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Transient Deformation Behaviours of Prestressed Concrete Beams under Repeated Over-load

Comportement de déformation momentanée des poutres en béton précontraint soumises à des surcharges répétées

Vorübergehendes Deformationsverhalten vorgespannter Betonbalken unter Schwellbelastung

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Introduction

The prestressed concrete members or frames must have the stabilized properties under the repeated over-loads developed during heavy earthquakes. That is, their deterioration mechanisms under the repeated over-load should be clarified. It may be considered that the transient deteriorations of prestressed concrete members under the repeated over-load are mainly caused from both the deterioration of concrete in compresion side and bonding ability of grout and the permanent strain set of prestressing steel. The basic properties of these factors under repeated over-load are not sufficiently clarified to predict the transient behaviors of the prestressed concrete members. Therefore, this study aims to obtain the knowledges of overall trends by an experimental approach.

TEST RESULTS UNDER THE NON-REVERSED REPEATED LOADS

Firstly, the transient flexural behaviors under the non-reversed repeated over-load were investigated. Main interest was focussed in the change of moment-curvature relationship during cyclic load.

Test beams

Test beams were cast with the synthetic lightweight aggregate concrete and grouted with cement paste after prestress transferring. The dimensions and details of test beams are shown in Fig. 1 (a). The prestressing tendon was of 16mm dia. and located at the distance of one-sixth the total depth of beam from the centroid and tensioned to the allowable stress which produced stress of one-third the compressive strength of concrete in the compression side and almost zero in the opposite side. Unless specified, the specimens had stirrups of 6mm dia. at the intervals of 150mm and two erection bars of 6mm dia. in each of compression and tension side of the section. Employed prestressing tendons were smmoth round bars treated by high frequency induced heat.

Effect of load intensity

The first factor considered was the load intensity at the instant of reloading, which was eventually expressed by the compressive extreme fiber strain $\varepsilon_{c.ul}$ of concrete, such as 1.8, 2.0, 2.2, 2.4, 2.6 or 2.8‰. The moment M-curvature ϕ relations under the loading history, including one cycle of complete loading and unloading between zero to the specified load level and again reloading until failure, were compared with those under the simple loading. Fig. 1 (a) to (c) show the changes of the moment-curvature relations during the loading, unloading and reloading stages respectively, which are given in non-dimensional expression by dividing with the theoretical values of M and ϕ for the monotonous loading. Likewise, the non-dimensional flexural stiffness-moment relations are briefly represented in Fig. 2 in which the solid line is for simple loading. Since the breaking points showing the degradation of stiffness seem to lie at almost the same moment, these degraded stiffnesses were plotted against the strain $\varepsilon_{c.ul}$ as shown in Fig. 3. This figure shows that the compressive extreme fiber strain $\varepsilon_{c.ul}$ of concrete at the beginning of reloading is useful as the factor governing the stiffness degrading of prestressed concrete beams. To residual curvature and decompression moment similar principle was applied, thus the calculated moment-curvature curve showed the considerably good agreement with the experiments as shown in Fig. 4.

Effect of the number of load repetition

The second factor considered was the number of load repetitions. In the test were used 1, 3, 5, 9, 15 unloading cycles with the constant load amplitudes between the specified upper limits and zero. The seismic design load of prestressed concrete member for buildings in Japan is corresponding to about 0.76 times the ultimate strength, assuming that the load factors are 1.2 for the dead and live loads and 1.5 for the seismic load. Under this design load, the compressive extreme fiber strains of beams is around 1.8‰. Therefore, the load producing the strain of 1.8‰ in the compressive extreme fiber of test beam by the virginal loading was repeated by the specified number of repetitions and, afterwards, monotonous increassing load was applied to failure. In one series of test, specimens had neither stirrups nor erection reinforcements except the prestressing steel itself. Another series of test, specimens had the standard stirrups described before and 2-ϕ9 mm and 2-ϕ6 mm axial erection reinforcing bars each in compression and tension side of the section respectively. The reduction in strength was not appreciable even after 15 cycles of loading. The ductilities of the specimens with ordinary reinforcements tended to increase with the increasing number of loading cycles, whereas those without ordinary reinforcements decreased after 9 repetition of loading. Based on the simplified stiffness degradation-moment relationship of the tested specimens with and without reinforcements respecitively, the degradations of stiffnesses were plotted against the number of loading cycles as shown in Fig. 5.

TEST RESULTS UNDER THE REVERSED REPEATED LOADS

Secondly, the transient flexural behaviors under the reversed repeated load were investigated. Effect of the auxiliary ordinary reinforcements. In this series, the test specimens were made from the similar materials. But the prestressing tendon was located in the centroid of the section. Transferred prestress was one-sixth the compressive strength of concrete. The amounts of the longitudinal non-tensioned ordinary reinforcements were 2-ϕ13 mm in the compression and tension sides of the section. Moreover, both types ot test beams with and without stirrups of ϕ6 mm at the intervals of 25mm were prepared. The variety of the section details of tested beams is shown in Fig. 6.

At first about 90% of the theoretical capacities of beams were applied then fully reversed repeated loadings were performed. The applied loads were unloaded when the moment-curvature curve in each cycle reached the envelope curve. Other test conditions were almost the same as those in the prescribed test result. Fig. 6 shows parts of the envelope curve of the moment-curvature relations where the values of moment and curvature are divided by the ultimate ones theoretically obtained under the monotonous loading condition. For the test beams APG-46 and-48 without any stirrups the reduction in flexural capacities is remarkable although the ductility increases to some extent. The test beam APG-49 with 2-ϕ13 mm compressive and tensile reinforcement and 2-ϕ6 mm stirrups spaced by 25 mm showed a considerable potential energy to resist the heavy repeated over-load. The stiffness reduction and the ductility at the peak condition during the load repetition are shown in Fig. 7.

Effects of the eccentricity of tendons and the curvature amplitudes

In conventional design of prestressed concrete structures, the eccentricities of the prestressing steel along the member axis are usually determined in proportion to the moment distribution due to the dead and live loads. Therefore, the prestressed concrete beam in the rigid portal frame as shown in Fig. 8 has the different moment-curvature properties in every section along its axis. For the estimation of the entire deformation of such member, it is necessary to obtain the effect of the eccentricity of the prestressing tendon on the moment-curvature relation. Some experimental results on this problem under repeated over-load are described. The tests were composed of the following three series;
(1) the beams with the same eccentricity - h/6 of the prestressing steel were tested under the three kinds of the constant curvature amplitudes, i.e. level 1, 2 and 3, which corresponded to 1.0, 0.8 and 0.5 times the theoretical ultimate moment of the beams under monotonous loading respectively,
(2) the beams with the five kinds of the eccentricities ranging from - h/6 to + h/6 were tested under the constant curvature amplitude corresponding to the theoretical ultimate moment of the beams,
(3) the beams with the section A to E as shown in Fig. 8 were tested under the constant curvature amplitudes, simulating the maximum moment distribution of steady state under horizontal seismic action. Alphabetical symbol and two digital numbers of the name of test beams show the eccentricities of the tendon and the applied curvature amplitudes in both directions. Except the eccentricities of the tendon test beams had the similar properties as used in the preceding experiments under the non-reversed repeated loads. Parts of the obtained moment-curvature relationships are shown in Fig. 9. In order to realize the trend of the mechanical deterioration the representative coefficients in the idealized moment-curvature relationships shown in Fig. 10 are adopted. Fig. 11 shows the changes of such coefficients against the load repetition number N.

SUMMARY

Flexural behaviors of prestressed synthetic lightweight aggregate concrete beams under repeated over-load are experimentally investigated. The factors considered in the test programs are the effects of the load intensity, the number of load repetition, the auxiliary ordinary reinforcements, the modes of repeated load and the eccentricities of the prestressing tendons.

RESUME

On étudie le comportement à la flexion de poutres en béton à aggrégats synthétiques légers précontraintes soumises à des surcharges répétées. Les facteurs considérés dans les programmes d'essais sont: les effets de la grandeur de la charge, le nombre de cycles de charges, les armatures auxiliaires normales, le type de charge répétée et l'excentricité des câbles de précontrainte.

ZUSAMMENFASSUNG

Es wurde das Biegeverhalten vorgespannter Leichtbetonbalken unter wiederholter Ueberbelastung experimentell untersucht. Die im Testprogramm berücksichtigten Faktoren sind die Effekte der Belastungsgrösse, der Anzahl der Last-Wiederholungen, die zusätzliche übliche Bewehrung, die Art der wiederholten Last und die Exzentrizität der Spannkabel.

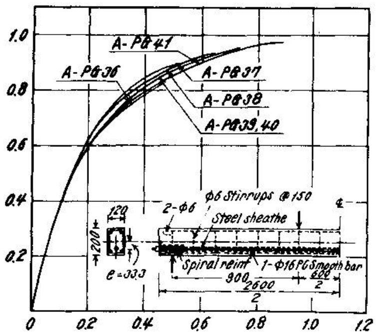

Fig. 1 (a) Non-dimensional moment-curvature curves during loading stage (Unit of specimen dimensions in mm).

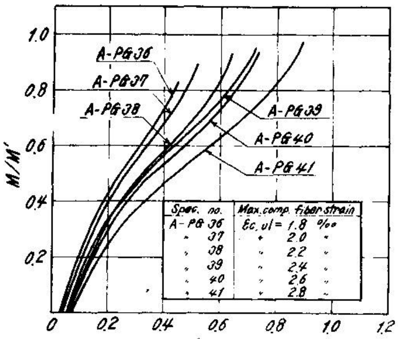

Fig. 1 (b) Non-dimensional moment-curvature curves during unloading stage from various load levels.

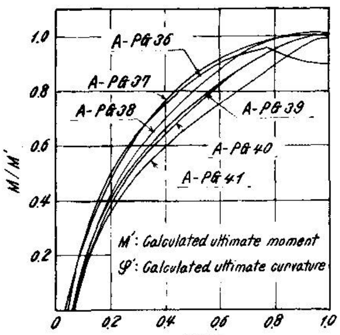

Fig. 1 (c) Non dimensional moment-curvature curves during reloading stage after complete unload.

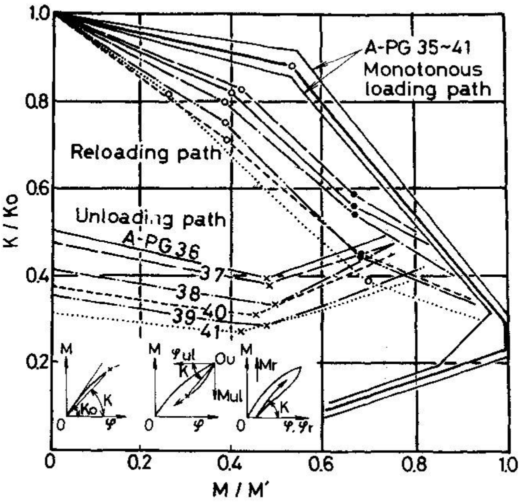

Fig. 2 Bi- or tri-linear approximation of flexural moment-stiffness relations under repeated over-load with various load levels.

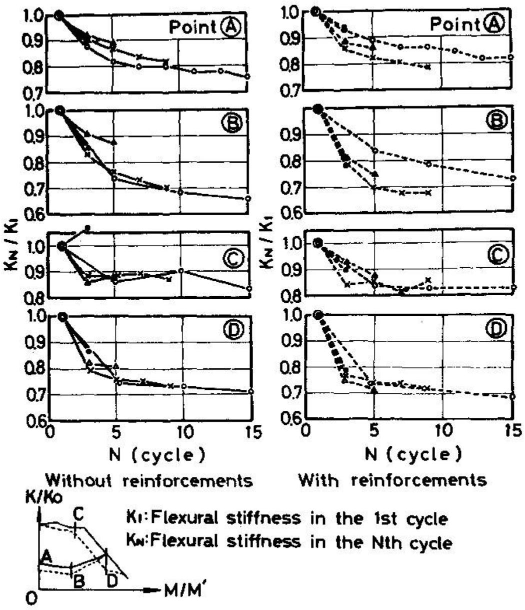

Fig. 5 Degrading flexural stiffness Kn/Ki against the load number.

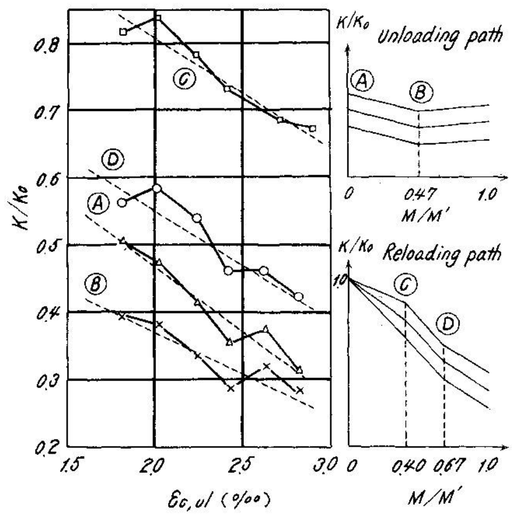

Fig. 3 Degrading flexural stiffness K/Ko against the compressive extreme fiber strain $\varepsilon_{c,ul}$ of concrete at the beginning of unloading.

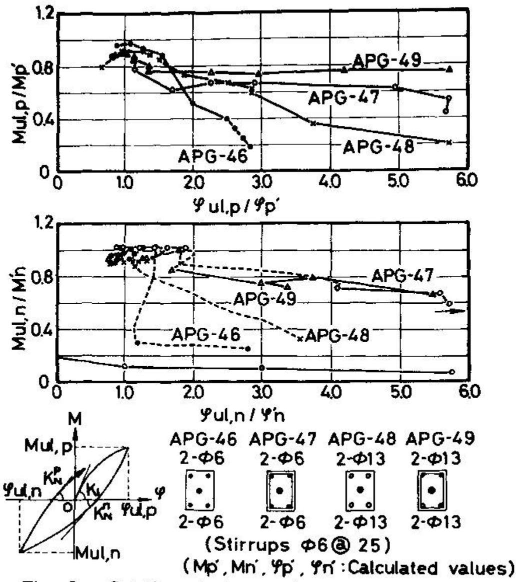

Fig. 6 Relations between the moment and curvature at the instant of unloading under full reversed repeated overload.

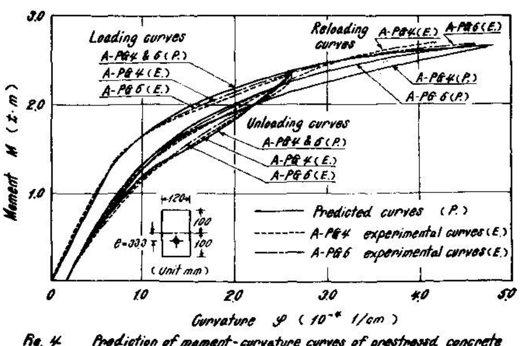

Fig. 4 Prediction of moment-curvature curves of prestressed concrete beams under repeated loadings.

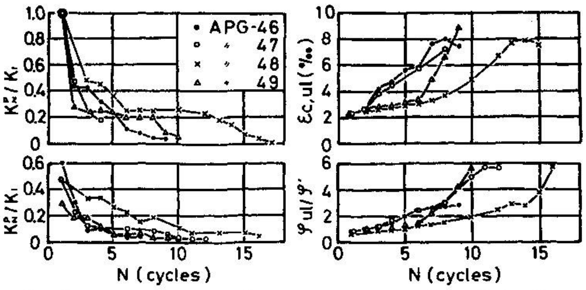

Fig. 7 Degradation of flexural stiffness Kn/Ki, and development of compressive extreme fiber strain $\varepsilon_{c,ul}$ of concrete and ductility factor φ_{ul}/φ' at the peak load against the load number.

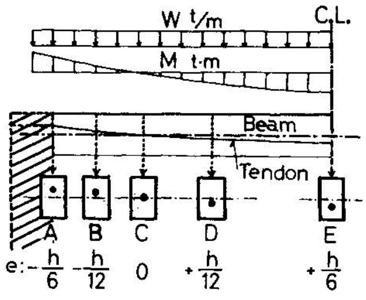

Fig. 8 Tendon profile of prestressed concrete beam in a rigid frame. (e : eccentricities.)

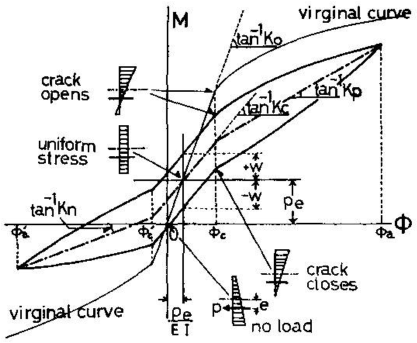

Fig. 10 Proposed model of N-th cycle moment-curvature curve of prestressed concrete beam under reversed flexural loading. (Φ_a, Φ_a' :specified constant curvature amplitudes)

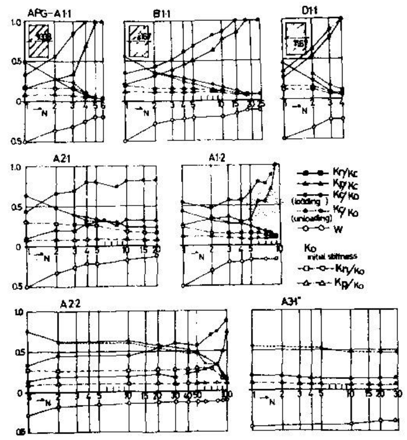

Fig. 11 Changes of representative coefficients of the moment-curvature model against the load repetition number N.

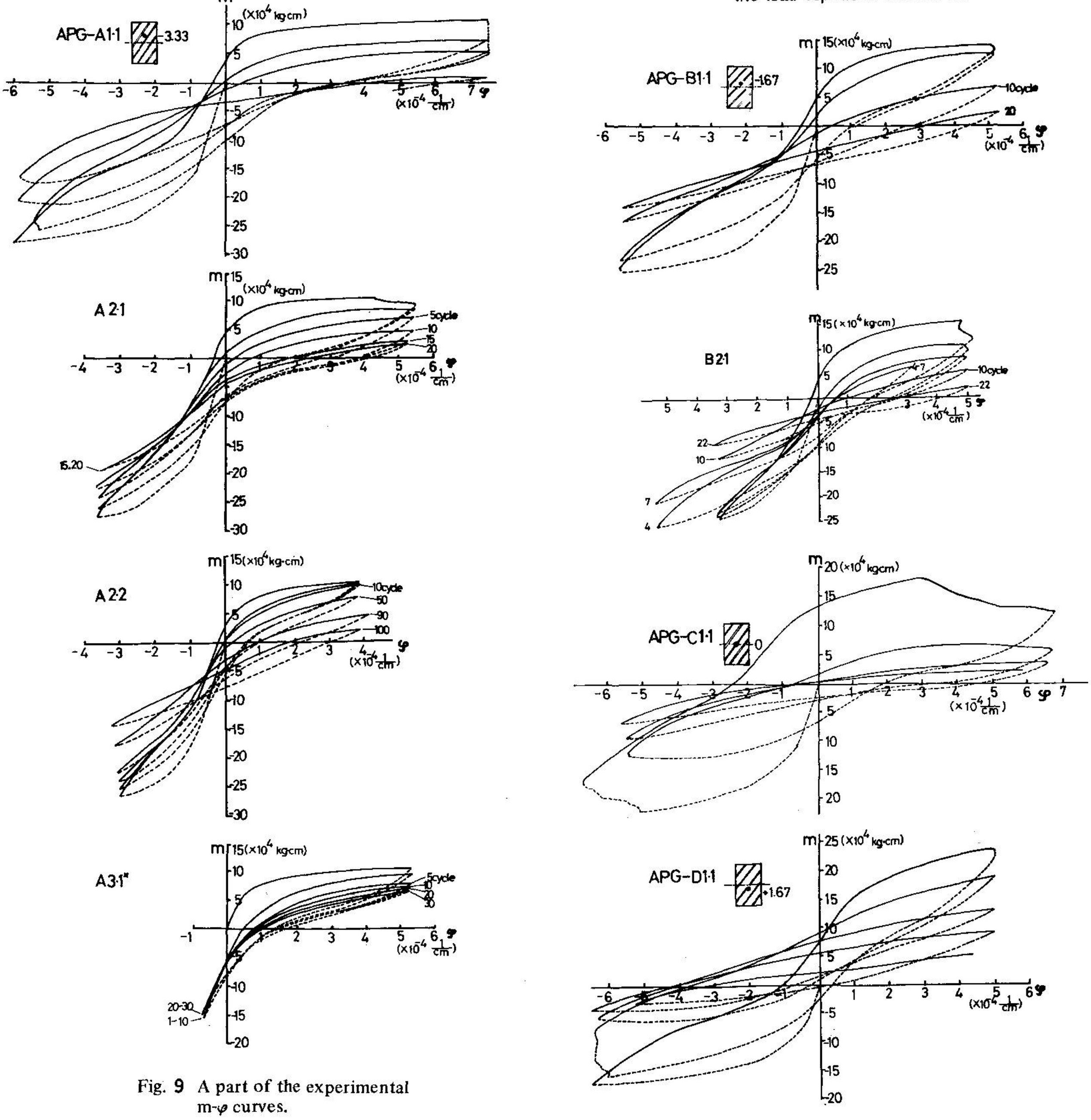

Fig. 9 A part of the experimental m-φ curves.