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

Band: 13 (1973)

Artikel: Local bond stress-slip relationship under repeated loading

Autor: Morita, Shiro / Kaku, Tetsuzo

DOI: https://doi.org/10.5169/seals-13771

IV

Local Bond Stress-Slip Relationship under Repeated Loading

Relation tension/glissement dans les attaches locales soumises à des charges répétées

Lokale Haftspannung/Gleitung-Beziehung unter wiederholter Belastung

Shiro MORITA
Associate Professor
Dept. of Architectural Engrg.

Tetsuzo KAKU
Research Associate
Dept. of Architectural Engrg.

Kyoto University, Japan

1. Introduction

It is well known that the bond deterioration between steel and concrete is a significant factor influencing the behavior of reinforced concrete structures under actions of repeated working loads, and also reversed cyclic overloads expected from strong motion earthquakes [1]. Though many studies have shown the stiffness deterioration characteristics of reinforced concrete members under cyclic loading, in most cases the influences of the bond deterioration on the behavior have not been studied extensively.

The ultimate objective of this investigation is to determine the analytical method for predicting the role of bond in the behavior of reinforced concrete structures under load reversals, on the basis of the experimentally determined basic law of bond deterioration. In this investigation reported herein the effect of the load history on the local bond-slip relation was studied from the pull- and push-out tests of the specimens having reinforcing steel bonded to concrete in a short length. Using the derived law of bond-slip, bond stress distribution along reinforcement in axially reinforced concrete prisms subjected to cyclic loads was calculated to explain the mechanism of hysteretic load-deformation curves of reinforced concrete members.

2. Experimental Study on the Local Bond-Slip Relationship

The hypothesis that the steel stress or strain distribution along reinforcement embedded in concrete can be determined from the basic law of local bond stress-slip relationship, has been confirmed by many researchers. Though it is difficult to measure not only local bond stress but also local slip, several test methods have been successfully developed [2,3]. In this study, the method introduced by Rehm [2] was used to various loadings including load reversals.

Test Specimen As shown in Fig. 1, five reinforcing bars for bond tests were embedded in a short reinforced concrete beam at right angles to its axis and were held in a virtical position at concrete casting. Each bar was contacted effectively with concrete in the

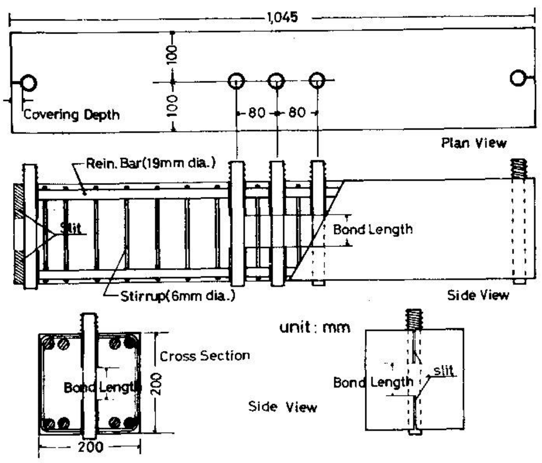


Fig. 1. TEST SPECIMEN

bond length of two times the pitch of transverse ribs. The bond zone was located at midheight of the beam to avoid the influence of the flexural stress of the beam. Since the bond zone for three bars at the central part of the beam was located deeply inside the concrete block, high bond stress was expected with the increase of the local slip. Test series of these bars was refered to as "Series A". On the other hand, two bars at the beam ends were located near the concrete surface, and serious damage of bond due to the formation of a longitudinal crack along the bar was expected at large slip levels. Slits were provided for concrete cover at the outside of the bond zone of these two bars; otherwise concrete cover at these parts might resist together to the wedging action of the bar within the bond zone. Test series of these bars embedded at the beam ends was refered to as "Series B". The nominal dimensions of the test specimen are indicated in Fig. 1. Deformed bars of 19 and of 25mm diameter were used in the tests and the bond length of 48mm for 19mm diameter bars, and of 66mm for 25mm diameter bars was provided. The depth of concrete cover for bars in Series B was held constant at 20mm. The concrete was a blend of Portland cement (1 part), river sand (2 parts) and river gravel (3 parts) with a maximum size of 20 mm. Water-cement ratio was 53% and the concrete strength f_c' at the time of loading tests (at 41 to 76 days after casting) varied from 305 to 347 kg/cm^2. Loading tests were performed on 18 bars of 25mm diam. and 12 bars of 19mm dia. in Series A, and on 8 bars of 25mm diam. in Series B.

<u>Test Setup</u> Loads were applied by Instron type testing machine of ±50 ton maximum capacity to the threaded end of the bar. Fig. 2 shows the loading arrangement for both series; the reinforced concrete beam acted as a simply supported beam in Series A and as a cantilever beam in Series B. Slip of the bar at the free end was measured by a differential transformer and cross-head speed of testing machine was controlled mostly at 1.0 mm/min. The out-put of the load cell and the output of end slip were fed into the X-Y recorder of the testing machine.

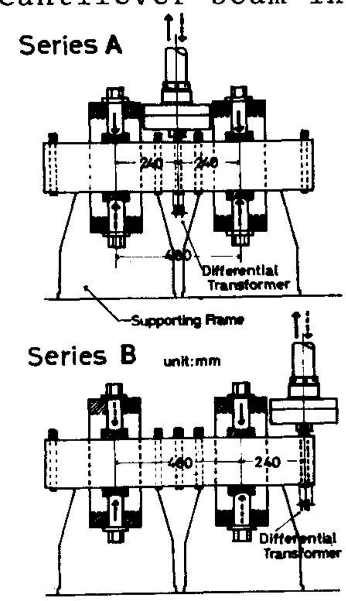


Fig. 2. LOADING ARRANGEMENT

<u>Load Histories</u> The influence of various load histories on the bond-slip behavior was examined. In every loading histories the direction of loading was also a significant factor. Therefore, the upward direction (bar in tension) was defined as positive and downward (bar in compression) as negative. Selected loading histories were assorted as follows;

MN··· Monotonic loading to failure.
RP··· Repeated loading in one direction with an additional slip in each cycle.
RV··· Reversed (bi-directional) loading with an additional slip in each cycle.
RL··· Cyclic reversed loading between constant load limits.

RS··· Cyclic reversed loading between constant slip limits. In these tests the slip limits were increased mostly after 10 cycles of the previous slip range.

RR··· Repeated or reversed loading in a randum manner in order to confirm the derived basic bond-slip law.

Designation of Test Specimen For example, the notation A 25-6-RS indicates the following characteristics.

A: Test Series A 25: Bar diameter of 25mm
6: Number of the bar RS: Load history RS

Test Results Under the assumption that bond stress distributes uniformly along the bar axis within the bond zone, the local average unit bond stress and the local average slip could be obtained from the test data. Because the differences between the free end slip and the average slip were negligibly small even at a high stress level, the experimentally obtained end slip was assumed to be equal to the local slip without modification. From the above mentioned approximation, each experimental curve was transformed to the local bond-slip curve.

In Fig. 3, the bond-slip curves under monotonic loading in either direction are shown. Each one represents the average curve of the results obtained on the specimens having the same characteristics. Fig. 3 shows that the loading direction gave a significant influence on the slope of the bond-slip curve at a relatively low bond stress level, and that a marked reduction in the maximum bond stress and a gradual decrease of bond stress with the further increase of slip were produced in Series B as expected.

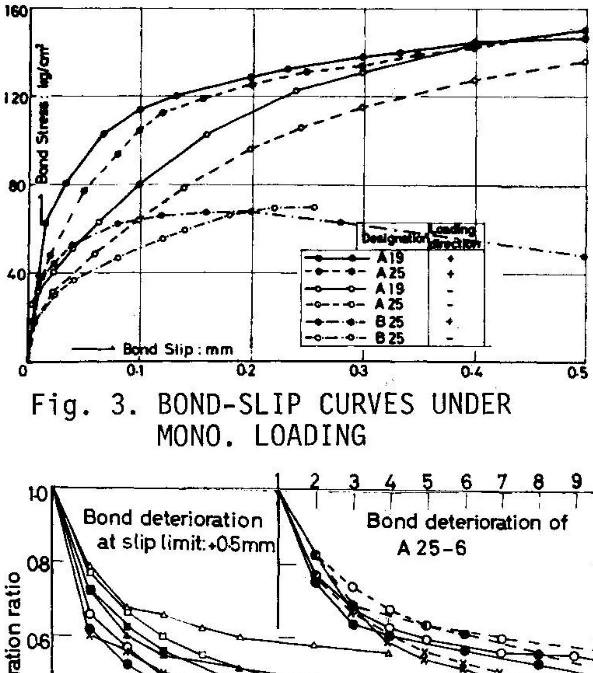


Fig. 3. BOND-SLIP CURVES UNDER MONO. LOADING

Typical test results of the bond stress-slip relationship under load repetitions or reversals are shown by solid lines in Fig. 4 (a)-(g). It could be pointed out as the general characteristics throughout the test results that a small number of repetition within a limited slip range did not give a significant effect on the bond-slip behavior at a larger slip than the peak slip in the previous cycles and, on the other hand, once the peak slip was increased, a considerable reduction in bond was produced at a lower slip in the subsequent load history. These behaviors were also indicated in the previous studies [4.5]. Fig. 5 shows the bond deteration due to cyclic loading between limit slips. In this figure the ratio of the peak bond stress at each of successive cycles to that at the first cycle ("bond deterioration ratio") was plotted against number of cycles. Fig. 5 indicates that parameters, such as bar diameter, the loading direction, the previous loading history within a lower

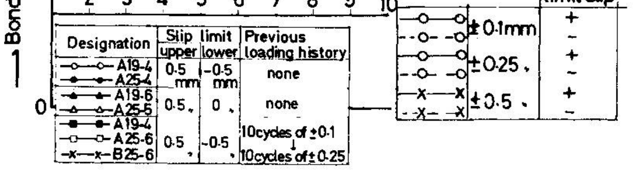
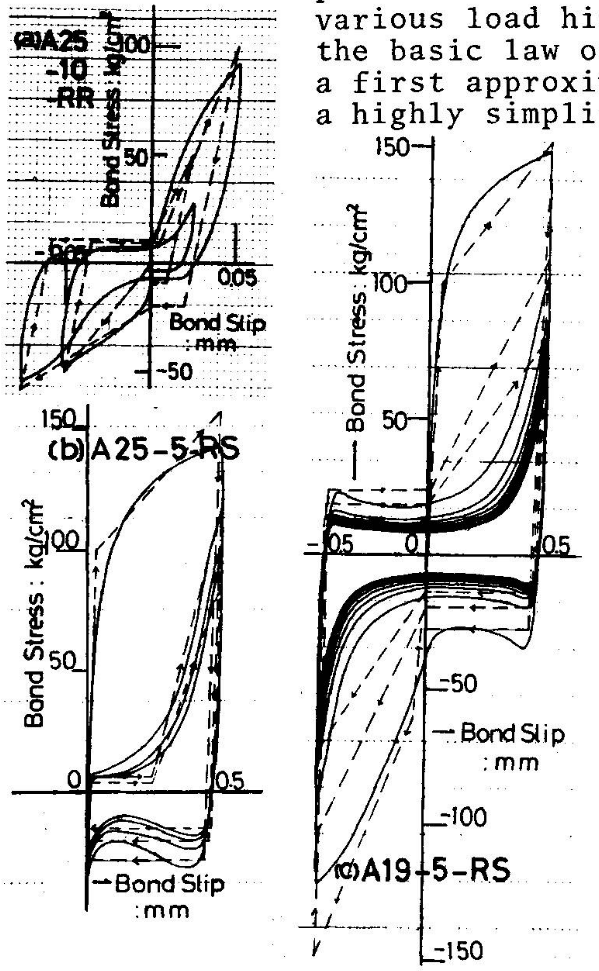


Fig. 5. THE BOND DETERIORATION RATIO (RS Tests)

Slip limit and the magnitude of slip limit, did not give any sensitive influences upon the bond deterioration ratio.

3. The Bond-Slip Law under Repeated Loading

From the experimental results of the bond-slip behavior under various load histories, it was attempted to derive the basic law of local bond-slip relationship. As a first approximation at this phase of the study, a highly simplified law was presented.



Envelope Curve The envelope curve was defined as the bond-slip curve obtained under monotonic loading to failure and approximated by the bi-linear relationship as shown in Fig. 6 within the slip range of ± 0.5mm.

Unloading and Reversed Loading Curves The assumed law for these curves is schematically explained in Fig. 7. The stiffness K_3 of linear unloading and the coefficients α and β_x, which define the magnitude of bond deterioration, were determined on the basis of the test results. The values of K_3, α and β_x were the following;

$$K_3 = 4 \cdot 10^4 \text{ kg/cm}^3 \quad (1)$$

$$\alpha = 0.18 \quad (2)$$

$$\beta_x = \begin{cases} 0.9 & \text{for } S_x < 5 \cdot 10^{-3}\text{cm} \\ 0.9 - 4.44\,(S_x - 5 \cdot 10^{-3}) & \text{for } 5 \cdot 10^{-3}\text{cm} < S_x < 5 \cdot 10^{-2}\text{cm} \end{cases} \quad (3)$$

where S_x in Eq.(3) indicates the slip value of the point x from which unloading is started.

Applying the law shown in Fig. 7 repeatedly, the bond-slip response

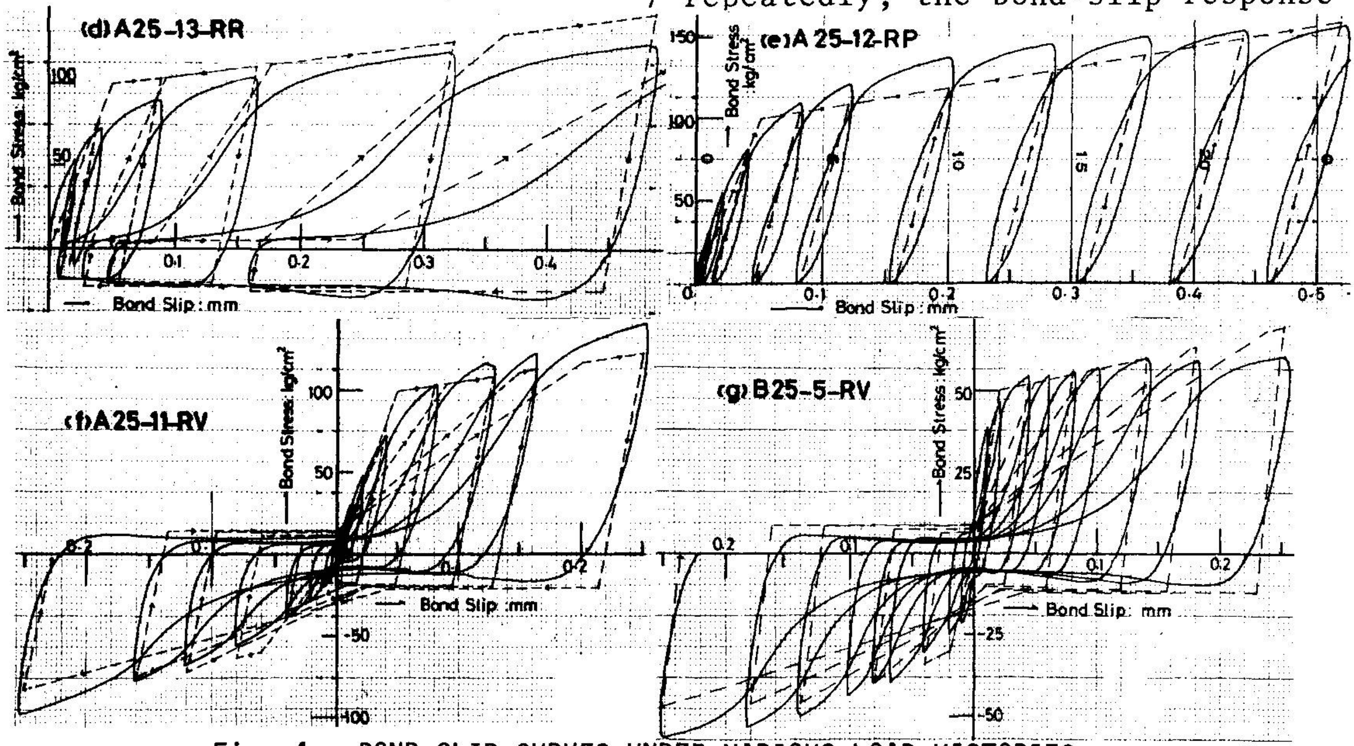
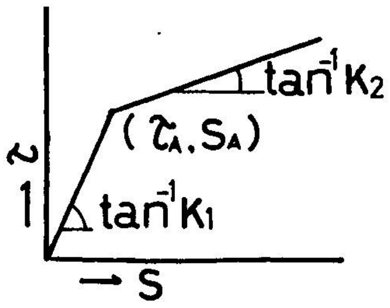


Fig. 4. BOND-SLIP CURVES UNDER VARIOUS LOAD HISTORIES

could be computed for the slip histories imposed to each specimen. These curves are shown in Fig. 4 by broken lines along with the experimental curves. The agreement of both curves seems to be fairly well. However, in the case of the cyclic loading tests between constant slip limits (Fig. 4(b),(c)), the bond deterioration at the peak slip is overestimated with the increase of the number of cycles. The main reason of this is that the coefficient β_X given by Eq.(3) varies not only with the slip S_X at the start of unloading, but also with the number of cycles. The law of bond-slip behavior assumed in this study must be improved in the advanced phase of the study.

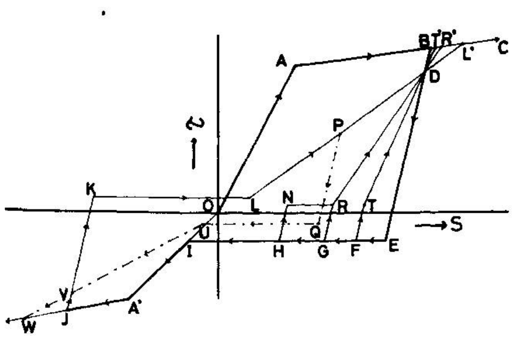
4. Application of the Basic Law of Bond-Slip



Test series	Loading direction	τ_A kg/cm²	S_A mm	K_1 x10³kg/cm³	K_2 x10²kg/cm³
A	+	100	0.05	2.0	1.10
	-	60	0.06	1.0	2.05
B	+	50	0.02	2.5	0.83
	-	30	0.02	1.5	1.94

Fig. 6. APPROXIMATION OF ENVELOPE CURVES

As the typical examples, the behaviors of the ordinary pull-out specimen and the tension specimen under repeated loading were calculated. Assuming that the axial stress in concrete distributes uniformly in a cross section and the shear deformation can be neglected, the distributions of local slip, bond stress and steel stress were calculated as a one-dimensional problem. An iterative method was used by dividing the embedded length of the bar into short elements (15 elements of equal length for the pull-out specimen and 20 for the tension specimen). Fig. 8 shows the applied load versus end slip curve of the pull-out specimen of which the dimension also shown in the figure. In this example, the envelope curve in the positive direction of Series A was used in both directions. It is noteworthy that the response of the typical hardening type can be seen under the action of load reversals between excessive slip limits. Fig. 9 shows that the hysteretic behavior of the tension specimen, similar to the results of previous studies [3,4], can be predicted on the basis of the local bond-slip law. It should be noted in this example that tensile stress transfered to concrete is enough to form a crack at the midspan at 5 ton or the less, but the formation of crack is not considered throughout the opposed history.



$\tau_D = \beta_B \tau_B$ $S_D = S_B - (1-\beta_B)\tau_B/K_3$ $\tau_E = \tau_F = \tau_G = \tau_H = \tau_I = -\alpha\tau_B$

$S_E = S_B - (1+\alpha)\tau_B/K_3$ $S_G = S_B/2$ $\tau_T = \tau_R = \tau_N = -\alpha\tau_E$

$S_R = S_B/2 - (1+\alpha)\tau_G/K_3$ $S_T = S_F - (1+\alpha)\tau_F/K_3$ $\tau_K = -\alpha\tau_J$

$S_N = S_H - (1+\alpha)\tau_H/K_3$ $S_K = S_J - (1+\alpha)\tau_J/K_3$ $S_L = (S_B + S_J)/2$

$S_Q = S_P - (1+\alpha)\tau_P/K_3$ $S_V = S_J - (1-\beta_J)\tau_J/K_3$ $S_U = (S_J + S_P)/2$

$\tau_Q = -\alpha\tau_P$ $\tau_V = \beta_J \tau_J$ β_B and β_J are given from Eq.(3)

Example to follow the law of loops.

Consider that unloading is started at an arbtrary point(τ,S) lying on the curve(E I A'W).

Range of S at unloading point	Example of subsequent route
$S_E > S > S_G$	F→T→D→T'→C
$S < S_G$ and $S_R < (S+S_B)/2$	H→N→R→D→R'→C
$S < S_G$ and $S_R > (S+S_B)/2$	J→K→L→D→L'→C

Fig. 7. BASIC BOND-SLIP LAW

5. Conclusions

The following conclusions were obtained; (1) The deterioration of local bond depends on the magnitude of the previous maximum local slip, and the larger the previous slip the greater is the reduction in bond stress at lower slip levels. (2) The deterioration of peak bond stress under cyclic loading between constant slip limits is rather moderate as shown in Fig. 5.

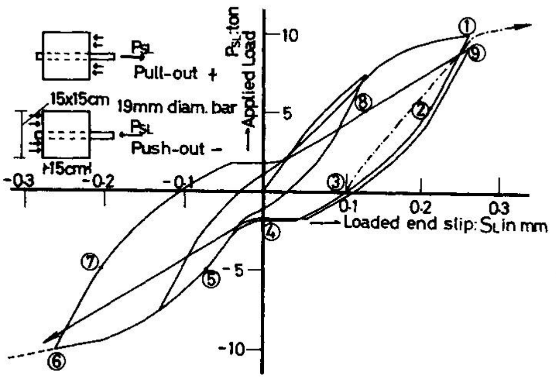


Fig. 8. COMPUTED BEHAVIOR OF THE PULL-OUT SPECIMEN

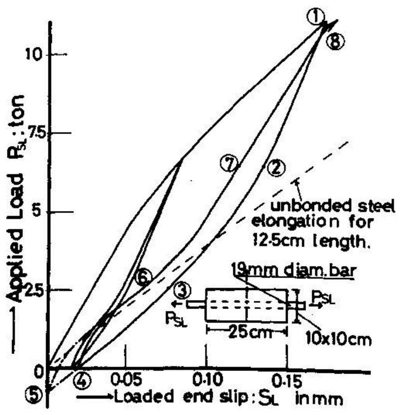


Fig. 9 COMPUTED BEHAVIOR OF THE TENS. SPECIMEN

(3) The proposed model of the local bond-slip law provides a satisfactory agreement with the test results under various load hystories.
(4) The load-deformation characteristics of reinforced concrete members can be predicted by use of the basic law.

[References]

[1] Bertero, V., and Bresler, B.,"Seismic Behavior of Reinforced Concrete Framed Structures", Proceedings of 4th WCEE, Chile, 1969, Vol.1.

[2] Rehm, G., "Über die Grundlagen des Verbundes zwischen Stahl und Beton", Deutscher Ausschuss für Stahlbeton, H.138, 1961

[3] Morita, S., et al, "Fundamental Study on Bond between Steel and Concrete", Trans. of the A.I.J. No.131, 132, 134 & 139, 1967.

[4] Bresler, B., and Bertero, V., "Behavior of Reinforced Concrete under Repeated Load" Proc. of the ASCE, ST 6, June, 1968.

[5] Ismail, M., and Jirsa, J., "Bond Deterioration in Reinforced Concrete Subjected to Low Cycle Loads", ACI Journal, Proc. Vol.69, No.6, June, 1972.

SUMMARY

The effect of the load histories on the local bond-slip relationship was studied from the pull- and push-out tests of reinforcing bars effectively contacted with concrete in a short length. From the test results the basic bond-slip law was derived and applied successfully to the prediction of the behavior of reinforced concrete members under load reversals.

RESUME

On a étudié l'influence du processus de charge sur la relation entre la liaison locale et le glissement de fers d'armature en contact avec le béton sur une petite longueur au moyen d'essais d'extraction et d'essais d'enfoncement.

De ces essais ou a dérivé la loi de base liaison-glissement et elle a été appliquée avec succès pour l'étude du comportement d'éléments en béton armé soumis à des inversions de charges.

ZUSAMMENFASSUNG

Der Einfluss der Belastungsarten auf das lokale Haft-Schlupf-Verhalten wurde anhand von Zug- und Hinausdrück-Versuchen an Armierungsstäben untersucht, deren Verbund mit dem Beton nur auf eine kurze Strecke gewährleistet war. Von den Versuchsresultaten wurde das grundlegende Haft-Schlupf Gesetz abgeleitet und erfolgreich zur Voraussage des Verhaltens von Stahlbetonteilen unter Lastumkehr angewendet.

Leere Seite
Blank page
Page vide