Proceedings of Ninth World Conference on Earthquake Engineering
August 2-9, 1988, Tokyo-Kyoto, JAPAN (Vol.IV)

6-4-1

REINFORCED CONCRETE COLUMNS UNDER CYCLIC AXIAL COMPRESSIVE FORCES

Alberto CASTELLANI (*) and Francesco SCIROCCO (*)

(*) Professors -Dept. of Struct. Eng.- Politecnico di Milano, Italy.

Summary

The stress-strain relationship of plain concrete specimen under compressive uniaxial load cycles is enveloped by a curve, which merged to be unique and identical with the stress-strain curve obtained under constantly increasing strain.

In the present research the extension of the "envelope curve" concept to plain or r.c. columns is attempted, with reference to compressive stresses only. The tests allow to assess that this curve is unique and coincides with the monotonic curve. However, in peculiar tests, discontinuities are introduced in the envelope by repeating cycles at low stress intensity.

The research is mainly based on testing of columns 80x20x20 cm in size.

Introduction

For cyclic loading histories, of increasing amplitude, the envelope curve of the stress-strain relation is defined as a curve connecting the starting of unloading curves as well as ends of reloading curves. The uniqueness of the envelope curve, and its coincidence with the monotonic stress-strain curve, has been debated for over two decades.

A state on the art on the subject has been reported by Aoyama and Noguchi, [1] and by CEB in 1983, [2]. According to Aoyama and Noguchi, seven researches recognized that a unique envelope curve can be defined, coinciding with the monotonic curve, within the data scattering of the falling branch. No disagreement has been explicitly published on the uniqueness of this curve.

For the discussion to follow, it is worth to mention the results reached by Sinha, Gerstle and Tulin on the basis of tests on 6x12 inches standard compression cylinders [9]:

1. The stress-strain relationship of concrete under compressive load histories possesses an envelope curve, which may be considered unique and identical with the stress-strain curve obtained under constantly increasing strain.

2. The stress-strain relationship of concrete subjected to cyclic loading possesses a locus of common points which are defined as the point where the reloading portion of any cycle crosses the unloading portion. Stresses above the common points produce additional strains, while stresses at or below these points will result in a stress-strain path going into a loop. It was also observed that the value of the common points depended of the minimum stress in the cycle, i.e., the cycle amplitude.

In the above tests, as well as in all tests mentioned in the present paper, load histories were such that strain rate, creep and fatigue effects could be disregarded.

In the present research the extension of the "envelope curve" concept to columns is attempted, with reference to compressive stresses only.

Experimental work

More than sixty 20x20 cm columns, from 80 to 100 cm high, were tested under monotonic or cyclic axial compression. The variable examined were: amount and spacing of lateral steel, concrete age, history of loading.

Deformed wires were used for both vertical and horizontal steel, the yield stress being $f_y = 3600\,\mathrm{kg/cm^2}$. A few batches were supplied for the concrete, 15-mm maximum aggregate size, a slump of 75 mm, and a target 28-day strength of $f_c = 250\,\mathrm{kg/cm^2}$. All columns were cast vertically. After aging, both ends were capped with hydrostone, and the surfaces, - concrete and reinforcement - were smoothed by a diamont drill to ensure good contact between the loading heads and the specimen. Skin imperfections were capped with high-strength mortar.

Two thin teflon sheets alternate with a film of stable solid lubrifing were then applied between the ends of the column and the loading heads of the testing machine, to ensure the minimum transfer of shear stresses between the heads of the machine and the specimens. During aging all columns and their concrete samples were stored in a room controlled by temperature and humidity.

The tests were carried out in a 150 tons MTS machine, equipped with two spherical hinges to minimize accidental excentricity. A digital computer controlled the hydraulic loading system. Deformation data were recorded using both optical and mechanical transducer. Computer programs were then developed to enable to mechanical energy of each cycle and that of the envelope curve to be determined. Further information on the test conditions is: increase of the peak strain from cycle to cycle = $2 * 10^{-4}$; main frequency = 0.05 cps; $f_c = 307 \div 362\,kg/cm^2$.

The research here reported is based on 32 column samples: 16 of plain concrete and 16 reinforced by 8 12 mm longitudinal bars, tied by rectangular ties, 6 mm every 15 cm. It is an appropriate horizontal reinforcing according to CEB code [9]. Two plane concrete columns and two reinforced concrete columns were tested monotonically increasing the deformation. The remaining columns were tested under cyclic loading of increasing amplitude.

Main results

Fig.1 is a typical force-elongation diagram of a plane concrete column, and Fig.2 the companion diagram for a reinforced column. Fig.3 and 4 report the envelope obtained by averaging the single test envelope respectively of plane and reinforced concrete columns. In the same figures, for comparison, are the pertinent monotonic load-elongation diagrams (each one average between two tests). Both comparisons therefore allow to assess that the envelope curve is unique and coincident with the monotonic curve.

Fig.5 is a further test of cyclic loading of increasing amplitude. Two groups of 5 cycles, fairly apart from the "common points" loading were inserted in the main program. It appears that discontinuities are introduced in the envelope by repeating cycles at low stress intensity. This is interpreted as a marginal discrepancy from the uniqueness of the curve, and a disagreement with the "common points" concept, as it was recognized for plain concrete specimens.

- Research developed under Contract CNR CT 86-02386.07.

References

1) Aoyama, H., Noguchi, H., 'Mechanical Properties of Concrete under Load Cycles Idealizing Seismic Actions', State of the art report, CEB, Bull. d'Inf. N.431, April 1979.
2) CEB 'Response of R.C. Critical Regions under Large Amplitude Reversed Actions', Bulletin d'Information n.161, Aug. 1983.

3) Cook, D.J., Chindaprasirt, 'Influence of Loading History upon the Compressive Properties of Concrete', Magazine of Concrete Research, vol.32, n.111, pp.89-100, June 1980.
4) Desayi, P., Iyengar, K.T., Sanjeeva Reddy, T., 'Stress-Strain Characteristics of Concrete Confined in Steel Spirals under Repeated Loading', Materiaux et Constructions, V.12, N.71, pp.375-383, 1979.
5) Higashi, Y., Ohkubo, M., Ohtsuka, M., 'Influence of Loading Excursions on Restoring Force Characteristics and Failure Modes of Reinforced Concrete Columns', Proceedings, Sixt World Conf. on Earth. Eng., New Dehli, vol.III, pp.3127-3132, Jan. 1977.
6) Karsan, I.D., Jirsa, J.O., 'Behaviour of Concrete under Compressive Loadings', ASCE Journal of the Struct. Div., V.95. ST12, pp.2543-2563, December 1969.
7) Shah, S.P., Fafitis, A., Arnold, R., 'Cyclic Loading of Spirally Reinforced Concrete', Journal of Structural Engineering, ASCE, V.109, N.7, pp. 1695-1710, July 1983.
8) Scott, B.D., Park, R., Priestley, M.J.N., 'Stress-Strain Behaviour of Concrete Confined by Overlapping Hoops at Low and High Strain Rates', ACI Journal, pp.13-27, January-February 1982.
9) Sinha, B.P., Gerstle, K.H., Tulin, L.G., 'Stress-Strain Relationship for Concrete under Cyclic Loading', ACI Journal, V.61 N.2, pp.195-211, February 1964.

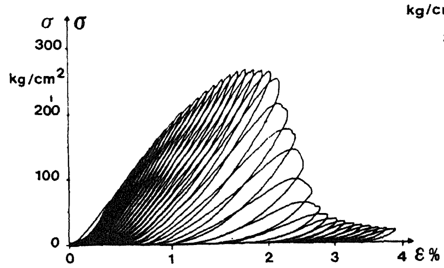


Fig. 1 : plane concrete

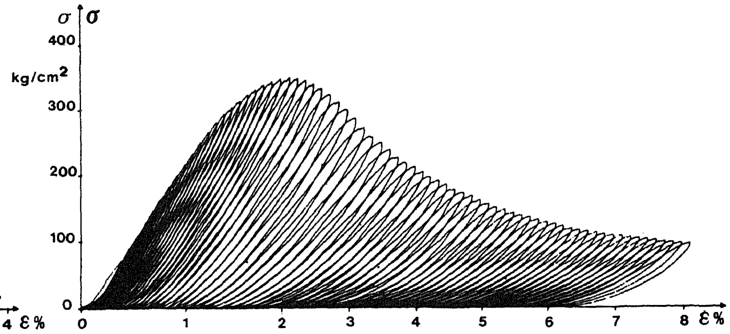
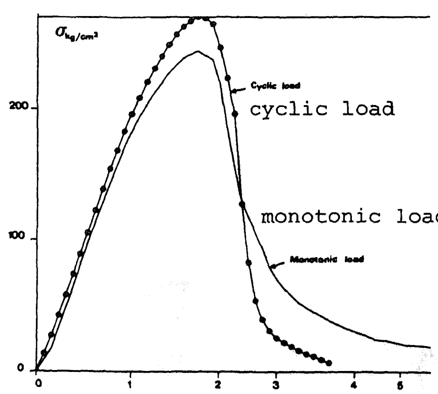


Fig. 2 : reinforced concrete



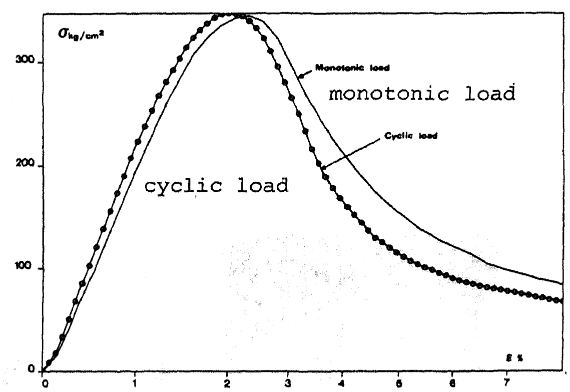


Fig. 3: Average value of the cyclic load envelope, and average value of monotonic load stress strain curve for plane concrete. Fig. 4: Same comparison for reinforced concrete.

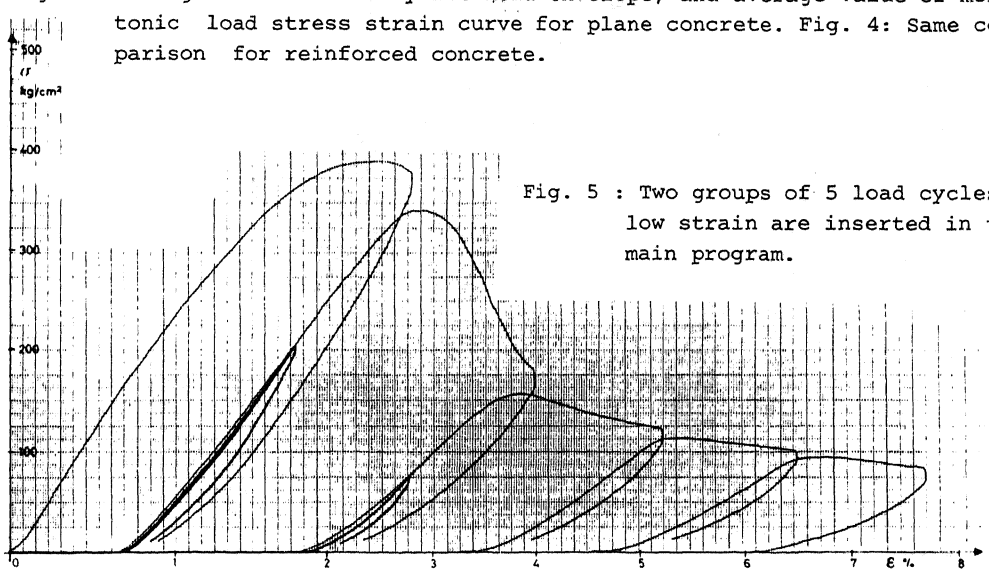
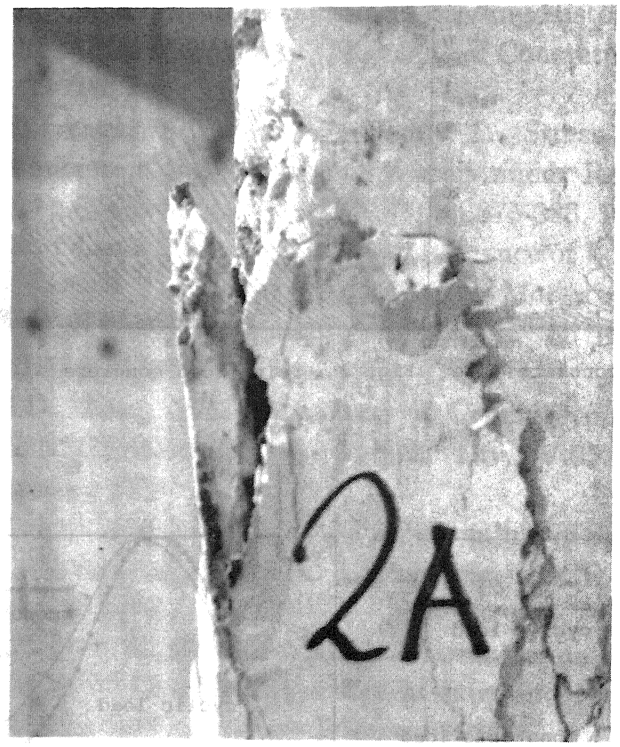


Fig. 5 : Two groups of 5 load cycles of low strain are inserted in the main program.



Aspect of progressive failure.