Long-term performance monitoring of bridges: major case studies

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Long-term Performance Monitoring of Bridges - Major Case Studies

Surveillance à long terme des ponts — étude de cas

Langzeitbeobachtungen an Brücken - Fallbeispiele

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SUMMARY
The paper presents comprehensive instrumentation schemes for three major prestressed concrete bridges under construction on the Ganga and Mandovi rivers in India. The significant parameters being monitored and the corresponding sensors and data acquisition systems are highlighted. Among the aspects covered are instrumentation for a cantilever bridge from foundation upwards and monitoring of the loss of prestress. Mathematical modelling for correlation and interpretation of the field data is also discussed. The paper concludes with considerations in developing standard instrumentation scheme for major bridges in future.

RÉSUMÉ
L'article présente des méthodes de mesures exhaustives pour trois grands ponts en béton précontraint, en construction sur les fleuves Gange et Mandovi en Inde. Il explicite les paramètres essentiels faisant l'objet du contrôle, les capteurs correspondants et les systèmes de saisie des données. Entre autres aspects possibles, il donne en exemple les instruments de mesure pour un pont à porte-à-faux, répartis au dessus de la fondation, et la surveillance de la perte de précontrainte. Il examine aussi un modèle mathématique pour corréler et interpréter les données recueillies sur place. Il fournit en conclusion des considérations sur le développement de méthodes de mesures standard pour les grands ponts futurs.

ZUSAMMENFASSUNG
Der Beitrag präsentiert umfangreiche Instrumentierungsprogramme für drei grosse indische Spannbetonbrücken über den Ganges und den Mandovi. Datenaufnehmer und -auswertungssysteme für die überwachten Schlüsselgrössen sind beschrieben. Darunter befindet sich die Instrumentierung einer Freivorbaubrücke von der Gründung aufwärts, einschliesslich der Aufzeichnung der Vorspannverluste. Desweiteren wird die mathematische Modellbindung zur Korrelation und Interpretation der Rohdaten diskutiert. Für die Zukunft wird die Entwicklung von Standardinstrumentierungen für Grossbrücken vorgeschlagen.

1. INTRODUCTION

A large number of major bridges are today distressed to a point where their serviceability has been severely affected and their safety called in question. Typical among the problems confronting bridge engineers today are the degradation of materials, corrosion of steel, loss of prestress, in-service performance of rehabilitated bridges, residual life, etc. These exigent issues have sharply brought home the point that the most effective way to meet this challenge is to continuously monitor the health and performance of these bridges from inception through instrumentation. Recognising this very critical need for scientific monitoring of the health of distressed/rehabilitated bridges and for creating a data base for in-service performance of majaor bridges, the Ministry of Surface Transport, Government of India, has recently sponsored research projects at the Structural Engineering Research Centre at Ghaziabad on three major bridges, aimed at their performance measurements and long-term monitoring through instrumentation. These studies, currently in progress, are reported in the following :

2. CASE STUDIES

2.1 Cantilever bridge on the Ganga at Varanasi

The Ganga Bridge at Varanasi, presently under construction, has several unique features. The cantilevers span 65 metres on either side of the piers. The open caisson (well) foundations are 70 metres deep, with inside and outside diameters of 8 m and 13 m, respectively.

The instrumentation scheme covers one river well (P7), one land well (P8), one pier (P7), one complete span of the superstructure (P6-P7) and the cantilever arm (P7-P8), with a view to obtain important data relating to the short-term and long-term behaviour of the bridge. The instrument data would be recorded both during construction and in service. The scheme of instrumentation covers several 'performance factors' such as actual stresses, strains, deflections, tilts, material characteristics, etc. as well as in-situ earth pressures on the wells.

Instrumentation of the well foundations

The parameters to be measured in the well foundations and the corresponding instrumentation techniques that have been used in a typical river well (P7) are summarised below (Fig. 1a & b):

Parameter	Technique
(i) Soil Pressure on well steining	- 18 Vibrating Wire earth pressure cells installed at three levels
(ii) Forces in well reinforcement	- 36 Vibrating Wire rebar load gauges installed in longitudinal and hoop reinforcement at three levels
(iii) Tilt of the well	Inclinometer - A torpedo-like sensor runs along the length of a grooved casing which is assembled in segments apace with the construction of the well to form a continuous vertical conduit through the steining. Readings provide data on the magnitude and direction of tilt of the well. Tiltmeter - A tiltmeter would be installed on the well cap to provide the data relating to the tilt of the well.

(iv)	Inspection of the inner surface of the well	- Underwater photography using a remote operated vehicle and videography, to provide evidence regarding deterioration, cracking and blemishes on the inner surface of the well - As a trial, the inner surface of one of the wells was scanned using a underwater camera

An even more extensive instrumentation scheme involving 48 pressure cells and 96 rebar gauges as well as the inclinometer system has been planned for a typical land well (P8) of the bridge.

Values of lateral (water/earth) pressures at different depths obtained from the pressure cells at the lowermost level as the sinking progressed are given in Fig. 2(a). The other two levels of instruments are still above the river bed and presently record water pressure only. Initial inclinometer profiles upto a depth of 30 m are shown in Fig. 2(b).

Instrumentation of the superstructure to study the short and long-term behaviour will be carried out during the construction of the bridge deck. Details of the relevant instruments/techniques are given below with reference to the next case study.

2.2 Bridges on Mandovi at Goa

Two bridges, under construction on the Mandovi, have double lane single cell box girders, with inclined webs in the new bridge and vertical webs in the recommissioned bridge.

The objective of instrumentation of the superstructure of the two bridges is to get an indication about the loss in prestress by instrumenting one span of each bridge. Since there is no direct practical method of knowing the level of prevailing prestress, it is proposed to monitor it indirectly by measuring as many other parameters as possible.

The various parameters to be measured and the corresponding techniques of measurement are summarised below (Fig. 1c, d & e):

	Parameter	Technique
(i)	Strain (at four sections)	- Embedded/Surface mounted Vibrating Wire (VW) strain gauges (36 Nos.) - Surface strains at 84 locations using 'Pfender gauge'
(ii)	Temperature (at mid span)	- VW temperature gauges (16 Nos.)
(iii)	Deflection	- Precision level with invar staff at 9 points - Water level indicators (18 Nos.)
(iv)	Slope	- Tiltmeter measurements at 24 points would give slopes in longitudinal and transverse directions
(v)	Integrity tests (Frequency and damping)	- Accelerometer, FFT Analyzer
(vi)	Modulus of elasticity	- 60 specimens of concrete to be tested at different ages
(vii)	Compressive strength	- 150 specimens of concrete to be tested at different ages

(viii) Creep coefficient	-	15 specimens of concrete for different permanent stress levels and incorporating strength variations
(ix) Shrinkage coefficient	-	30 specimens of concrete
(x) Relaxation of H.T. Strand	-	As per standard procedure
(xi) Friction and wobble coeff. of sheathing	-	Through field tests before final prestressing

Out of the 13 spans, each about 50 m long, of the New Mandovi Bridge, a typical span (P13-P14) has been selected for instrumentation. Instruments required for one span have been procured and laboratory tests are in progress.

3. MATHEMATICAL MODELLING

A mathematical model evolved at the design stage of a bridge does not necessarily help in assessing its behaviour or predicting its residual life. Actual data on materials and the periodically obtained values of the different parameters can be incorporated in the 'design model' to obtain a realistic model for predicting the behaviour of the bridge.

To monitor the prestress indirectly, a large number of measurements of strains, deflections, and slopes are recorded. In order to work out the total prestressing force and its average eccentricity at the section, a data reduction algorithm has been developed to compute these quantities from the longitudinal strains in concrete measured at that section. An equation relating to the prestressing force P v/s longitudinal strain ε can be expressed as follows:

$$\{\varepsilon\}_{m\times1} = \frac{1}{E}\,[K]_{m\times3}\,\{P\}_{3\times1} + \frac{M}{E\,I_x}\{y\}_{m\times1} \qquad \ldots (1)$$

where

$$\{P\}_{3\times1} = \begin{Bmatrix} P \\ P.e_x \\ P.e_y \end{Bmatrix}$$

and P is the total prestressing force on the section and e_x, e_y are its eccentricities.

M, E, I_x = additional moments, modulus of elasticity and Moment of Inertia

$\{y\}_{m\times1}$ = y coordinates of the section where strains are measured

In order to minimise the errors in the measurements, least square technique has been used. It will minimize the sum of squares of approximation errors at the data points. The sum of the squares of the error of equation (1) is given in the form

$$Err\{P\} = \sum_{n=1}^{m}\left[\varepsilon_n - \frac{1}{E}\left\{K_{n,1}P_1 + K_{n,2}P_2 + K_{n,3}P_3 + \frac{M y_n}{I_x}\right\}\right]^2 \ldots (2)$$

where $P_1 = P,\ P_2 = P.e_x,\ P_3 = P.e_y$

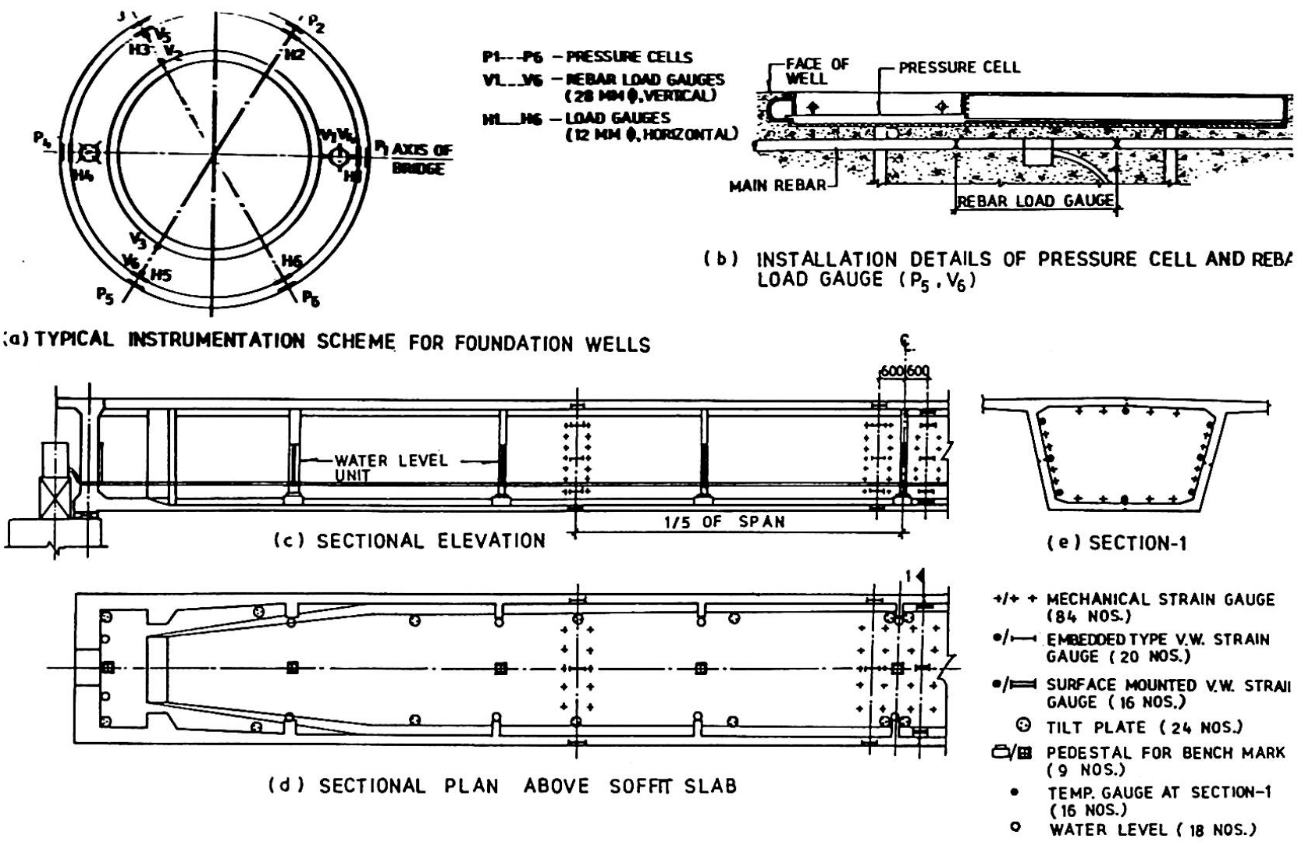

FIG. 1 INSTRUMENTATION SCHEMES FOR GANGA AND MANDOVI BRIDGES

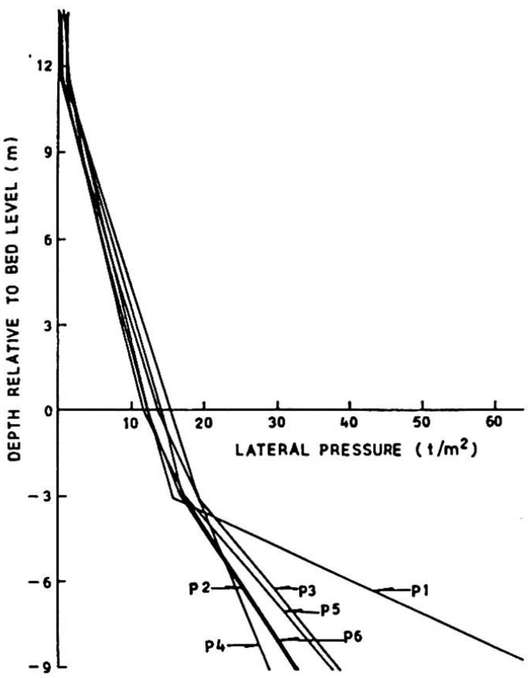

FIG. 2 (a) LATERAL PRESSURE VALUES OBTAINED FROM PRESSURE CELLS (t/m²)

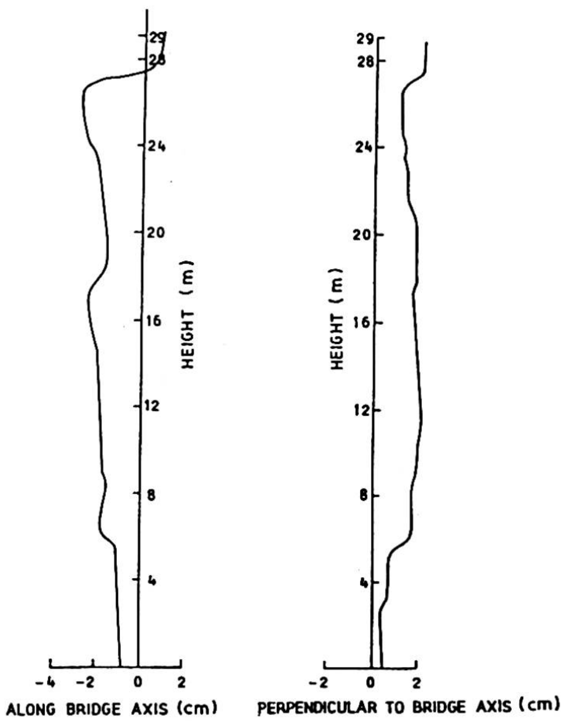

FIG. 2 (b) INITIAL PROFILE OF INCLINOMETER CASING

For errors to be minimized, $\partial Err / \partial P = 0$ ...(3)

On using equation(2)and(3)one gets

$$\{P\}_{3\times1} = E\left[[K]^T_{3\times m}[K]_{m\times3}\right]^{-1}\left[[K]^T_{3\times m}\{\varepsilon\}_{m\times1} - \frac{M}{EI_x}\{y\}_{m\times1}\right] \quad ...(4)$$

Thus we can compute the prevailing prestressing force P and its point of action at the section under consideration. This approach will help to update the mathematical model for prestressed sections. Similarly, other algorithms required to assess/predict the behaviour would also be improved with the help of other parameters, the values of which would be generated in the field.

4. CONSIDERATIONS IN INSTRUMENTATION OF BRIDGES

In planning an instrumentation scheme for a bridge several considerations must be borne in mind.

(i) Instrumentation cannot retrace the distress history, i.e. it cannot lead us to the causes which brought about the distress, but can only help us to monitor the condition of the bridge from the time the instruments were installed.

(ii) Instrumentation is not an end in itself. Correct interpretation of data acquired through instrumentation calls for realistic mathematical modelling of the structural and material behaviour.

(iii) Instrumentation on a major scale entails considerable expenditure on equipment and fieldwork, much of which is irretrievably lost within the body of the structure. The type of instruments and their quantum need therefore to be planned carefully.

(iv) All experimental work involves an element of error and instrumentation in the field even more so. Furthermore, some mortality of the instruments employed is unavoidable. Hence the utmost need for providing adequate redundancy of measurement and for making data logging as automatic as possible.

(v) Finally, it cannot be overemphasised that the human element is of crucial importance in experimentation. Success in any instrumentation effort can result only from a high degree of commitment to the effort by the individuals involved in it. None but perfectionists fill the bill.

5. ACKNOWLEDGEMENT

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