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Use of the Tensile Strength in Anchorage to Concrete

Emploi de la résistance à la traction lors d'ancrages dans le béton

Rechnerische Erfassung der Bauteilbeanspruchungen durch Befestigungen

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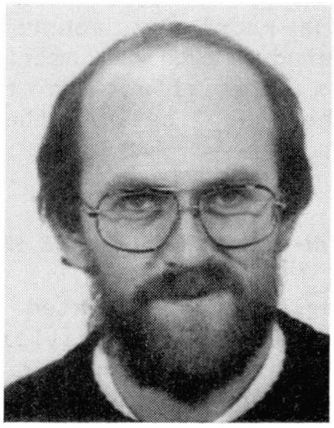

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SUMMARY

Anchoring elements, such as headed studs, are used to transfer concentrated loads into reinforced concrete members. From experimental evidence it is known that, provided the steel strength of the stud is high enough, failure occurs by pulling out a concrete cone formed by circumferential crack growth in the so-called mixed mode, with significant size effect. Numerical analyses indicate that the dominant influence factor on the failure load is the concrete fracture energy. It is shown that in such applications, the load transfer from the anchor into the concrete may safely be done by using the concrete tensile strength.

RÉSUMÉ

Des éléments d'ancrage tels que les boulons sont utilisés pour transmettre localement des charges dans une structure en béton armé. Selon l'évidence expérimentale, il est clair que si la résistance de l'acier du boulon est suffisante, la ruine est atteinte par arrachement d'un cône en béton: une fissure circulaire se développe, accompagnée d'un effet de taille significatif dans ce qu'on appelle un «mode mixte». Les analyses numériques indiquent que l'influence dominante sur la charge ultime a l'énergie de fracture du béton. Il est très intéressant que dans ce type de structures, le béton puisse transmettre des charges de l'ancrage à la masse enserrante sans l'aide de l'armature, et ceci grace à la mobilisation de sa résistance à la traction.

ZUSAMMENFASSUNG

Befestigungselemente wie Kopfbolzen werden häufig eingesetzt, um Lasten in Stahlbetontragwerke einzuleiten. Versuche zeigen, dass das Versagen bei ausreichend hoher Stahltragfähigkeit durch die Ausbildung eines Betonausbruchkegels hervorgerufen wird. Die Bruchlast hängt nach den Ergebnissen der numerischen Untersuchungen hauptsächlich von der Betonbruchenergie ab. Es wird diskutiert, dass in diesen Anwendungsfällen die Betonzugfestigkeit in Anspruch genommen werden kann, ohne dass ein Sicherheitsrisiko besteht.

1. INTRODUCTION

In engineering practice, headed anchors are often used to transfer loads into concrete structures. From experimental evidence it is known that, provided the steel strength of the anchor is high enough, headed anchors fail by pulling a concrete cone. The failure is due to the failure of concrete in tension by forming a circumferential crack growing in the so-called mixed mode [1]. In recent years several attempts have been made to understand this growth and to predict the failure load of headed studs [1] - [4]. Summarizing these activities, it can be said that material models based on plasticity and on stress-strain relationships together with stress failure criteria are not capable of predicting the behavior of anchors as observed in experiments [1], [5]. Furthermore, the predicted failure load depends on the element size and load step size. A better explanation of anchorage behavior can be expected using more general material models based on fracture mechanics. Some recent results of the numerical analysis using axissymmetric finite elements and a non-local microplane model for concrete are shown and discussed. The main objective of this study is to demonstrate the influence of different concrete properties and the size effect on the failure load. Furthermore, it is discussed why in these applications the concrete tensile strength can be used without safety risk.

2. REVIEW OF THE NON-LOCAL MICROPLANE MODEL

The microplane models were initiated by G.I.Taylor [6], who suggested the principle for the modeling of plasticity of polycrystaline metals. Recently [7], this approach has been extended to include strain softening of concrete, and has been renamed more generally the "microplane model", in recognition of the fact that the approach is not limited to plastic slip but can equally well describe cracking and strain softening damage.
Basically, on the material level one may distinguish two types of interactions among particles or damage sites in the microstructures, which must be somehow manifested in the continuum model: (1) Interaction at a **distance** among various sites (e.g., between A and B, in Fig. 1); and (2) interaction **among various orientations** (see angle α in Fig. 1).
The interactions at a distance control the localization of damage. They are ignored in the classical, local continuum models, but are reflected in non-local models [8]. According to the non-local strain concept, the stress at a point depends not only on the strain at that point but also on the strain field within a certain region around the point. In the current study, an effective form of the non-local concept is used in which all variables that are associated with strain softening are non-local and all other variables are local [9]. The key parameter in the non-local concept employed is the characteristic length l_c over which the strains are averaged. However, it is still not clear how to correlate the characteristic length with concrete properties in general 3D stress-strain states. In a preceding paper [9] the non-local microplane model as well as an effective numerical iterative algorithm for the loading steps used in the finite element code are described in detail.

3. REVIEW OF THE NUMERICAL STUDIES ON THE BEHAVIOR OF ANCHORAGES

The behavior of headed studs embedded in reinforced concrete blocks is studied in [10] - [12]. In these studies, the influence of the different material and geometrical parameters on the concrete cone failure is investigated. The concrete
tensile and compression strength, fracture energy, initial Young's modulus and

the size of the stud are varied. To demonstrate the size effect, the influence of the embedment depth on the failure load is studied.
The analysis is performed using axissymmetric four-node finite elements and the non-local microplane model. A typical finite element mesh employed in the analysis is shown in Fig. 2. Fig. 3 shows a comparison between test results and results of the numerical analysis and demonstrates that the non-local microplane model can correctly predict the concrete cone failure load.
Fig. 4 demonstrates the influence of the concrete fracture energy G_F on the failure load. In these studies, the concrete tensile strength was kept constant. According to the Fig. 4, the failure load is roughly proportional to the square root of G_F. The influence of the tensile strength, for a constant value of G_F, on failure load is shown in Fig. 5. It indicates that the concrete tensile strength has a small influence on the concrete cone failure load. Both results are also confirmed by Sawade [5]. Concrete compression strength and the size of the head have a significant influence on the displacement field, but a relatively little influence on the failure load [11].
Because the analysis shows the dominant role of the concrete fracture energy on the anchor behavior a large size effect on the failure load must be expected. Indeed, results of numerical analyses obtained in [11] and [12], as well as test results indicate a significant size effect that is close to that predicted by linear elastic fracture mechanics (Fig.6).
In spite of the fact that the G_F value has a dominant influence on the concrete cone failure load, the design of fastenings should be based on the concrete compression strength, since this concrete property can easily be measured and is known to the designer.

4. USE OF THE TENSILE STRENGTH IN ANCHORAGES

In many applications, no reinforcement can be provided in the region of headed anchors that could take up the load transferred by the anchor into the structure. Therefore, these forces must be resisted by the concrete tensile strength. In contrast to that, generally in reinforced concrete design, the concrete tensile strength is neglected and any tensile stresses in the concrete are taken up by reinforcement. This approach is justified by the fact that tensile stresses may be induced in the concrete by the restraint of imposed deformations i.e. due to creep, shrinkage, temperature variations or support settlements, which may reach the concrete tensile strength and cause cracks in the concrete. These stresses are parallel to the tension stresses (i.e. bending stresses) induced by loads. Therefore, failure of the structure may be caused by the restraint of imposed deformations if no reinforcement is present to take up the tensile forces due to loads.
In the case of headed studs embedded in concrete, the situation is somewhat different. The failure surface is not perpendicular to the load directions and the tensile stresses on the failure plane are inclined to the concrete surface (Fig. 7). Therefore, the tensile stresses induced by the anchor load intersect with additional tensile stresses generated in the concrete and due to the restraint of imposed deformations, which are parallel to the concrete surface over a small part of the failure area only. Furthermore, the fracture process is very stable up to peak load because the circumferential crack forms a cone and the crack tip has to penetrate a larger area the move it grows. Therefore, if the additional stresses cause locally the formation or widening of a microcrack, stable stress redistribution is possible. According to rough theoretical investigations a reduction of the concrete cone failure load by about 20% can be expected if the additional tensile stresses σ_{add} reach the concrete tensile strength [13]. This possible reduction of the failure load is smaller than the reduction which must be expected if the anchor is located in a crack [14]. It should be taken into account in the design of the

fastening. Naturally, reinforcement must be present to prevent failure of the structure serving as anchor ground.

5. CONCLUSIONS

The numerical results as well as experimental observations indicate that the failure of headed studs embedded in plain concrete is due to failure of concrete in tension (circumferential cracking) rather than in compression. The failure load is mainly influenced by the concrete fracture energy G_F. However, the design of fastenings should be based on the concrete compression strength, since that value is known to the designer.
In spite of the fact that the concrete cone failure load is governed by the tensile properties of concrete, no reinforcement is necessary to take up the concrete tensile stresses induced by the anchor. This can be explained by the fact that the tensile stresses induced in the concrete by other external loads or by restraint of imposed deformations , e.g. due to temperature variations, intersect hardly with the tensile stresses induced by the anchor. Furthermore, the fracture process is very stable so that a stable stress redistribution is possible if local cracks are caused in the concrete by these additional tensile stresses. However, reinforcement may be provided to increase the anchor strength.

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7. FIGURES

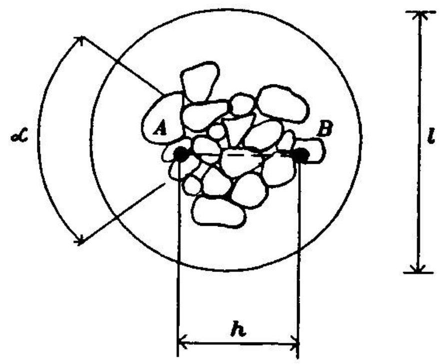

Fig. 1 Interaction among the various orientations and at distance

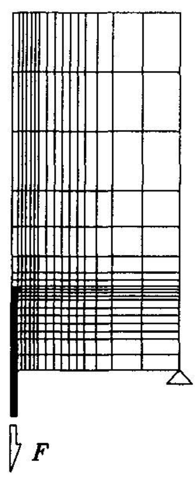

Fig. 2 Typical finite element mesh used in the analysis

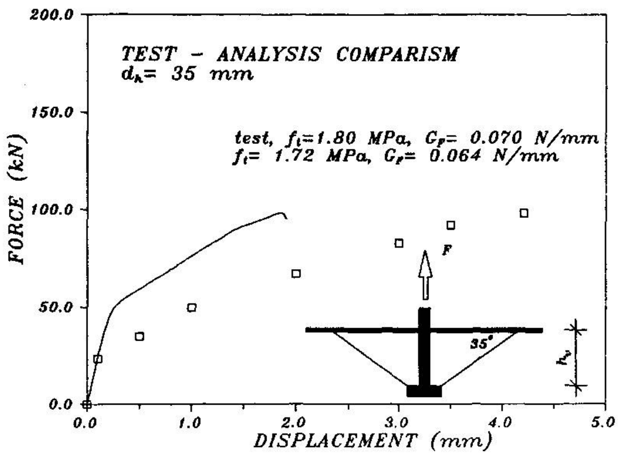

Fig. 3 Experiment-analysis comparison

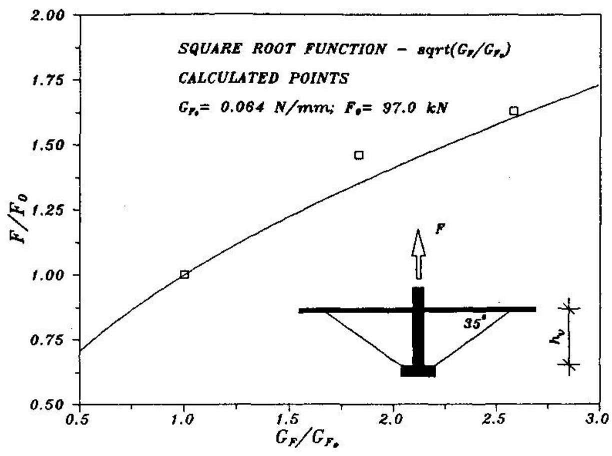

Fig. 4 Influence of the fracture energy on the failure load

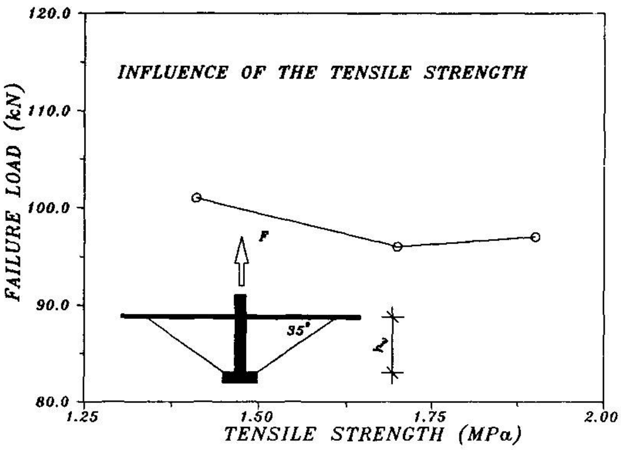

Fig. 5 Influence of the tensile strength on the failure load

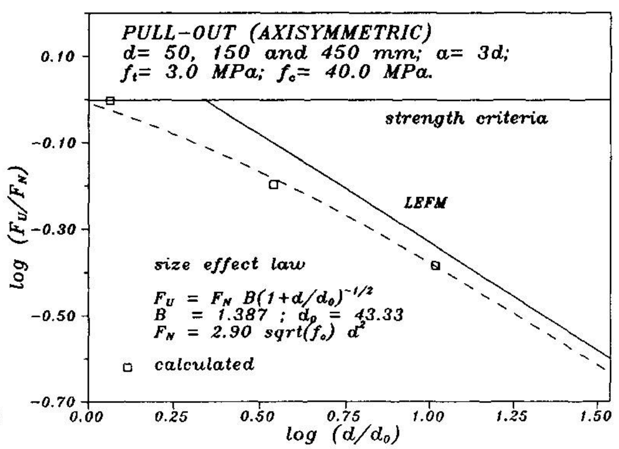

Fig. 6 Size effect on the pull-out load

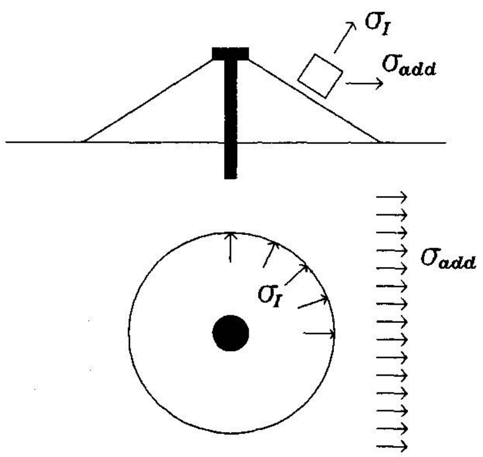

Fig. 7 3D stress state along the concrete cone failure surface and additional tensile stresses