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Time-Dependent Behaviour of Prestressed Concrete Structures

Comportement différé des structures précontraintes

Zeitabhängiges Verhalten von Spannbetonkonstruktionen

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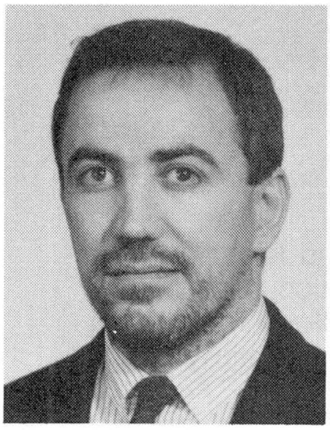

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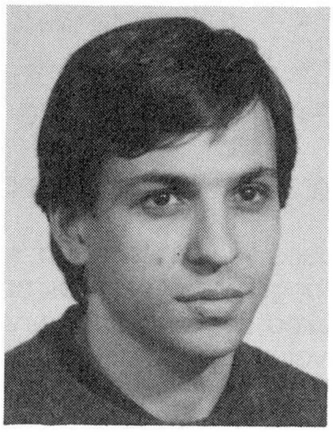

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SUMMARY

This paper describes a model which permits the analysis of the time-dependent behaviour non-cracked prestressed concrete structures under service loads. The influence of the quality and reliability of the input data on the accuracy of the results obtained is stressed. Results obtained with the model are then compared to experimental data. Finally, from the comparison with experimental results it is concluded that such a model is a valuable computational instrument once its limitations are recognized.

RÉSUMÉ

Le modèle décrit permet l'analyse du comportement différé de structures en béton précontraint non-fissurées à l'état de service. L'accent est particulièrement mis sur la qualité des données introduites et sur la fiabilité des résultats obtenus, qui sont ensuite comparés aux données expérimentales. Un modèle comme celui présenté ne peut être utile qu'à condition de tenir compte de ses limites.

ZUSAMMENFASSUNG

Dieser Bericht beschreibt ein Modell für die Analyse des zeitabhängigen Verhaltens ungerissener Spannbetonkonstruktionen unter Gebrauchslast. Der Einfluss der Qualität und der Zuverlässigkeit der Daten auf die Präzision der Ergebnisse wird besonders hervorgehoben. Die Ergebnisse aus der Theorie und den Versuchen werden dann verglichen. Dieser Vergleich führt zu dem Ergebnis, dass dieses Modell, unter Berücksichtigung seiner Einschränkungen, gültig ist.

1. INTRODUCTION

When dealing with singular structures (cable-stayes bridges, cantilever construction, bridges built by phases) it is important to evaluate with good accuracy the evolution with time of strains and stresses. This sort of problems cannot usually be tackled in a simplified manner and therefore requires the use of more complete models which take into account all the phenomena involved.

This paper describes a model which permits the analysis of the behaviour with time of evolutive non-cracked prestressed concrete structures for service loads. The influence of the quality and reliability of the input data on the accuracy of the results obtained is stressed. Results obtained with the model are then compared to experimental data. Finally, from the comparison with experimental results it is concluded that such a model is a valuable computational instrument once its limitations are taken into account.

2. DESCRIPTION OF THE PROPOSED MODEL

2.1 Stress-Strain Diagram and Time-Dependent Behaviour of Concrete

For instantaneous loads, concrete is considered as an elastic and linear material characterised by its longitudinal modulus of elasticity. This assumption is justified by considering non-cracked sections and service loads. The model allows for different formulations of the evolution with time of the longitudinal modulus of elasticity.

Time dependent behaviour of concrete due to creep and shrinkage is handled according to the general approach proposed by CEB [1]. In order to avoid storing the whole stress history of the structure an alternate method, based on a Dirichlet series aproximation of the creep coefficient curves as proposed by Zienckiewicz and Watson [2] has also been implemented.

Several formulations for both creep coefficient and shrinkage strain are supported, including methods proposed by ACI[3] and CEB[4]. Experimental data may also be used through a Dirichlet series approximation.

2.2 Stress-Strain Diagram and Relaxation of Steel

Both prestressed and non-prestressed steels are considered as linear and elastic materials for both tension and compressive instantaneous loads. Again this assumption is valid while considering service loads only.

Relaxation of steel in prestressed concrete members occurs at variable length because of interaction with creep and shrinkage of concrete. The model uses a formulation explained in Fig. 1 and reference [5] which takes this into account. This method proposes an analytical formulation for relaxation at constant length at different initial stress levels and a procedure to represent the evolution of stress with time.

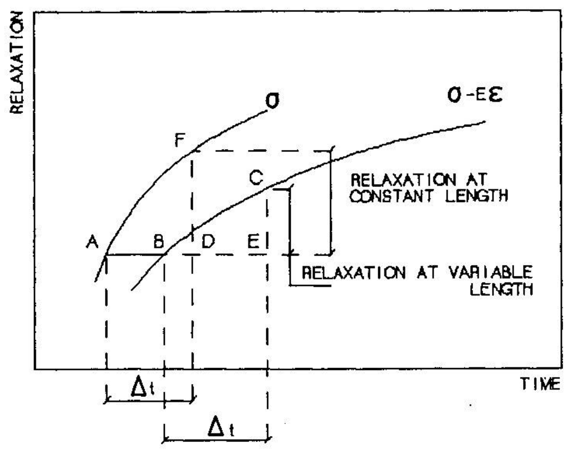

Fig. 1 Relaxation at variable length

2.3 Concrete-Steel Bond

Perfect bond between concrete and steel bars is assumed, both for prestressed and non-prestressed steel.

2.4 Analysis

The model allows changes in the geometry of both the structure (new nodes and bars) and of the different sections (composite sections), and can therefore simulate an evolutive construction process.

For each construction phase a different structure is considered. The structures are divided into a sufficient amount of sections. At each time interval incremental strains due to creep and shrinkage of concrete and relaxation of steel are determined for each section. These strains are then introduced on the structure and new bending moments and axial forces due to these time-dependent phenomena are obtained.

Strains, curvatures, bending moments and axial forces are referred to the same fiber throughout the analysis. This fiber does not necesarily coincide with the center of gravity of the sections which is itself subject to change with time. Using only one reference fiber makes stresses and strains which occur at different times additive without any need for transformation.

2.5 About the Data Required by the Proposed Model

As pointed out before the major drawback of a general model like the one proposed in this paper is the large amount of data required. Furthermore the results obtained will be no more precise than the data entered. It is therefore important to be aware of what data is necessary in order to measure the appropriate variables at the proper time if possible and, if not, to evaluate the possible errors due to this lack of precise data.

In reference to concrete, values are needed for:

- Evolution with time of the longitudinal modulus of elasticity. Analysis is specially sensible to this variable and care should be taken in determining its value.
- Creep coefficient.
- Shrinkage strain.

In reference to steel, data required includes:

- Modulus of elasticity of the different steel types used.
- Parameters defining the relaxation of prestessing steel.

3. COMPARISON WITH EXPERIMENTAL RESULTS

In this section reference is made to experimental results obtained at the E.T.S.I. Caminos, Canales y Puertos of the Polytechnical University of Madrid. These results are detailed in reference [6]. A more detailed comparison can be found in reference [7] including other experimental data dealing with a composite section and a two span continuous beam.

3.1 Available Experimental Data vs Required Data

As mentioned in paragraph 2.5, it is important to take into account the quality of the available data. The Corres-Rodríguez tests were very careful in this sense since they were designed with the purpose of testing an analytical model for determined prestressed concrete structures. All required data is therefore available.

Parallel to measuring strains on the beams themselves, a series of complementary tests were carried out. For concrete these included compression and tension strength, evolution of the modulus of elasticity as well as creep and shrinkage tests. Tension strength tests were also carried out for both prestressing and non-prestressing steels. Finally, relaxation of prestessed steel at constant length was measured for three different initial stresses.

3.2 Data for the Model

3.2.1 Evolution with time of the Modulus of Elasticity of Concrete

Because of the large amount of data available a particular model adjusted by means of the least squares method was used (see Equation (1)).

$$E_c = E_{c28}(2.5t/(t+42))^{0.10} \tag{1}$$

In this equation E_{c28} is the modulus of elasticity of concrete at 28 days and t is the age of concrete in days.

3.2.2 Creep Coefficient and Shrinkage Strain

Experimental results from creep and shrinkage tests were compared to analytical results given by ACI[3] and the former CEB[4] models. For the creep coefficient excellent agreement was found between experimental data and the model proposed by ACI while the 1978 CEB model was found to consistently overestimate creep.

For shrinkage strain neither ACI nor CEB models provided a close fit to experimental results although differences were not truly significant.

In view of these results the ACI models were used to represent both phenomena.

3.2.3 Relaxation of Steel

From the constant length relaxation tests enough information was provided in order to adjust by the least squares method the parameters required by the Elices-Sanchez-Gálvez model [5] mentioned in paragraph 2.2.

3.3 Discussion of Results

Figures 2 and 3 compare respectively the experimental and theoretical evolution of the curvature and deflection obtained at midspan of beams 1 and 2. As can be seen good agreement is obtained by application of the analytical model in both cases.

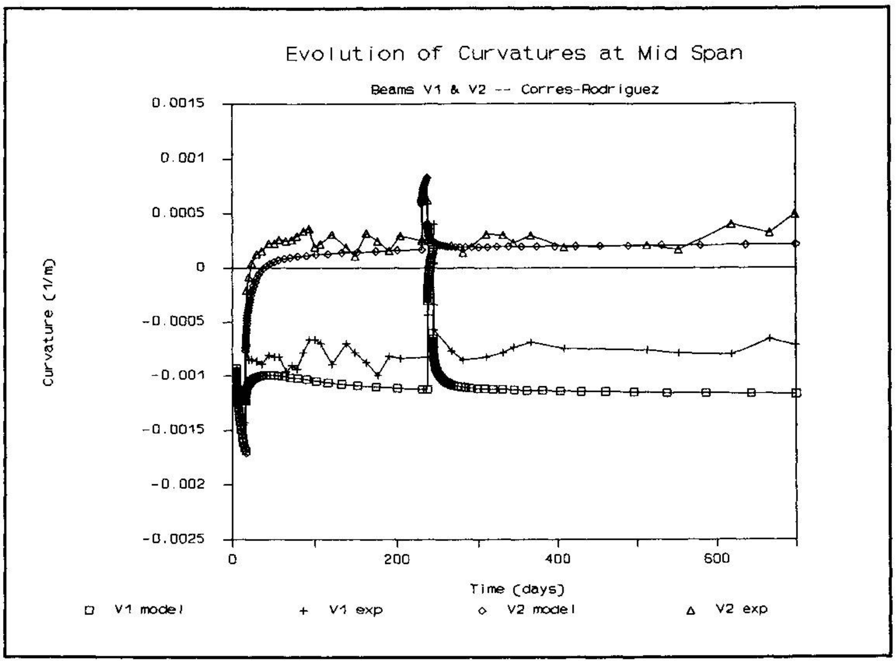

Fig. 2 Evolution of mid-span curvatures

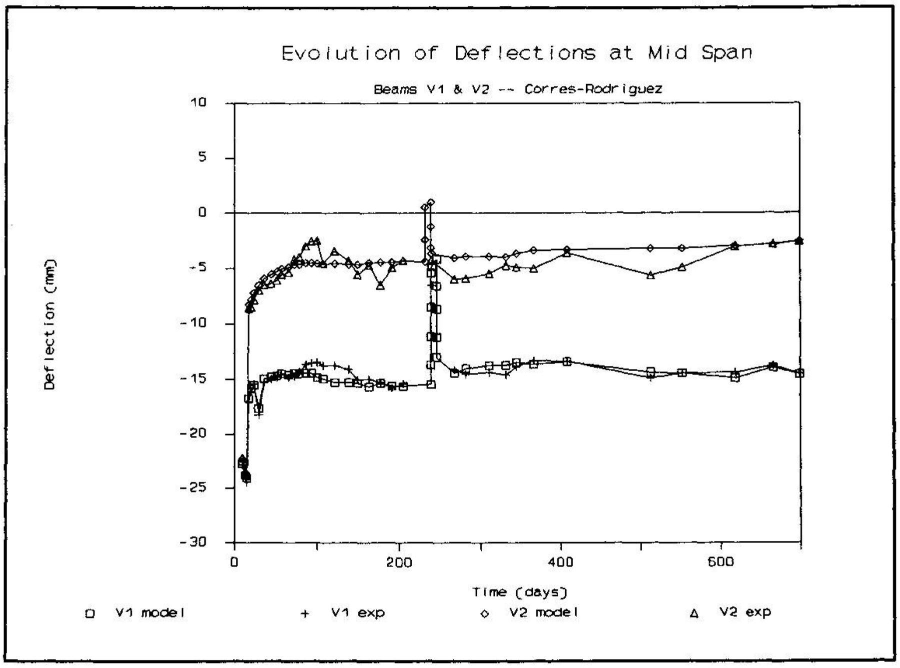

Fig. 3 Evolution of mid-span defelections

4. CONCLUSION

In this paper a flexible and general analytical model for the study of evolutive non-cracked prestressed concrete structures subject to service loads has been outlined. This model implements, as an alternative to Dirichlet series approximation of the creep coefficient, the general method proposed by CEB [1] and uses special procedure to represent relaxation at variable length.

Results obtained with the model have been compared with experimental tests obtaining good agreement.

As discussed above, this sort of model requires a large amount of data which in most cases cannot be accurately determined through analytical formulae and which greatly influence final results. It is therefore important to define the degree of precision required.

In this line it can be concluded that such a model is an ideal tool for the analysis in the service limit state of prestressed concrete structures if accurate data is available. In design, the use of such a model requires realistic estimates of creep coefficients, shrinkage strains and modulus of elasticity of concrete. In such conditions the accuracy provided by the model should be sufficient in most cases to point out the main aspects of the behaviour of the structures. Finally, in construction, experimental tests must be carried out to measure "in situ" the more important variables used by the model in order to obtain more accurate results.

5. ACKNOWLEDGEMENTS

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