Zeitschrift: IABSE reports of the working commissions = Rapports des commissions de travail AIPC = IVBH Berichte der Arbeitskommissionen

Band: 13 (1973)

Artikel: Shear strength of concrete beams under cyclic loading - a preliminary study

Autor: Singh, H.N. / Gerstle, K.H. / Tulin, L.G.

DOI: https://doi.org/10.5169/seals-13748

Shear Strength of Concrete Beams under Cyclic Loading — A Preliminary Study

Résistance au cisaillement de poutres en béton sous charges cycliques — Une étude préliminaire

Schubfestigkeit von Betonbalken unter zyklischer Belastung — Eine Vorstudie

H.N. SINGH
Engineer
Pennsylvania Department of Highways
Franklin, Pa., USA

K.H. GERSTLE
Prof. of Civil Engineering
University of Colorado
Boulder, Colorado, USA

L.G. TULIN
Prof. and Chairman
Dept. of Civil and
Environmental Engineering
University of Colorado
Boulder, Colorado, USA

Introduction

Numerous studies of the response of reinforced concrete members to cyclic loadings, many of which have been summarized at this meeting, have indicated that in general, the flexural strength of under-reinforced beams remains unimpaired under histories of loading consisting of a reasonable number of cycles. However, there is a body of evidence indicating that their shear strength may suffer under such loadings; a number of continuous beams (1), designed to fail in flexure under monotonically increasing loads, actually failed in a diagonal tension mode under cyclic loading which appeared to be triggered by bond cracking of the concrete at the level of the tensile steel.

An explanation of such premature shear failures may be found in the progressive deterioration of bond between reinforcing steel and concrete under cycles of high loads. Since the tensile crack pattern of concrete beams is closely associated with bond, it follows that any deterioration of the bond will affect the nature of the tensile cracks. Recently developed methods of analysis (2,3) can account for the effect of bond loss on the crack propagation within the concrete in a rational manner.

Following this line of thought, the pilot study discussed in this paper was divided in the following parts:

1. Experimental determination of the bond deterioration under repeated loading.
2. Development of a theory of shear strength of concrete beams which includes the effect of this bond deterioration.
3. Cyclic tests of concrete beams designed to fail in shear to check predictions.

While the investigation is at present incomplete, we feel that it is sufficiently important to focus attention on the importance of shear strength under cyclic loadings to warrant presentation of preliminary results.

Pullout Tests

A theory of bond behavior of pullout specimens, as shown in Fig. 1(a) under monotonic and cyclic loading is presented which may help explain the relation between bond deterioration and opening of tensile concrete cracks. Based on limited experimental evidence (4) it is assumed that each point along the embedment length of a bar has a fixed capacity to develop bond strength. When this capacity is reached, the strength begins to deteriorate. Bond failure of the specimen is possible only after all points along the embedment, one after the other, have achieved their full capacity. A plot of the peak strength of all points will be called the "envelope curve", and is shown in Fig. 1(b). Under applied tension force, bond stresses will develop, leading to a bond stress distribution as shown by Curve A-B-C in Fig. 1(b). The area under this curve between the loaded end and any point is proportional to the force transferred to the concrete, and the total area under the bond stress curve is proportional to the total applied load. Thus, the force in the tension bar at any point can be plotted as shown in Fig. 1(c). The area under this latter curve, in turn, is proportional to the elongation of the bar. As long as the free end of the bar is prevented from slipping, all of this elongation appears as slip of the loaded end.

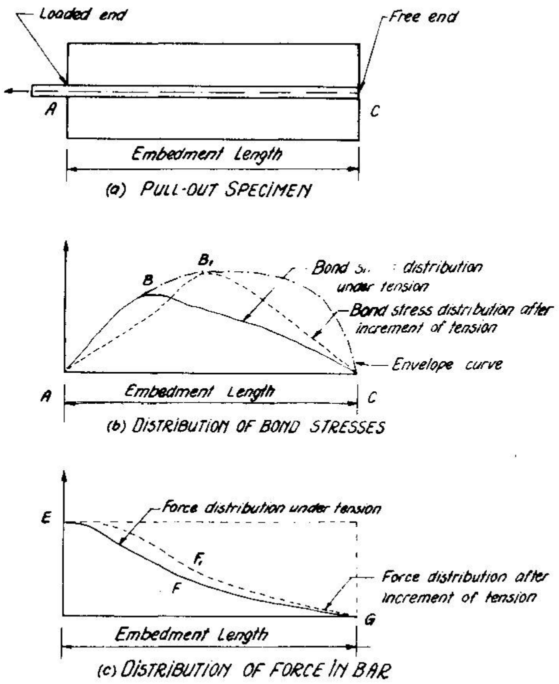

FIG. 1 - REPRESENTATION OF PULL-OUT SPECIMEN AND PERTINENT CHARACTERISTICS IN ANALYSIS

As the load on the bar is increased, the bond stress distribution changes, with those portions of the bar whose bond stress has attained the envelope value subject to bond deterioration, and others with ascending stresses, leading to a new bond stress distribution as shown by Curve A-B_1-C of Fig. 1(b). The difference between the area under the force diagram corresponding to this stress distribution, E-F_1-G in Fig. 1(c), and the previous one, E-F-G, is proportional to the increment of slip at the free end occurring due to the additional load. Under further increase of applied load, the area under the envelope curve is swept, with that bond stress distribution containing the largest area denoting the maximum bond strength.

These concepts can also be used to explain the action under cyclic loading. If the bar is subjected to repeated load of constant magnitude, some bond deterioration will occur with each cycle which will cause a redistribution of the bond stresses, shifting the bond stress curve toward the free end while maintaining its area constant. Thus, the area under the force diagram is increased, denoting increasing bar slippage. It can also be seen that this action may cause the envelope curve to be swept by successive bond stress distributions, leading to eventual bond failure under applied load smaller than one applied monotonically.

Pullout tests under monotonic and cyclic loadings were performed on 54 specimens in order to determine strength and slip characteristics under both types of loading. The cyclic loads were initially applied at low load levels, repeated until the slip measurements showed stabilization, then increased by 1000 lb. increments and the process repeated to failure. The points on curves of cyclically applied load versus slip which indicate stabilization were connected by curves called "load-slip curves under cyclic loading". In Fig. 2 such curves are plotted for the case of specimens with 3 inch embedment length, and compared with similar load-slip curves for monotonic loading. These results are typical of many (5), and indicate increased slip and reduced strength due to cyclic loading, as predicted by the preceding theory.

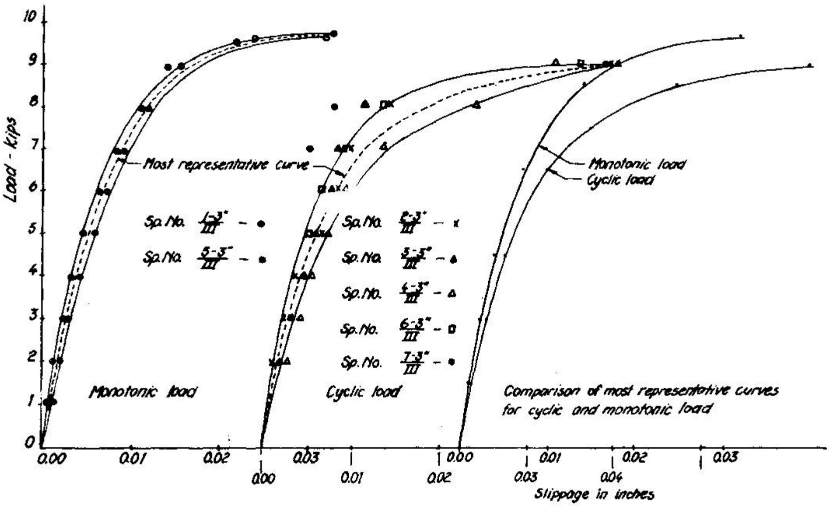

FIG. 2 - LOAD-LOADED END SLIPPAGE AND MOST REPRESENTATIVE CURVES FOR 3" EMBEDMENT LENGTH

Shear Strength of Beams under Cyclic Loading

Space limitations preclude adequate discussion of theories relating bond slip to shear failure of beams. Such theories have been based on technical beam theory (2) and on finite element analyses (3). The effect of bond deterioration which may result from repeated load histories may be summarized as follows:

1. Relative displacement of crack edges may lead to increased dowel forces which in turn may cause dowel cracking parallel to the tensile reinforcement.
2. Similarly, such widening of cracks may lead to aggregate interlock cracking, as explained by Fenwick (6).
3. Lastly, it has been shown by Krahl et. al. (2) that propagation of diagonal cracks into the compression zone may result from bond deterioration, leading to premature diagonal tension failure.

Beam Tests

To gain some insight into the shear strength of beams under cyclic loading, a series of ten simple beams, of concrete and reinforcement identical to that used in the pullout specimens, and designed to fail in shear, was tested. Most of the beams had two test sections at opposite ends of the span; one of these was tested monotonically, the other cyclically under 1000 lb. increments, loads at each level being applied repeatedly until stabilization of deflections. Instrumentation consisted of dial gages and gage plugs for the determination of concrete strains.

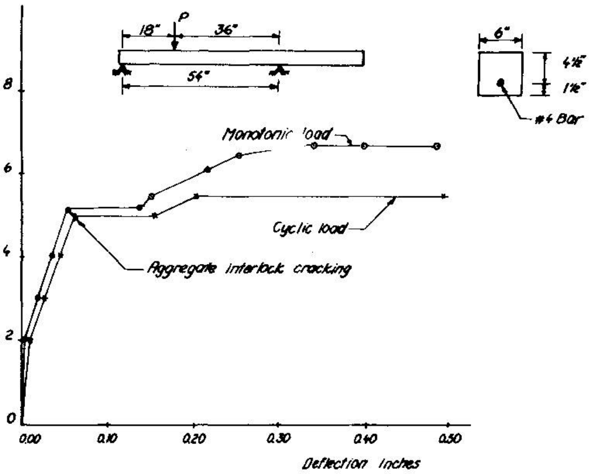

FIG. 3 - A TYPICAL LOAD-DEFLECTION CURVE FOR THE BEAMS

Fig. 3 shows a typical set of load-deflection curves for monotonically and cyclically applied loads, and Fig. 4 shows some of the beams after shear failure. A number of observations can be made on basis of these and similar results:

1. Shear failure under cyclic loading seems to occur as a consequence of aggregate interlock cracking; this occurs at a lower load applied cyclically than applied monotonically.

2. Aggregate interlock cracking seems to be somewhat more pronounced in cyclic than in monotonic loading. Prior to aggregate interlock cracking, load repetitions cause only minimal crack propagation and incremental deformations.

3. The effects of aggregate interlock cracking and dowel cracking are dominant in controlling the shear strength of beams under cyclic loading.

Conclusions

Present theories of flexural strength under cyclic load histories must be supplemented by means of predicting the cyclic shear strength under a variety of conditions. The tools for arriving at such predictions are available, but much more work is needed before the information can be applied to design of concrete structures.

References

1. Gerstle, K. H., and Tulin, L. G., "Shakedown of Continuous Concrete Beams", Proc. Int. Symp. on Repeated Loading, RILEM, Mexico City, 1966.
2. Krahl, N. W., Khachaturian, N., and Siess, C. P., "Stability of Tensile Cracks in Concrete Beams", Proc. A.S.C.E., Jnl. Struct. Div., Vol. 93, No. ST1, February 1967.
3. Nilson, A. H., "Nonlinear Analysis of Reinforced Concrete by Finite Element Method", Jnl. A.C.I., Vol. 65, No. 9, Sept. 1968.
4. Perry, E. S., and Thompson, J. N., "Bond Stress Distribution on Reinforcing Steel in Beams and Pull-out Specimens", Jnl. A.C.I., Vol. 63, No. 8, August 1966.
5. Singh, H. N., "Shear Strength of Reinforced Concrete Beams under Cyclic Loading", M.S. Thesis, University of Colorado, 1969.
6. Fenwick, R. C., and Paulay, T., "Mechanisms of Shear Resistance of Concrete Beams", Proc. A.S.C.E., Jnl. Struct. Div., Vol. 94, No. ST10, Oct. 1968.

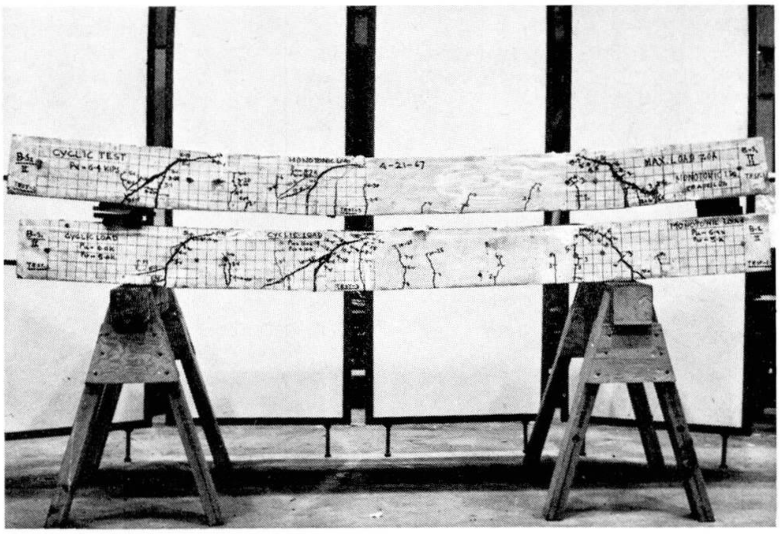

FIG. 4 - SHEAR FAILURE OF BEAMS

SUMMARY

The influence of bond deterioration on the shear strength of reinforced concrete beams under cyclic loadings has been discussed. It was shown that this bond deterioration may lead to aggregate interlock cracking, to dowel cracking, and to propagation of diagonal tensile cracks. A pilot series of beams was tested to obtain preliminary information about these effects.

RESUME

L'influence de détériorations dans l'assemblage sur la résistance au cisaillement de poutres en béton armé sous charge cyclique a été discutée. Il a été démontré que ces déteriorations peuvent donner lieu à une accumulation de fissures enchainantes, à la formation de fissures contigues et à la propagation de fissures de tension diagonales. Des essais ont été faits sur un certain nombre de poutres en vue d'obtenir des informations préliminaires sur ces effets.

ZUSAMMENFASSUNG

Der Einfluss von Schäden im Verband auf die Schubfestigkeit von Stahlbetonbalken unter zyklischer Belastung wurde diskutiert. Es wurde gezeigt, dass solche Verbandschäden zur Anhäufung ineinandergreifender Risse, zu zusammenhängender Rissbildung und zur Ausbildung diagonaler Streckrisse führen können. Eine Anzahl Balken wurde geprüft, um Vorinformationen über diese Einwirkungen zu erhalten.

Leere Seite
Blank page
Page vide