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DISCUSSION PRÉPARÉE / VORBEREITETE DISKUSSION / PREPARED DISCUSSION

Experimental Observations of Prestressed Structures with Reference to Long-Term Deformations

Observations expérimentales des déformations de longue durée sur des structures de béton précontraint

Beobachtungen an Spannbetonkonstruktionen in bezug auf Langzeitverformungen

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I. FOREWORD

In calculating prestressed concrete structures in Italy consideration is generally given to constant creep and shrinkage values, which the standards indicate as a minimum. In any case, these values are not related to the intrinsic characteristics of the concrete and structure nor to the environmental conditions under which the structure will be operating. When the slow deformations of the concrete considerably surpass the predicted standard values, the damage to the structure's serviceability might be of importance.

Here below are described two prestressed concrete structures whose abnormal deflections produced by the permanent and service loadings has made it necessary to undertake some experimental tests. This study has revealed the predominant importance of the slow deformation phenomena of the concrete in determining directly and indirectly (through large losses of prestress) the abnormal deflections under consideration.

It should be observed that this type of investigation, begun some time after the completion of the structure, usually encounters two kinds of difficulties, namely:

a) indirect measurements (deflections and rotations, pre-existent stresses, cracking effects) or direct but overall ones (strains due to different causes) must be performed, and they greatly reduce the accuracy of the results obtained;

b) it is generally not allowed to rigorously separate the phenomena investigated (e.g., the viscous phenomena from those of shrinkage) nor to determine a "weight" to be assigned to the various influencing parameters (nature of the material, curing age at prestressing time, environmental curing conditions, constructional defects, etc.).

In view of these objective difficulties, independent experimental procedures have been developed in order to obtain,if not accurate values of the shrinkage and creep coefficients, at least possible value ranges.

2. BRADANO VIADUCT (I)

The viaduct is a post tensioned concrete structure. The cross-section is of the box type, with three webs containing the cables, and the cantilevered girders are articulated at mid-span (fig. I).

The viaduct was built in I959 and four years later particularly large deflections (8-I0 cm) of the span center lines were observed. This made it necessary to undertake an especially accurate check program:

a) leveling measurements. This were made from time to time in I959-I964 and went on systematically in I964-I968, permitting to follow the lowering with time of the span center lines with respect to the fixed sections. It should be noted that, because of the post-tensioning and permanent loadings, a rise of the crown sections had to occur at first, due to creep. This indeed happened the initial period of the structure's life, thereby confirming the correct degree of initial prestress. But thereafter, because of the slow tension losses, the bending moments of the permanent loadings prevailed and the crowns of the spans began to sink (fig. 2). Besides the considerable size of the deflections, unusual is also the speed of the sinking, which is not yet completed at I0 years after the completion of the structure (fig. 3).

b) Static and dynamic loading tests. These permitted to establish the perfectly elastic behavior of the structure under the working loads and the natural vibration frequency, which proved to be very close to the calculated one. Indications were thus obtained regarding the E_b value, shown to be about 350,000 $Kgcm^{-2}$, **at 9 years.**

Direct tests on five specimens extracted thereafter have yielded E_b values rancing from 290,000 to 350,000 $Kgcm^{-2}$ (against the predicted value of 400,000 $Kgcm^{-2}$). Ultimate load tests on the same date furnished σ'_{br}=344 $Kgcm^{-2}$ against the predicted 375 $Kgcm^{-2}$ at 28 days.

c) Evaluation of the residual prestress (σ_{ap}), in a direct way by testing the cable wires, and indirectly by tests on the stress release in the concrete. The former tests, made by cutting a steel wire, measuring its shortening and correlating it to Young's modulus as determined in laboratory, yielded the following average results (8 tests):

- at 4 years after completion of the structure σ_{ap}=82,5 $Kgcm^{-2}$
- " 5 " " " " " " σ_{ap}=72 $Kgcm^{-2}$

against the design σ_{ap} of 90 $Kgcm^{-2}$.

The indirect tests consisted in setting up 4 rosette-like strain gage bases read by a removable deformeter (fig. 4) at the intrados and extrados of the various fixed sections and then

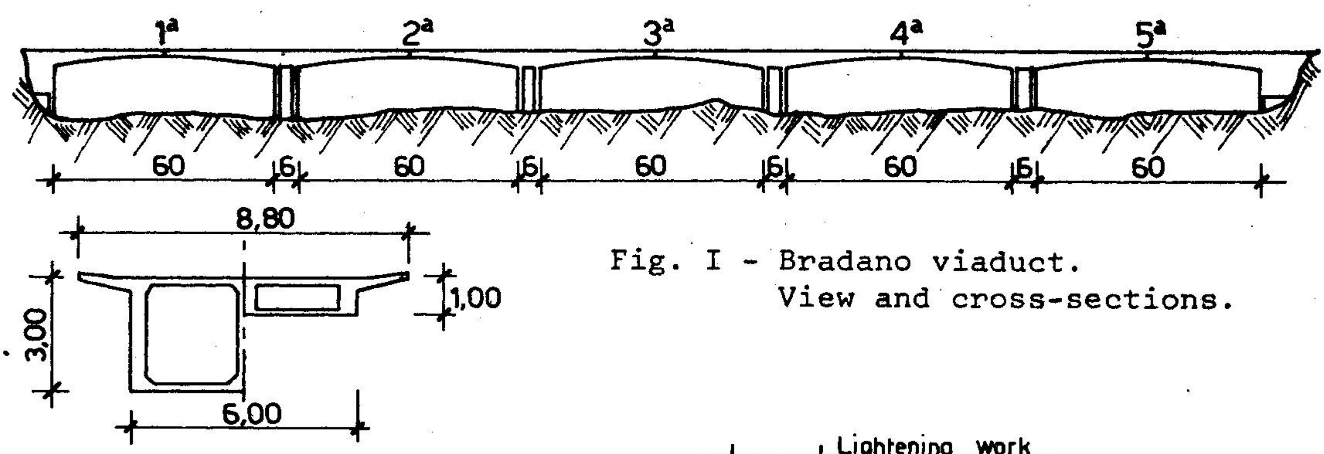


Fig. I - Bradano viaduct.
View and cross-sections.

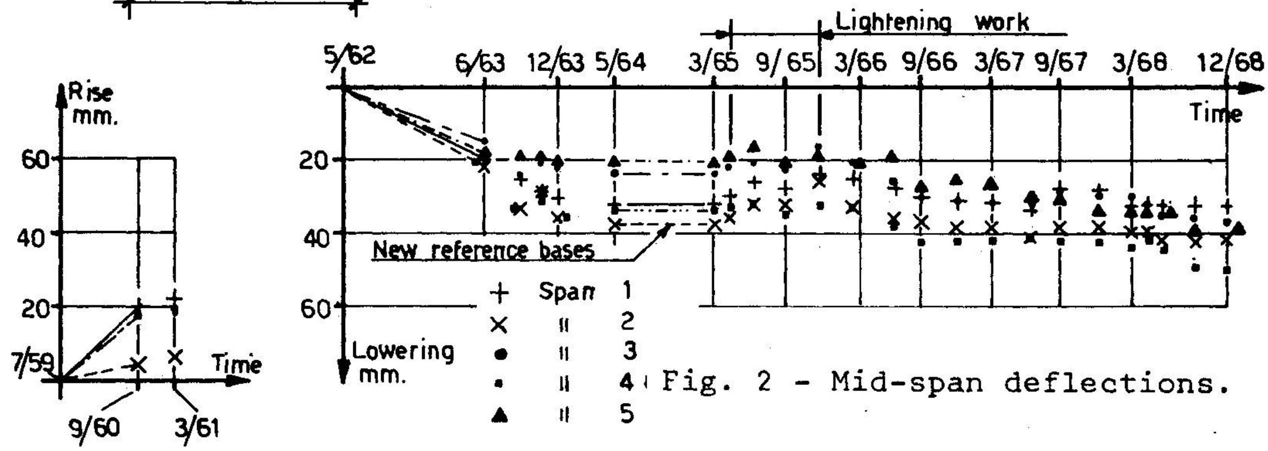


Fig. 2 - Mid-span deflections.

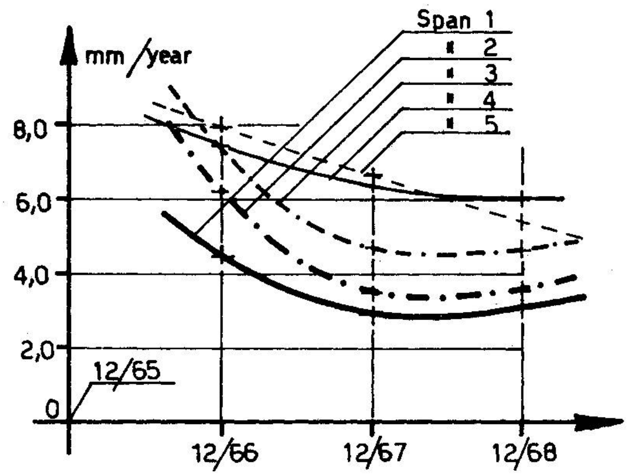
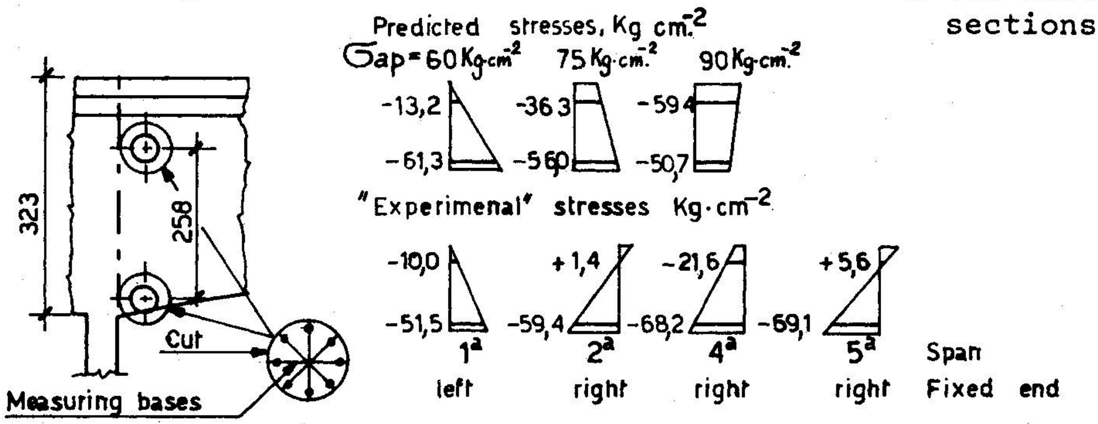


Fig. 3 - Mid-span lowering speed.

Fig. 4 - Predicted and actual stresses in the fixed sections.



cutting into by core boring. The strains thus released have permitted to pass by means of Young's modulus E_b and Poisson's ratio measured on the extracted specimens to the pre-existent stress values. Therefore, assuming a linear distribution of the stress, the "experimental" stress diagrams were obtained, comparable with those calculated for different values of the residual prestress (fig. 4). It proved to be σ_{ap}=60÷70 Kgmm^{-2} at 9 years of the structure's life. The total prestress loss has thus been 38-48 Kgmm^{-2}, against the I8 Kgmm^{-2} predicted for an infinite period of time.

d) Shrinkage tests. These tests were conducted in a room with constant temperature (20°C) and humidity (55%) on specimens prepared of the same aggregates and at the same proportions adopted for the prototype concrete.

Therefore, using the C.E.B. expression (2) for the shrinkage evaluation:

$$\varepsilon_r = \varepsilon_c \cdot K_b \cdot K_d \cdot K_d \cdot K_t$$

the value K_b has been derived, and its application to the actual structure yielded:

$$\varepsilon_r = 25 \div 30 \cdot 10^{-5}$$

The results of the tests clearly show the substantial agreement between the high deflections values and the reduced residual prestress.

A comparison of the prestress tension losses, performed to bear out quantitatively these facts, leads to the following considerations:

a) assuming as valid the design value of steel relaxation (equal to 7% of the initial prestress) and taking into account the initial Young's modulus E_b (obtained from the experimental one) the creep factor, when supposing ε_r = 50.10^{-5}(°),is

$$\phi_N > 3,8$$

b) assuming as correct the design value of shrinkage and steel relaxation (ε_r = 25.10^{-5}), the creep factor is:

$$\phi_N > 4,8$$

These undoubtedly unusual values of the slow concrete deformations are believed to be caused by a particularly unfavorable concomitance of intrinsic and ecological factors, such as:

intrinsic factors: excess of fine material in the aggregates and, therefore, a high percentage of cement paste; high value of W/C; mineralogical and surface nature of the calcareous aggregates, quarried in a zone of predominantly tufaceous rock (°°).

ecological factors: particularly high annual mean temperature; frequent insolation throughout the year; on an average, low relative

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(°) Due to exceptional climatic conditions.

(°°) Not many studies exist on the influence of the aggregates on the phenomena under examination (known are those of Davis, U.S.A., and Kordina,Germany). However, it is believed that in some cases this influence may not be negligible.

humidity and low rainfall; high windiness.

3. PRESTRESSED CONCRETE FLOOR BEAM WITH POST-TENSIONED CABLES (I)

The beams, designed for an office floor, have a T like cross-section and a I4.3 m span (fig. 5).

The deflections, measured during the acceptance tests 3 months after the tensioning, were found to be about twice the calculated ones. This excessive deformability was clearly caused by a too early cracking.

Assuming as cracking moment the expression

$$M_f = W_i(\sigma'_{bi} + \sigma_{br}) \qquad (I)$$

where

W_i = lower section modulus

σ'_{bi} = stress at the intrados edge

σ_{br} = tensile strength of the concrete

it was necessary, to explain the phenomenon, to assume a high loss of prestress, even when supposing that parasitic microcracks (due to the prevented shrinkage) had already at the beginning exhausted the tensile strength of the material.

Having ascertained that these losses were in no way to be attributed to steel relaxation, tests were carried out to find the actual state of stress in the cables and, hence, the slow losses that occured.

The following was, therefore, determined experimentally:

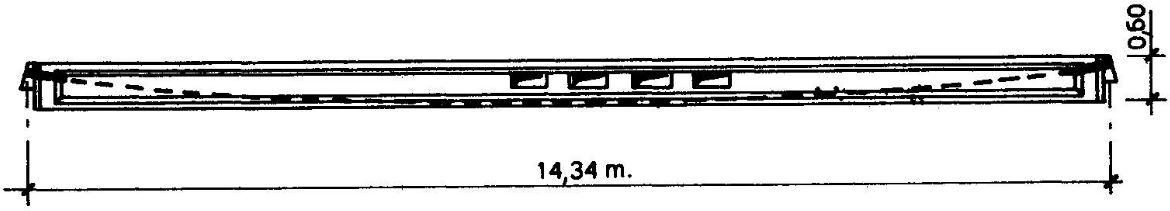
a) actual cracking moment, obtained by a distributed load test;

b) state of stress in two sections of the concrete near the supports (fig. 6) determined by means of the strains "released" by core boring and Young's modulus E_b measured on the extracted specimen (fig. 7).

The largest possible cable prestress was derived from the experimental cracking moment, putting into equation (I) $\sigma_{br} = 0$ (pre-existent microcracking) whereas the lowest possible prestress value was deduced from the stress measured in the tested sections (in fact, a part of the prestress loss had to be attributed to the permanent deformations produced by the previous loading test).

The residual prestress, determined by the above outlined criteria, was 0,88-0,80 the design one for an infinite period of time. This accounts for the excessive deformability of the beam and, hence, its reduced serviceability.

A comparison between these prestress losses and those obtained analytically (considering the experimental E_b value of 230,000 $Kgcm^{-2}$ against the predicted one of 39I,000 $Kgcm^{-2}$) yields, with $\varepsilon_r = 25.I0^{-5}$ like the design one, a maximum $\phi_H = 5.I$. Instead, assuming hypothetically $\varepsilon_r = 50.I0^{-5}$, we get $\phi_H = 3.I$ against the predicted 2.5. In this case it is believed that the phenomenon should essentially be attributed to the intrinsic properties of the material which had a particularly high strength ($\sigma'_{br} = 420$ $Kgcm^{-2}$, as an average of ten specimens at 2I0 days), associated with a low



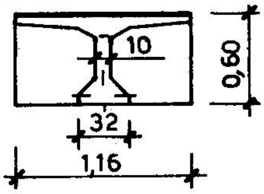
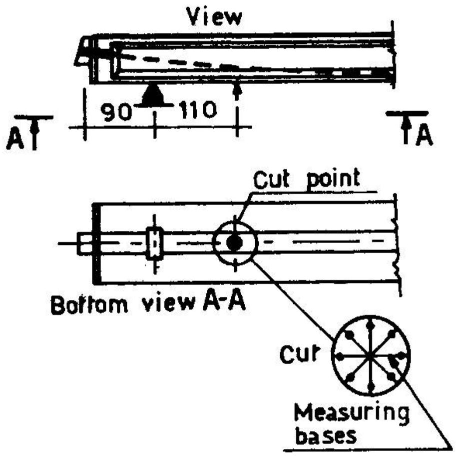


Fig. 5 - Floor beam. View and cross-section.

Young's modulus (E_b = 230 Kgcm^{-2}, an average of four specimens extracted at 2I0 days).



- Fig. 6 -
Test for evalueting the pre-exístent concrete stress.

4. CONCLUSIONS

I) The experimental analysis of the phonomena under examination is particularly difficult when the study is undertaken after the start of the construction, which is very frequently the case in the structures behaving abnormally only after a certain period of time. In these cases it might be possible to indicate value ranges believed to comprise the creep and shrinkage deformations, whereas it is practically impossible to determine quantitatively, but only to suppose the "weight" to be attributed to the various influencing factors.

2) Not infrequently the slow deformation values are higher than the predicted standard ones, causing severe consequences to the deformability of prestressed concrete structures. It is, therefore, believed that in designing prestressed concrete structure it is necessary to check the slow deformability characteristics of the material, possibly by conveniently extrapolated short-term tests or by evaluating parameters which empirically may be correlated to those characteristics. Moreover, particular care should be taken in evaluating the influence of the environmental factors, like humidity, temperature insolation, windiness, etc.

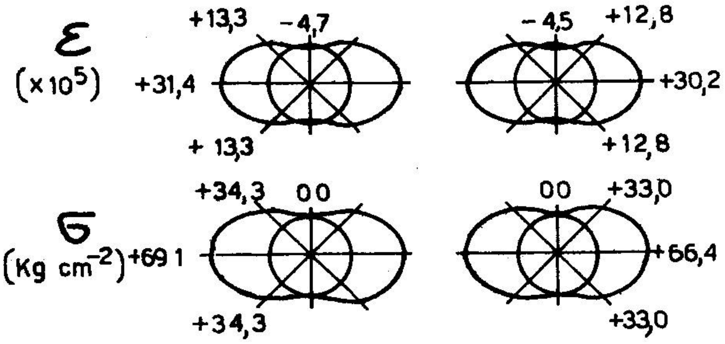


Fig. 7 - Polar diagrams of the strains and stresses released by core boring.

Finally it is suggested

that, inversely to the profundity of the quantitative analysis of the phenomena examined, it is advisable in the design stage to use adequate factors of safety.

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SUMMARY

The paper emphasizes the particular sensitivity of prestressed concrete structures as regards greater-than-average rheological phenomena of concrete.

In this connection, the investigation carried out on two structures is described, indicating its limits and results. The usefulness of an advance careful evaluation by the designers of the slow deformation phenomena of concrete is thus brought out.

RESUME

On met en relief la sensibilité particulière des structures en béton précontraint au point de vue des phénomènes rhéologiques du béton de grandeur supérieure à la moyenne.

On décrit à ce propos les recherches développées sur deux structures dont on présente les limites et les résultats, justifiant ainsi l'utilité pour l'ingénieur d'une étude soignée des phénomènes de déformations lentes.

ZUSAMMENFASSUNG

Es wird die besondere Empfindlichkeit der Spannbetontragwerke gegenüber ungewöhnlichen rheologischen Erscheinungen des Betons hervorgehoben.

Zu diesem Zwecke werden die an zwei Bauten vorgenommenen Untersuchungen beschrieben, wobei Schwierigkeiten und Ergebnisse angegeben werden und somit die Nützlichkeit gezeigt wird, während des Entwurfes eingehende Voruntersuchungen über die langsamen Betonverformungen anzustellen.

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