deformed bars of suitable shape it is considerable.

Finally, I wish to refer to Professor TORROJA's remark about «the most appropriate types of bar for reinforced concrete» (p. 703).

Regarding the shape I think that the provisions of ASTM [3] should be either adopted or taken as a basis of further research if this is deemed to be necessary. The American Standard is based on very comprehensive research and this should not be ignored.

Regarding the quality of the bars, I am of the opinion that cold worked deformed bars in which sharp edges are avoided and which are not overworked so as to become brittle at low temperatures are preferable to bars having a natural yield point. The lack of a definite yield point is a great advantage from the point of view of the mode of failure, as may be seen from the results of M. LAZARD (p. 761, Conclusions, 4 th. paragraph) and of M. LEWIS (pp 771, 779).

REFERENCES

1. WASHA, GEORGE W. — *Plastic Flow of Thin Reinforced Concrete Slabs.* Journal of the American Concrete Institute, Vol. 19 No. 3, Nov. 1947 p. 237.
2. WASHA, GEORGE W. and FLUCK, P. G. — *Effect of Compressive Reinforcement on the Plastic Flow of Reinforced Concrete Beams.* Journal of the American Concrete Institute, Vol. 24 No. 2, Oct. 1952 p. 89.
3. ASTM — *A 305-53 T.* Tentative Specifications for Minimum Requirements for the Deformations of Deformed Steel Bars for Concrete Reinforcement.

SUMMARY

It is submitted that the limiting factor for the admission of high working stresses in the tensile reinforcement is the deformation of the structure and that the bond strength of deformed bars should be determined on prisms with transverse reinforcement at slips of the unloaded end of 0.1, 0.25 and 0.50 mm respectively.

ZUSAMMENFASSUNG

Es wird vorgeschlagen, dass die zulässigen Zugspannungen in der Bewehrung durch die Formänderung der Bauteile beschränkt werden müssen und dass die Haftfestigkeit von Rippenstählen an Prismen mit Bügelbewehrung bei Gleitwegen des freien Endes von 0,1, 0,25 und 0,50 mm bestimmt werden soll.

RESUMO

O autor é da opinião de que o emprego de tensões de trabalho elevadas nas armaduras de tracção é limitado pela deformação da estrutura e de que a força de aderência de armaduras deformadas deveria determinar-se em prismas armados transversalmente para escorregamentos medidos na extremidade de 0,1, 0,25 e 0,50 mm.

RÉSUMÉ

L'auteur est d'avis que l'emploi de contraintes de travail élevées dans les armatures de traction est limité par la déformation des structures et que la force d'adhérence des armatures déformées devrait être determinée sur des prismes armés transversalement pour des glissements mesurés à l'extremité libre de 0,1, 0,25 et 0,50 mm.