Creep effects in some arch and cantilever bridges

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Creep Effects in some Arch and Cantilever Bridges

Effets du fluage sur quelques ponts en arc et en encorbellement

Kriechwirkungen in einigen Bogen- und Freivorbaubrücken

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1 – INTRODUCTION

The techniques followed by the Laboratório Nacional de Engenharia Civil for the observation of structures, mainly bridges and dams, have been published at several instances (1 to 6). The present paper simply calls the attention to the techniques used for the measurement of strains and stresses, particularly taking into account the effects of creep.

For the accurate measurement of strains and stresses in reinforced and prestressed concrete structures accoustic strain gauges embedded in the concrete are used. These strain gauges have cylindrical body and heads and total lengths varying between 21 and 34 cm. They yield accuracies of the order of 5×10^{-6}. (4)

When measuring strains the main difficulty consists in distinguishing the part due to stresses from the part due to shrinkage and temperature. Also the evolution of the mechanical properties with time - creep effect - is in general difficult to follow and to interpret. In order to overcome this difficulty the strain gauges are embedded in the structure at three different conditions: i) active gauges, ii) compensating gauges and iii) controlled gauges, fig. 1.

The active gauges measure the total strains in the structure. The compensating gauges are introduced inside double wall cylindrical boxes, built of thin copper sheet. Thus they are subtracted from the action of stresses. The controlled gauges are also inserted into similar double wall cylindrical boxes. However metallic cushions filled with oil placed at the top of the boxes allow to apply known stresses on the concrete cylinders where the strain gauges are embedded. By controlling the pressure of the oil in the cushion, mechanical tests of the concrete inside the structure, particularly creep tests, can be performed.

By the simultaneous use of an active and a controlled gauge it is even possible to perform a direct measurement of stresses, not involving the knowledge of the mechanical properties of the concrete. In fact, if the pressure of the oil in the cushion is varied in such a way that the strains indicated by both the active and the controlled gauges are permanently equal, the pressure applied corresponds without further corrections to the existing stresses.

In practice instead of varying the pressure on the controlled gauge it is preferable to apply a constant pressure, which corresponds to performing a creep test. This procedure, as compared with the usual technique of performing creep tests in the laboratory, has the great advantage that a very close similitude between the conditions around the active and the controlled gauge is automatically obtained. In this way, the creep corrections to be introduced in the active gauges can be very accurately computed. Thus the overall accuracy of the results is great, as shall be seen.

In order to reach this high accuracy, the thermal and hygrometric conditions around the active, the compensating, and the controlled gauges must be as similar as possible. Consequently, in the case of structures formed by walls, the cylindrical boxes indicated above are substituted by simple thermal and hygrometric insulations, as indicated in fig. 2.

2 – RESULTS OF TESTS

Figs. 3 to 5 show the results of creep tests performed in three bridges: two arch bridges and a prestressed cantilever bridge. These creep tests refer to controlled gauges and were run during periods varying from 500 to 2000 days.

The creep tests at Abreiro bridge were performed from 1956 to 1958, during 900 days, by applying a constant stress of 45 kgf/cm^2, fig. 3.

The creep tests at Arrabida bridge were performed in 1962 and 1963, during 500 days, by applying a constant stress of 80 kgf/cm^2, fig. 4. The measurement of strains and displacements is still being continued at the present date. However the creep tests were discontinued in 1963 due to rupture of the metallic cushions of the controlled gauges.

The creep tests at the north viaduct of the Tagus River bridge started in 1964 and are still in progress. The results presented refer to a period of about 2000 days. The stress applied is 100 kgf/cm^2, fig. 5.

Fig. 6 indicates the results obtained by a group of strain gauges at section S of one arch of Arrabida Bridge. As can be seen the creep test was performed at a stress near to the one due to the applied loads.

The diagrams of the evolution of strains, shrinkage and creep in the prestressed viaducts of the Tagus River bridge are presented in (6).

Table I indicates for the different bridges: the mean value of the resistance of the concrete at 28 days, obtained by testing 20 cm cubes; the instantaneous modulus of elasticity; the creep coefficient corresponding to 500 days, φ_e; and the 500 days modulus of elasticity, obtained by dividing the instantaneous modulus of elasticity by $1 + \varphi_e$.

The creep coefficient relates the strains due to creep ε_f, with the instantaneous ones due to the applied stress, ε_o. Linear creep is thus assumed.

The number of compression tests performed, from which the indicated mean values were computed, varied from about 20 in the case of Abreiro bridge to several hundred in the case of Arrabida bridge.

It is interesting to compare the results presented in Table I with those that would be obtained by using the expressions recommended by FIP-CEB (7).

Assuming that the experimental modulus of elasticity, E_e, corresponds to the secant modulus, E_s, as defined by FIP-CEB, R12, 222 and that this last one is 10% lower than the tangent modulus, E_t; adopting expression

$$E_t = 21000 \sqrt{R'_b}$$

where R'_b is the resistance in cylinders expressed in kgf/cm^2; and further taking this resistance as 0.85 of the resistance in cubes R'_{bc}; it comes

$$E_s = 0.9 \times 21000 \sqrt{0.85\, R'_{bc}} = 17500 \sqrt{R'_{bc}}$$

The values of E_e, E_s and E_s/E_e are indicated in Table II.

For Arrabida and Tagus River bridges the computed values differ respectively plus and minus 8% from the experimental ones. In case of Abreiro bridge the computed value is 36% higher than the experimental one. It must be referred that in this case the modulus of elasticity considerably increased in time and reached the mean value of 2.7×10^5 kgf/cm^2 at the age of 300 days.

As regards creep, FIP-CEB Recommendations give the creep coefficient φ_t by the product of 5 coefficients

$$\varphi_t = k_c\, k_d\, k_b\, k_e\, k_t$$

which, respectively, consider

k_c - relative humidity of the air
k_d - age at loading
k_b - amount of cement and water/cement ratio
k_e - fictitious thickness
k_t - time and fictitious thickness.

For the cases under consideration these coefficients take the values indicated in Table II and lead to the values φ_t also indicated in the same table. The agreement between computed and measured values is very good for Arrabida and Tagus River bridges and poor for Abreiro bridge. Attention is called to the fact that in this case the coefficient k_t (influence of time) takes a very low value due to the great thickness of the arch, about 100 cm.

In all the cases, the stresses at different sections of the bridges were computed by using the results of the active gauges, duly compensated by the controlled gauges.

In Abreiro bridge, the accuracy with which it was possible to compute the stresses was fairly good. However, due to technique improvements this accuracy was considerably increased in Arrabida and Tagus River bridges.

For instance, in the case of Arrabida bridge the axial forces computed from the measured stresses satisfy the conditions of equilibrium with a mean error of 2% and maximum errors of about 4% . In this bridge a total of 214 gauges were used to determine stresses at 8 sections. It is interesting to note that due to creep there was an important evolution of the bending moments in the sections of the arches. The evolution in time of the displacements agrees with the measured evolution of strains.

As is well known, creep effects are very important in cantilever prestressed concrete bridges. The measurements performed at the Tagus River bridge allowed an understanding of the general behaviour of the structure and contributed to an accurate forecasting of the evolution of the cantilever displacements in time.

3 – CONCLUSIONS

For studying the behaviour of reinforced and prestressed concrete structures accurate measurement of strains and stresses is needed. The measurement of stresses is particularly difficult due to creep effects.

Thus, for the observation of structures, the simultaneous use of active, compensating, and controlled gauges is advisable, the last ones allowing to perform compression tests, particularly creep tests, in the structure, in just the same conditions as those under which the other gauges are operating.

The results on creep obtained at Arrabida arch bridge and at the prestressed cantilever viaduct of Tagus River bridge agree closely with the creep expression presented at the "FIP-CEB Recommendations". For Abreiro bridge the agreement is much worse.

In these three bridges the measurement of stresses was performed along several years with high accuracy. The verification of equilibrium conditions allowed to check this accuracy.

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TABLE I

BRIDGE	28 DAYS MEAN RESISTANCE R_{bc} (kgf/cm²)	INSTANTANEOUS MODULUS OF ELASTICITY E_e (kgf/cm²)	500 DAYS CREEP COEFFICIENT φ_e –	500 DAYS MODULUS OF ELASTICITY E_{500} (kgf/cm²)
ABREIRO	$3.0 \ 10^2$	$2.2 \ 10^5$	0.80	$1.2 \ 10^5$
ARRABIDA	$5.6 \ 10^2$	$3.8 \ 10^5$	0.75	$2.2 \ 10^5$
TAGUS RIVER	$3.9 \ 10^2$	$3.7 \ 10^5$	1.72	$1.4 \ 10^5$

TABLE II

BRIDGE	MODULUS OF ELASTICITY			CREEP COEFFICIENT		
	MEASURED E_e (kgf/cm^2)	COMPUTED E_s (kgf/cm^2)	COMPUTED / MEASURED E_s/E_e —	MEASURED φ_e —	COMPUTED $k_c\ k_d\ k_b\ k_e\ k_t = \varphi_t$ —	COMPUTED / MEASURED φ_t/φ_e —
ABREIRO	$2.2\ 10^5$	$3.0\ 10^5$	1.36	0.80	$2.3 \times 0.8 \times 1.0 \times 0.7 \times 0.2 = 0.3$	0.4
ARRABIDA	$3.8\ 10^5$	$4.1\ 10^5$	1.08	0.75	$2.1 \times 0.7 \times 0.9 \times 0.75 \times 0.7 = 0.7$	0.93
TAGUS RIVER	$3.7\ 10^5$	$3.4\ 10^5$	0.92	1.72	$2.3 \times 1.0 \times 1.4 \times 0.75 \times 0.7 = 1.7$	0.98

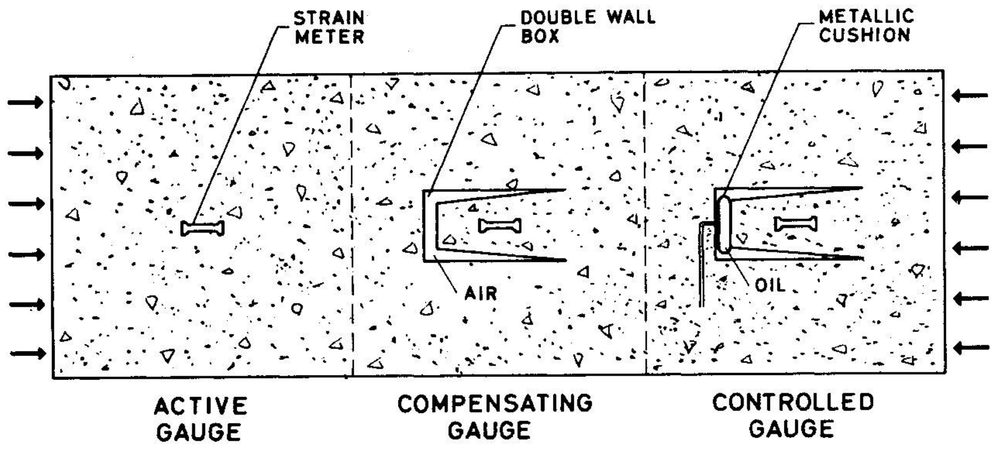
STRAIN METER
DOUBLE WALL BOX
METALLIC CUSHION
AIR
OIL
ACTIVE GAUGE
COMPENSATING GAUGE
CONTROLLED GAUGE

Fig. 1

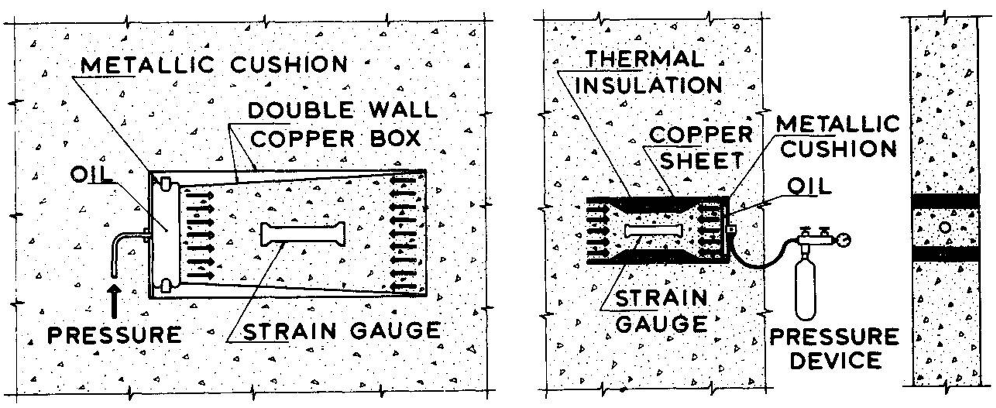
METALLIC CUSHION
DOUBLE WALL COPPER BOX
OIL
PRESSURE
STRAIN GAUGE
THERMAL INSULATION
COPPER SHEET
METALLIC CUSHION
OIL
STRAIN GAUGE
PRESSURE DEVICE

Fig. 2

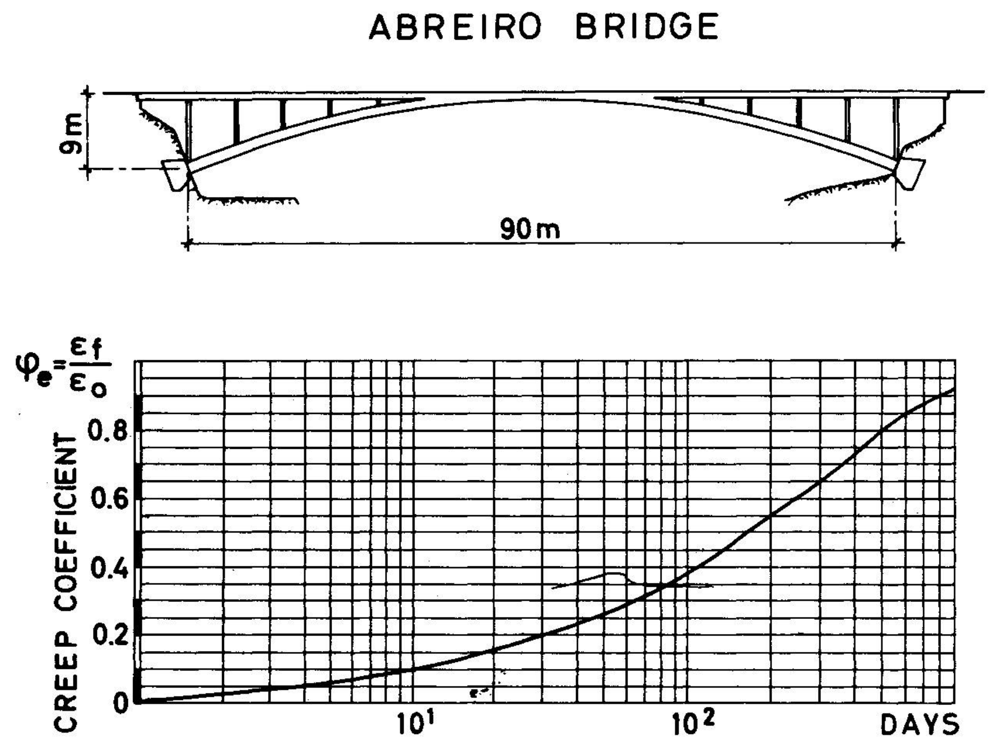
ABREIRO BRIDGE
9m
90m
$\varphi_e = \frac{\varepsilon_f}{\varepsilon_o}$
CREEP COEFFICIENT
0.8
0.6
0.4
0.2
0
10^1
10^2
DAYS

Fig. 3

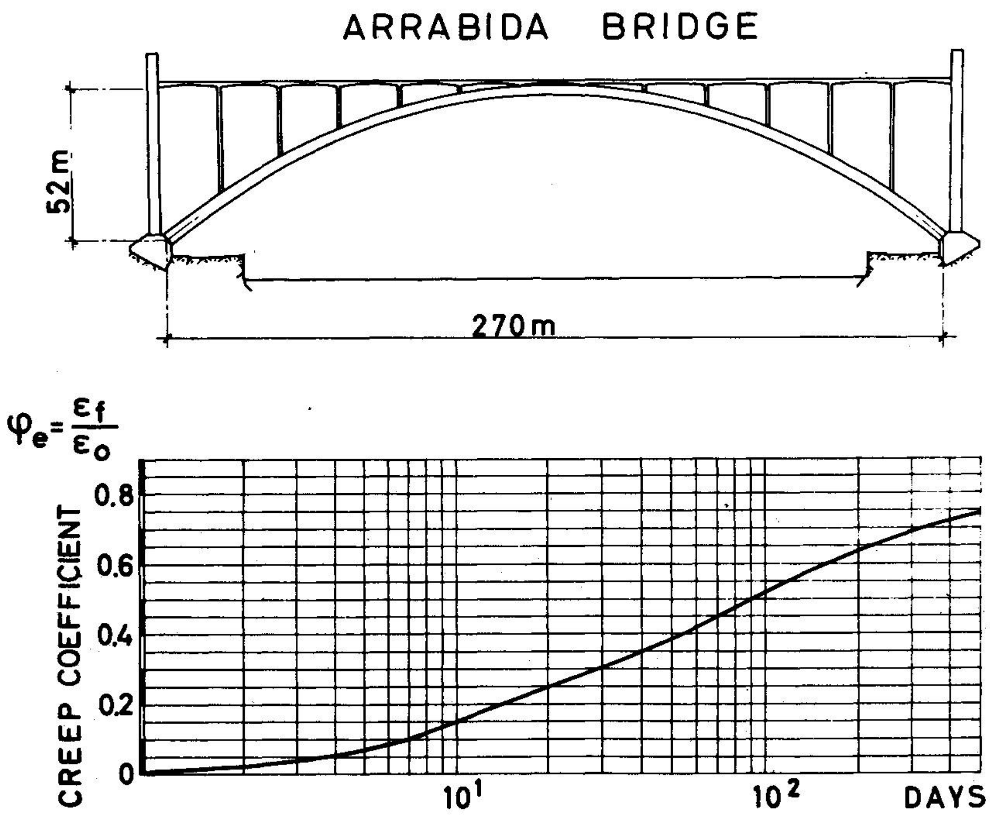
ARRABIDA BRIDGE
52m
270m
$\varphi_e = \frac{\varepsilon_f}{\varepsilon_o}$
CREEP COEFFICIENT
0.8
0.6
0.4
0.2
0
10^1
10^2
DAYS

Fig. 4

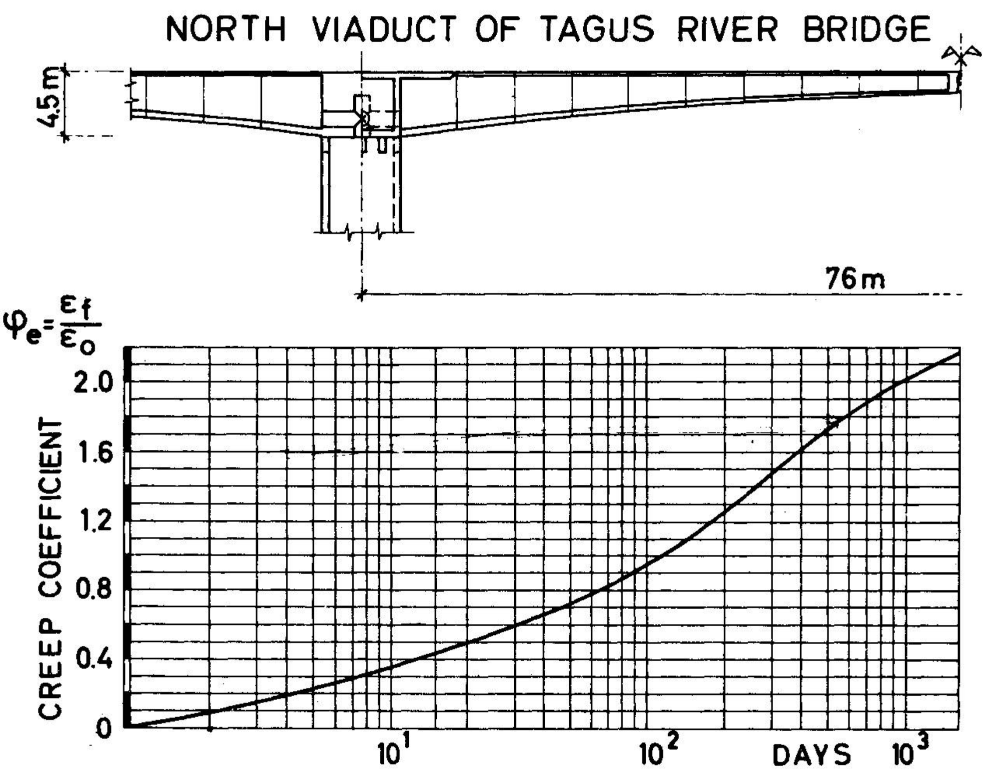
NORTH VIADUCT OF TAGUS RIVER BRIDGE
4.5m
76m
$\varphi_e = \frac{\varepsilon_f}{\varepsilon_o}$
CREEP COEFFICIENT
2.0
1.6
1.2
0.8
0.4
0
10^1
10^2
DAYS
10^3

Fig. 5

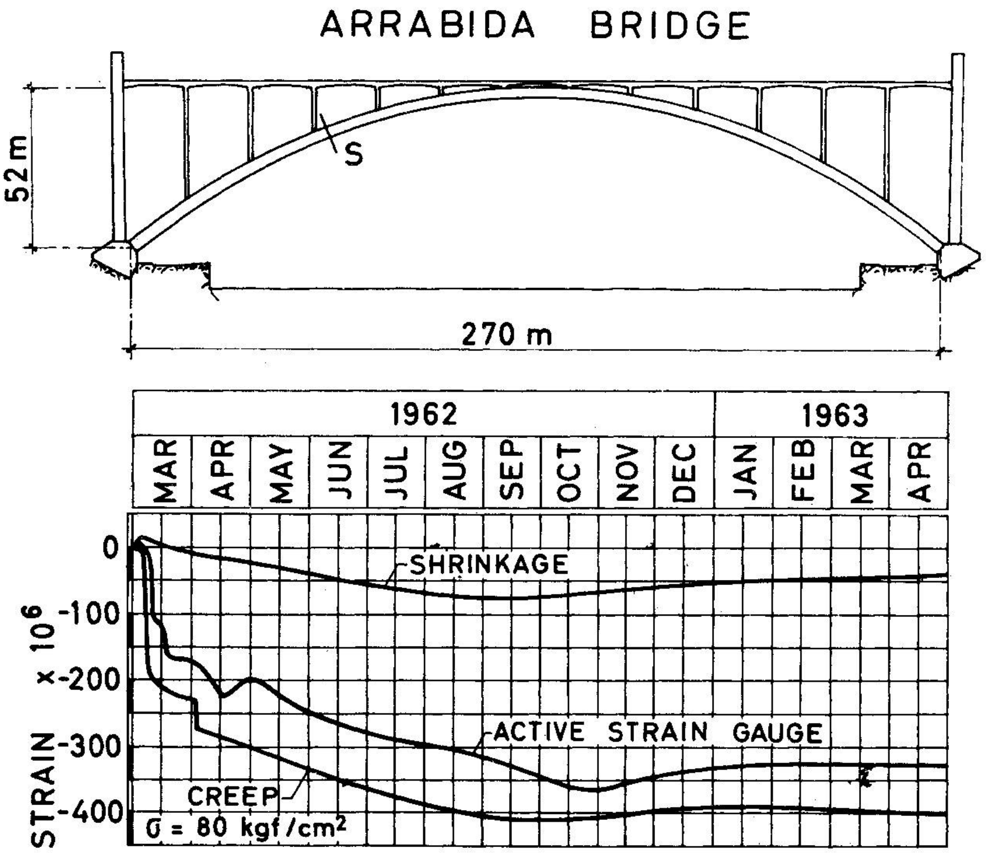
ARRABIDA BRIDGE
S
52m
270 m
1962
1963
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
0
-100
-200
-300
-400
STRAIN $\times 10^6$
SHRINKAGE
ACTIVE STRAIN GAUGE
CREEP
σ = 80 kgf/cm²

Fig. 6

SUMMARY

The techniques followed at LNEC, Lisbon, for the in situ measurement of strains and stresses in reinforced concrete structures are briefly described.

The results of creep tests performed in three bridges are presented and interpreted.

Attention is called to the advantages of performing creep tests in the bridges using controlled gauges.

RESUME

On décrit sommairement les techniques suivies au LNEC pour mesurer in situ les déformations et les contraintes des ouvrages en béton armé.

Les résultats des essais de fluage effectués sur trois ponts sont présentés et interprétés.

On souligne les avantages d'effectuer des essais de fluage à l'aide d'extensomètres contrôlés.

ZUSAMMENFASSUNG

Es werden die Verformungs- und Spannungsmessungstechniken kurz beschrieben, die im LNEC, Lissabon, für Ortsmessungen angewandt werden.

Die an drei Brücken durchgeführten Kriechversuche werden dargestellt und ausgewertet.

Es werden auch die Vorteile hervorgehoben, die sich aus mit kontrollierten Dehnungsmessern durchgeführten Kriechversuchen ergeben.