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Autor(en): **Kuttab, Atallah S. / Haldane, David**

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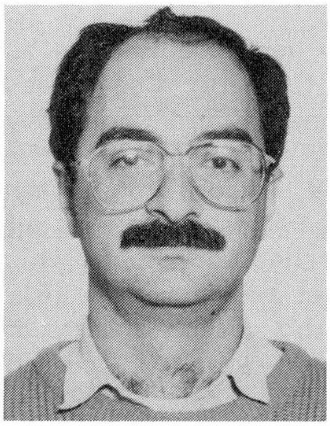
Detailing for Shear with the Compressive Force Path Concept

Cisaillement et concept de champ de forces de compression

Atallah S. KUTTAB
Assistant Professor
Birzeit University
Birzeit

David HALDANE
Senior Lecturer
Heriot-Watt Univ.
Edinburgh, Scotland



Atallah Kuttab is a member of CEB Task Force Group GTG 24 «Practical Design Utilising Multiaxial States of Stress», and member of CEB Permanent Commission PC 4 «Members Design».

David Haldane is actively involved in the numerical modelling and the experimental validation of the behaviour of structural concrete members particularly in the fields of deep beams and impact loading.

SUMMARY

The paper presents the results from tests on simple beams which were reinforced in compliance with the compressive force path concept using stirrups that did not extend the full depth of the beam. The test specimens when compared with conventionally reinforced ones showed higher strength and ductility. Furthermore, it is shown that the classification of beams according to their shear span to effective depth ratio is not only confusing but unnecessary.

RÉSUMÉ

Ce rapport présente les résultats de tests effectués sur des poutres simples en béton, armées sur la base du concept de champ de forces de compression et possédant des étriers courts ne s'étendant pas sur toute le hauteur de la poutre. Les échantillons expérimentaux se sont montrés plus résistants et ductiles que les échantillons armés de façon conventionnelle. De plus, il est démontrée que la classification des poutres en function du rapport «a/d» dans ce cas porte non seulement à confusion mais n'est pas nécessaire.

ZUSAMMENFASSUNG

Im vorliegenden Artikel werden die Versuchsergebnisse von einfachen Stahlbetonträgern, die nach dem «compressive force path concept» mit nicht über die ganze Höhe des Trägers reichenden Bügeln bewehrt wurden. Die Versuche zeigten im Vergleich zu konventionell verstärkten Trägern erhöhte Festigkeit und Duktilität. Darüber hinaus wurde deutlich, dass die Klassifikation von Trägern in Bezug auf das «a/d» Verhältnis nicht nur verwirrend, sondern unnötig ist.

1. INTRODUCTION

The practice of detailing reinforced concrete members is somewhat irrationally dependent to a large extent on its structural function. As an example, the provision of transverse reinforcement in a column implies that compressive zones in general require the presence of such reinforcement; while on the other hand, the introduction of transverse reinforcement to a simple beam is largely dependent on whether or not shear stresses are present. This apparent inconsistency in present day practice appears to have originated from the adoption of design principles based on an uniaxial state of stress. In addition, the design of structural concrete for some cases, for example shear design, follows physical models which do not represent the true behaviour.

In this context, MacGregor (1) described the ACI(2) shear design equations as "empirical mubo-jumbo". The tendency in present Code Drafting Committees (2,3,4,5) is to move towards procedures comparable in rationality and generality to the plane sections approach for flexure and axial load. The objective of the design procedures for shear is to try to assess the amount of shear reinforcement required to carry that portion of the shear forces in excess of that which can be sustained by the concrete alone. In order to achieve this aim various approaches based on concepts such as the latest truss models (6), the compression field theory (7), the lower and upper-bound of the theory of plasticity (8), etc are being adopted. Essentially, the element which is common to these models is the assumption that the diagonally cracked concrete forms the strut through which the load is transferred from the point of application to the support. This has necessitated extensive research in order to determine the characteristics of diagonally cracked concrete (7) and the impact of size effects related to concrete in tension (9). This approach has resulted in semi-empirical relationships which have required continuous modification to "fit" the results which were available from experimental investigations. The complexity of the approach lies in the modelling of physically unstable media, due to the continuous cracking of concrete, in the analysis which poses problems in satisfying both equilibrium and compatibility of strains in the idealised structure.

In fact, research over the past three decades which was aimed at resolving the riddle of shear, most notably the work by Kani (10), has resulted in models based either on the behavioural characteristics of the concrete cantilevers which form between adjacent flexural cracks, or the development of arch action in the beams as the ultimate loads were approached. Kotsovos (11) has more recently used the compressive force path concept to explain the behaviour of simple beams in shear. It was concluded that the concrete below the neutral axis did not contribute significantly to the shear capacity of the beam. This was in direct agreement with the findings of the investigations carried out by Kani (10) in which the approach based on the strength of the concrete cantilevers and the one based on the presence of arch action were totally dependent on the strength of the concrete in the compression zone. The indications from published research work are that for concrete beams unreinforced for shear, the concrete in the compression zone is almost entirely responsible for the ability of the section to resist the applied shear loadings.

It is advocated here, based on the behaviour of unreinforced concrete in shear, that the shear capacity of a beam could be enhanced and thus increasing its overall strength by confining the concrete in the compression zone. This is normal practice in the case of either disturbed regions or axial members (12). The adoption of such an approach would therefore transform the complexity of the flexure-shear interaction to one of designing a compression member. A series of tests has been undertaken on simple beams reinforced with stirrups which did not extend down over the full depth of the beam thus locally confining the concrete in the enclosed compression zone. In addition to observing the strength variations between the individual beams comparisons have been made with the behaviour of beams which were conventionally reinforced.

2. RESEARCH SIGNIFICANCE

This investigation forms part of a research programme whose principal objective is the development of a set of design procedures for structural concrete members which are compatible with their true behaviour. It is believed that the adoption of concepts based on observed failure modes will result in simpler and more realistic approaches to the analysis and design of such structural concrete members.

3. TEST SPECIMENS AND EXPERIMENTAL RESULTS

The test beam specimens, which were all under-reinforced, are described in Figure 1. Typical failure modes and load-deflection relationships for the various specimens are illustrated in Figures 2 and 3 respectively.

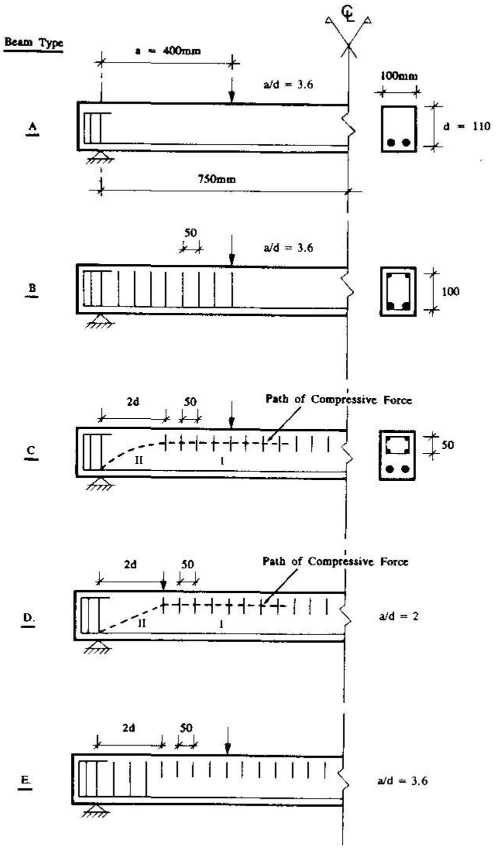


FIGURE 1. TEST SPECIMENS.

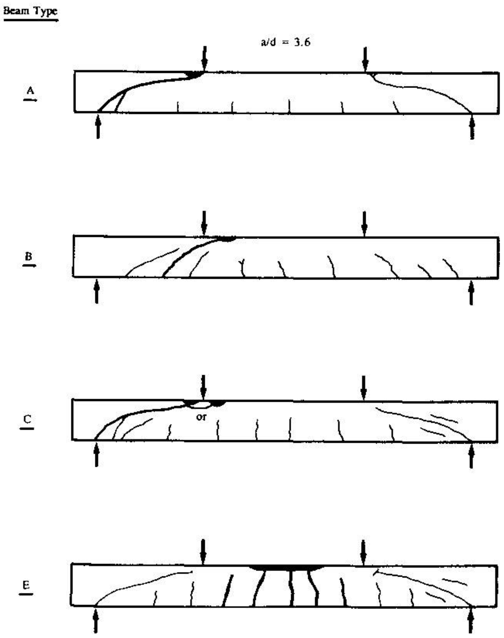


FIGURE 2. MODES OF FAILURE.

Notes:

1. Concrete strength is 28MPa (28 days).
2. Diameter and strength of main steel reinforcement is 12mm and 410MPa respectively.
3. Diameter and strength of transverse steel reinforcement is 6mm and 280MPa respectively.

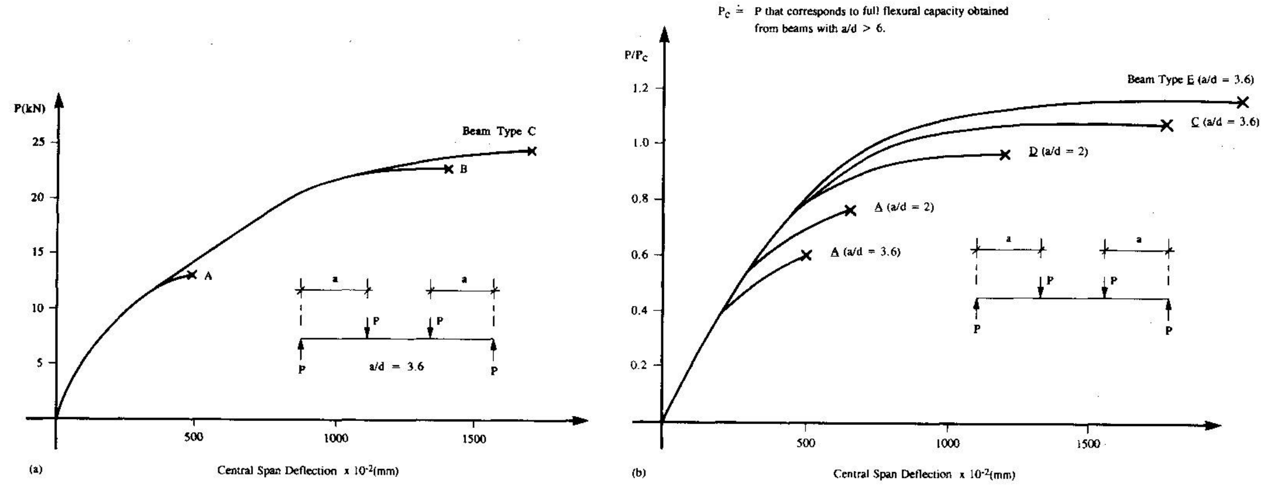


FIGURE 3 (a & b). LOAD DEFLECTION RESULTS.

4. DISCUSSION OF RESULTS

4.1 Modes of Failure

The resulting modes of failure of the beams without stirrups (type A beam in Figure 2) and those reinforced in compliance with Code provisions (type B beam in Figure 2) were as expected. In the case of the type C beams shown in Figure 2, the failure mode cannot be explained in terms of current theories. It was expected, and in accordance with the current theories of beam behaviour, that the failures of the type A and the type C beams would be similarly controlled by their shear capacity since both were unreinforced for shear. However, the type C beams were able to attain their full flexural capacity. The crack patterns present in the type C beams were comparable to those obtained in the type B beams in terms of extensiveness, but characteristically similar to those present in the type A beams. The type C beams contained a major diagonal crack, similar to the one found in the type A beams, which was prevented from splitting the compression zone by the presence of the transverse reinforcement. This allowed the type C beams to develop their full flexural capacity and thus behave in a characteristically ductile manner.

4.2 Load Capacity and Ductility

The type C beams, in which only the compression zone was reinforced with stirrups, and in accordance with the latest truss models or compression field theory, were expected to have the same load carrying capacity as those without stirrups i.e. type A beams. From Figure 3(a) it was found that their load carrying capacity exceeded that of the type A beams by about 90%. In the case of the type C beams, the shear load could not have been carried by a truss structure as generally assumed in present Codes of Practice. The type C beams were found to have a 7% higher load carrying capacity and an approximately 20% higher ductility than the type B beams despite the fact that the type of stirrups normally forming the ties in the truss structure were not present in this case. The increased ductility exhibited by the type C beams could be explained by considering the forces to which the compression zone is subjected to when the concrete becomes an unstable media due to continuous cracking. In the type B beams, the forces carried by the concrete after cracking are transferred to the stirrups which are anchored in the compression zone. It can be argued that this sudden transfer of stresses will produce impact loading on the compression zone which in turn would initiate a premature failure due to local crushing of the compression zone. This will therefore result in a reduction in the ductility of the beam. Alternatively, for the case of the type C beams the equilibrium of stresses at a section is solely controlled by the characteristics of the concrete in the beam. The provision of passive confinement by the introduction of stirrups in the compression zone creates a multiaxial state of stress in that region which would be able to satisfy equilibrium and compatibility conditions. The degree of ductility exhibited by the beams will depend to a large extent on the level of confinement provided in the compression zone.

4.3 Dependence on "a/d" value

Based on the compressive force path concept, the provision of the necessary transverse reinforcement in the beams, such that they will attain their full flexural capacity, would follow the same procedure regardless of the value of their shear span to effective depth ratio, a/d (13). For example, the compressive zone denoted by I in Figure 2 (type C and type D beams), requires confinement (by the provision of stirrups) regardless of the value of a/d and irrespective of whether or not it is subjected to shear forces. The region denoted by II in Figure 2 (type C and type D beams) follows traditional deep beam behaviour and therefore does not prevent the beam attaining its full flexural capacity. In fact, the type C and D beams were reinforced accordingly. The normalised results together with those of type A beams are shown in Figure 3(b) for comparative purposes. Both types of beams attained the full flexural capacity with higher ductilities than the type A beams. However, the provision of conventional stirrups in the deep beam region as in type E beams (refer to Figure 1) improved both ductility and strength as shown in Figure 3(b).

5. SUMMARY AND CONCLUSIONS

a) The load carrying capacities and ductilities of beams (Figure 3) were enhanced when the compression zone was passively confined with stirrups which did not extend down the full depth of the beam (Figure 1).

b) The special detailing approach adopted in the case of the type C beams (Figure 1) has recognised and attempted to conform to the true flow of stresses in the beam. The approach was essentially based on the compressive force path concept which accepts that the concrete below the neutral axis does not make a significant contribution to the load capacity of the beam. The acceptance and subsequent validation of such an approach will, for example, lead to the removal of the requirement for further investigations into the constitutive relationships for cracked concrete and the significance of the associated size effects in this context.

c) The complex problem of flexure-shear interaction could potentially be reduced to one of the design of axial members. Therefore, the work done on axial loaded concrete members (12) is expected to be directly applicable to this subject area.

d) When the analysis and design of structural concrete members is based on observed modes of behaviour it is anticipated that more rational procedures will be evolved. For example the existing classification of procedures for beam design which are normally dependent on the a/d ratio will become redundant and will lead to the removal of the lack of rationality which presently exists.

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REFERENCES

1. MACGREGOR, J.G., Challenges and Changes in the Design of Concrete Structures, Concrete International: Design and Construction, Vol. 6, No. 2, February 1984, pp. 48-52.
2. ACI COMMITTEE 318, Building Code Requirements for Reinforced Concrete, ACI 318-89) American Concrete Institute, Detroit, 1989.
3. Design of Concrete Structures for Buildings, (CAN3-A23.3-M84) Canadian Standards Association, Rexdale, 1984, 281pp.
4. Code of Practice for Design and Construction, (BS8110) British Standards Institution, London, 1985, Part 1, 154pp.
5. CEB-FIP Model Code for Concrete Structures, Comite Euro-Internationale du Beton and Federation Internationale de la Preconstrainte, English Edition, Paris, 1978, 156pp.
6. SCHLAICH, J., SCHAFER, K., and JENNEWEIN, M., Toward a Consistent Design of Structural Concrete, PCI Journal, May/June 1987.
7. COLLINS, P.C., and MITCHELL, D., A Rational Approach to Shear Design - The 1984 Canadian Code Provisions, ACI Journal, Vol. 83, November/ December 1986, pp. 925-933.
8. NIELSON, M.P., BRAESTRUP, M.W., JENSEN, B.C., and BACH, F., Concrete Plasticity, Special Publication, Danish Society for Structural Science and Engineering. Lyngby/Copenhagen, October 1978, 129pp.
9. BAZANT, Z.P., and OH, B.H., Crack Band Theory for Fracture of Concrete, Materials and Structures, Vol. 16, No. 93, May/June 1983, pp. 155-177.
10. KANI, G.N.J., The Riddle of Shear Failure and Its Solution, ACI Journal, Vol. 61, No. 4, April 1964, pp. 441-467.
11. KOTSOVOS, M.D., Compressive Force Path Concept: Basis for Reinforced Concrete Ultimate State Design, ACI Structural Journal, Vol. 85, No. 1, January/February 1988, pp. 68-75.
12. KUTTAB, A.S. and DOUGILL, J.W., Grouted and Dowelled Jointed Precast Concrete Columns: Behavior in Combined Bending and Compression, Magazine of Concrete Research (London), Vol. 40, No. 144, September 1988, pp. 131-142.
13. KUTTAB, A.S., Assessment of Concrete Structures Utilising Multiaxial Properties, Proceedings of the International Symposium on "Re-Evaluation of Concrete Structures" organised by the Danish Concrete Institute (DABI), Copenhagen/Lyngby, June 1988.