INSTRUMENTATION TECHNIQUES TO MONITOR LOSS OF PRE-STRESS AND CORROSION OF STEEL IN PRE-STRESSED CONCRETE

PREFACE

Prestress concrete girders provide an advantage of ballasted deck over bridges. As such, there is a tendency of adopting more and more PSC girders on Indian Railways. Concrete structures are supposed to give trouble free and maintenance free service, if constructed properly. Normally, durability aspects are usually lost sight of. Because of which, many times, concrete structures develop defects during their service. Corrosion of prestressing steel and reinforcing steel is considered to be the most common problem. It can lead to loss of prestress also.

2. Member Engineering, vide his inspection note No.13 bearing No. 2000/W-2/TP/01 dated 16.11.2000, desired RDSO to take the study of instrumentation of bridges for monitoring (i) loss of prestress and (ii) corrosion in PSC girders.

3. Accordingly, RDSO collected literature on the subject. Apart from discussions with the Bridge Engineering Chair, Rookee it was also discussed in Railway Bridge Technology Development Group wherein Dr. M.G. Tamhankar, who has lot experience in this field, was also invited for a presentation. After detailed study of literature, interaction with Dr. M.G. Tamhankar and considering the views of the members of Railway Bridge Technology Development Group, this report has been prepared for the guidance of the field engineers on monitoring ‘loss of prestress’ and ‘corrosion’ in PSC girders.

4. Instrumentation technique is now-a-days gaining lot of importance though the same is at research stage in India. Very limited instrumentation has been done on bridges in India. Some of the road bridges are reported to have been instrumented, they are: New & Old Mandavi bridge (Goa), New and old (Airoli bridge), Thane Creak bridge (Mumbai), Ganga bridge (Varanasi), Pamban bridge (Rameshwaram),Yamuna bridge, ITO New Delhi etc. It is understood that any useful conclusion is yet to be drawn from the instrumentation of these bridges. SERC, Ghaziabad, under the leadership of Dr. M.G. Tamhanker, was associated in instrumentation of these bridges. CECRI/ Karaikudi, also undertake work of instrumentation for corrosion monitoring.

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1.0 INTRODUCTION:

1.1 Pre-stressed concrete (PSC) girders are being widely adopted on Indian Railways. To have trouble free service from pre-stressed concrete girders, lot of care is required at the time of construction. Durability aspect is usually lost sight off. Because of this, many times PSC structures develop defects during their service life. The most common problem is corrosion of reinforcing steel and pre-stressing cables. It can lead to loss of pre- stress force, though loss of pre-stress can be due to other reasons also. These defects may lead to failures if not detected well in time. It may be difficult to detect these by normal inspections. However, use of proper instrumentation may be of some help in this regard.

1.2 This report has been prepared with a view to provide guidelines to field engineers. Efforts have been made to provide latest information on instrumentation and application of NDT techniques to monitor loss of pre-stress and corrosion of reinforcing and pre-stressing steel.

1.3 It is very important to do proper planning for instrumentation to achieve the desired objective. The planning may include selection of critical locations, type of sensors, access for their installation, period and frequency of monitoring, recording and analysis of data etc. The coordination between instrumentation, design and construction/maintenance agencies, and agency for processing and interpretation of data will lead to successful and effective instrumentation.

2.0 LOSS OF PRE-STRESS :

2.1 The initial pre-stressing force applied to the concrete element reduces due to elastic shortening of the concrete, anchorage losses, frictional losses etc. The pre-stressing force further reduces with the passage of time due to creep, shrinkage, temperature effect and relaxation of steel. The loss of pre-stressing force may reduce load carrying capacity of the structure.

2.2 It will be worthwhile to note that **no direct method is available to measure loss of pre-stress**. However, it can be ascertain by knowing the changes in stress levels in pre-stressing cables. The change in stress level can be known by periodical measurement of the same. The force in pre-stressing steel can be measured by using Vibrating Wire (VW) Load Cells or Vibrating Wire (VW) Strain Gauges.

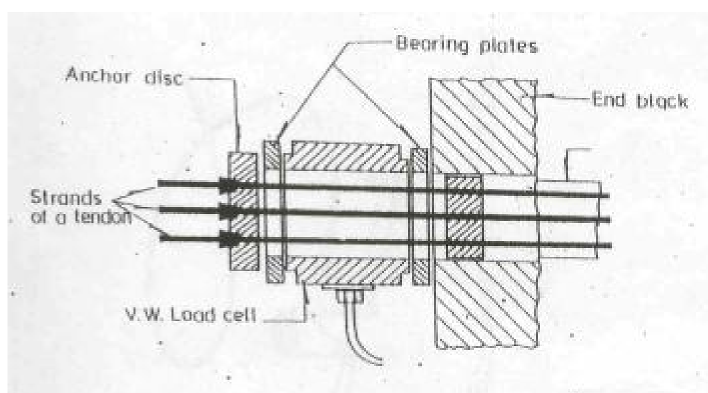
2.3 Vibrating Wire (VW) Load Cell:

2.3.1 It consist of a set of vibrating wire gauges mounted parallel to each other equally spaced in a ring in an alloy steel cylindrical housing. The studs of vibrating wire are attached with diaphragm of load cell. The load cells are manufactured with a centre hole to accommodate tendons or anchor cables. These load cells are available in various ranges from 100 to 5000 KN. The change in pressure on the diaphragm will change the tension of vibrating wire. The natural frequency of wire is proportional to the tension of the wire. Thus, by measuring the natural frequency of wire pressure on diaphragm can be known. Natural frequency of the wire can be co-related with the diaphragm pressure. The natural frequency of wire can be expressed as below:

$$f = 1/2l * \sqrt{T/m}$$

where
- f = Natural frequency of the wire
- l = Length of the wire
- T = Tension of wire
- m = Mass/unit length

2.3.2 The operation of VW Load cell is based on electrical plucking of the vibrating wire. The wire, vibrating at its resonance frequency, which varies with the tension in the wire, induces an alternative current in the coil which is detected by the read out unit.



Arrangement

2.3.3 The VW load cell, sandwiched between two plates, is installed at the pre-stressing end of the girder. The cable of load cell is connected to common read out unit. Read out units generally measures the period or frequency of the wire from which force in cable can be obtained. The read out unit can be connected with P.C. and data can be analysed using custom-made software for this purpose. Initial reading is taken soon after the load cell is installed. Subsequent readings are taken at each stage of pre-stressing. However, after cement grouting of cable it may not be possible to measure the force. If the cable duct is filled with grease or gel, the pre-stressing force can be measured periodically during service.

2.3.4 Summary: **From the above, it can be noted that V.W. load cell system is suitable for new construction and not for existing bridge**. V.W. load cell measures the force in pre-stressing wire. Once the cable duct is cement grouted the force transfer to load cells does not take place. However, if the cable duct is filled with grease, oil etc. load cell continue to give the force in pre-stressing steel. Hence, in the present system where cable duct is cement grouted load cell system will not help. **Load cell system can also be used to monitor the force in pre stressing steel, at the time of pre-stressing, to avoid over stressing of the same.**

2.4 Vibrating Wire Strain Gauge:

2.4.1 With the help of Vibrating Wire Strain Gauge, the change in strain can be obtained with periodical measurement of strain. The stress can be calculated by multiplying strain with modulus of elasticity. The pre-stress force can be obtained by multiplying stress with cross sectional area of pre-stress cables.

2.4.2 V. W. Strain Gauge operates on the principle that a tensioned wire, when plucked, vibrates at a frequency that is proportional to the tension in the wire. The gauge is constructed in such a way that a wire is held in tension between two end flanges. Force in concrete changes the distance between its two flanges and results in a change in the tension of the wire. Strain is then calculated by applying calibration factors to the frequency measurement.

2.4.3 Vibrating Wire Strain Gauges are of two types i.e. i) weldable type and ii) embedment type. Weldable type strain gauges are fixed on the surface of the structure. They do not function in embedded state. Therefore, embedment type strain gauges are more suited for our purpose.

2.4.3 VW embedded strain gauge:

2.4.3.1 VW embedded strain gauge is embedded in concrete nearer to pre-stressing cable to assess change in strain and subsequently change in pre-stressing force. The

gauge may be installed either before or immediately after placement of the concrete. Their unique design provides superior performance. These are available in 6 and 10-inch lengths.

2.4.3.2 For new construction the strain gauge is embedded in concrete around pre-stressing cable during placement of concrete. The leads of the gauge are taken out and connected to read out or data logger unit. The datum reading of the gauge is recorded immediately after installation of gauge. Subsequent readings are taken at each stage of pre-stressing during construction and at pre-decided interval during service.

2.4.3.3 For existing bridges, bore is drilled in concrete at desired locations and strain gauge is installed. After Installation of strain gauge, the bore is again filled up. The leads of the gauges are taken out and connected to data logger unit. Datum and subsequent reading of strain are taken at pre-decided intervals.

2.5 Summary: **This technique is suitable for use on new as well as existing bridges.** Not much of literature on actual use of above instrumentation system is available either in India or abroad. The technique of VW strain gauge is better suited than VW load cells. For new bridges the same should be planned at the design stage itself so that strain gauge can be fixed at pre-decided locations before placing concrete. The pre-stress level is monitored by periodical observations. SERC (GZB) which has now merged with CRRI, New-Delhi and CBRI, Roorkee, has done some work in instrumentation under the leader-ship of Dr. M.G.Tamhanker, who is presently working as Professor Emeritus at IIT, Mumbai.

3.0 CORROSION:

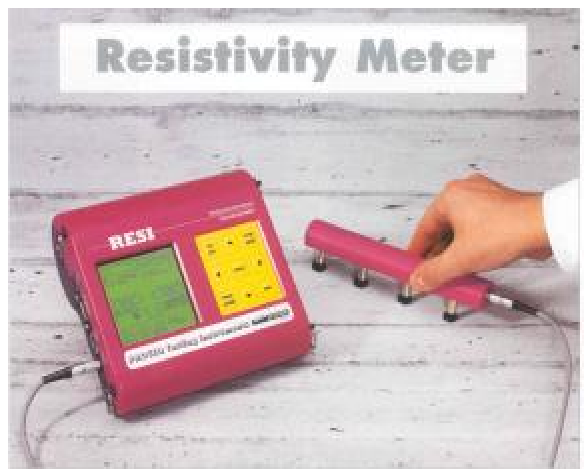
3.1 There is need to know the extent of corrosion in pre-stressing steel as well as that of reinforcing steel. **No instrument / technique is available, at present, which can measure the extent of corrosion of steel.** Corrosion in pre-stressing steel may lead to loss of prestress. It can only be qualitative measure, no relation is available to quantify corrosion in the form of pre-stress loss. However, measurement of concrete properties, such as resistivity and potential of concrete can assess the probability of corrosion of reinforcing steel. Resistivity Meter and Corrosion Analyzing Instrument, which are easily available, can measure these properties.

3.2 RESISTIVITY METER:

3.2.1 The corrosion of steel in concrete is an electro-chemical process that generates a flow of current. Resistivity of the concrete influences the flow of this current. The lower the electric resistance, the more easily corrosion current flow through the concrete and the greater is the probability of corrosion. Thus, the resistivity of concrete is a good indication of probability of corrosion. Resistivity Meter can measure the electrical resistance of reinforced concrete components. The probable rate of corrosion with respect to value of resistivity of concrete is normally considered as given in table below.

Resistively level (Kilo-ohm / cm)	Possible corrosion rate.
< 5	Very high
5 to 10	High
10 to 20	Moderate to low
> 20	Insignificant

3.2.2 Resistivity meter is very handy and portable equipment weighing about 2.2 Kg. It has two or more probes, which are placed on concrete surface with conductive gel between probes and surface. The concrete resistivity is displayed on a LCD. Now a days, resistivity meters are available with non-volatile memory and coloured graphic display from which data can be transferred on PC.



3.2.3 To measure the resistivity, metallic probes are placed over the concrete surface. A known current is passed on the outer probes and resulting potential drop between inner probes is measured. The resistance is computed by dividing potential drop by the current. A conductive gel is used between probe and concrete surface to make effective contact.

3.2.4 Summary: **With the help of resistivity meter, probability of corrosion can be assessed. This is a very simple technique and can be adopted easily in the field without any disruption to traffic.** The reistivity meters are manufactured by M/s PROCEQ SA, Switzerland; James Instruments Incorp., USA; Colebrand Ltd. etc. and are easily available through their Indian agents i.e. M/s AIMIL and others.

3.3 CORROSION ANALYSING EQUIPMENT:

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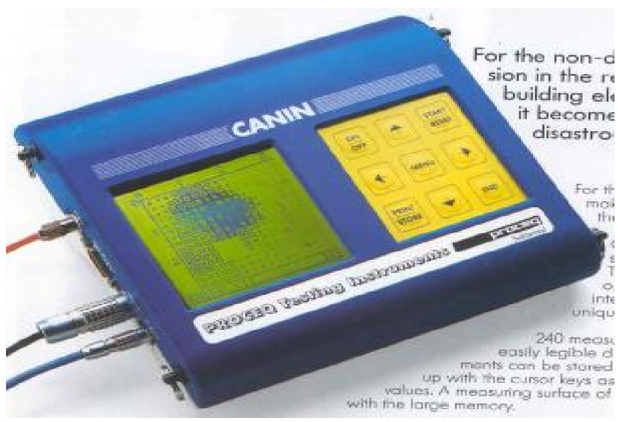
3.3.1 Difference in potential between concrete surface and steel is a good indicator of current flow. The electrochemical process produces an electric current, which is measurable as an electric field on the surface of the concrete. This potential field can be measured with an electrode known as Half-cell. By making measurement over the whole surface, a distinction can be made between likely corroding and non-corroding locations. The probability of corrosion with respect to the values of potential difference is normally considered as given in table below:

Potential Value	Possible Corrosion Rate.
≤ 0.20 V	90% probability of no corrosion
0.20 to - 0.35 V	corrosion activity uncertain
≥.0.35 V	more than 90% probability of corrosion

3.3.2 Corrosion Analysing Instrument is small, handy equipment weighing about 5.5 Kg. with large display and simple operation. Measured values can be represented on the display. Measurements can be stored in the memory. Its data can be transferred to PC.



3.3.3 The steel in concrete structure should be accessible at few locations to provide electrical connection. <u>For new structures</u>, such locations should be decided at the design stage itself. The connections project out of the concrete. <u>For existing bridges</u>, re-bars /pre-stressing wires are to be exposed to make electrical connections. For this, bore are to be made by drilling the concrete at desired locations and an electric cable is connected with pre-stressed cable and projected outside. After connecting them from out side, the same can be plugged back using epoxy mortar. The positive terminal of voltmeter is connected to exposed re-bars and negative terminal (common) to reference half-cell. The surface of concrete is divided in to number of grids. The reference electrode is moved along the nodal point and corresponding potentials are recorded. These are referred as corrosion potential.

3.4 Summary: Potential difference between concrete surface and reinforcements / pre-stressing cables can be accurately measured by corrosion analysing equipment based on Half- cell principle. This is simple method and can be adopted in the field without disruption to traffic. Corrosion analysing equipment are manufactured by M/s PROCEQ SA, Switzerland; James Instruments Inc. USA; Colebrand Ltd. etc. and are easily available through their Indian agents i.e. M/s AIMIL Ltd. and others.

4.0 CATHODIC PROTECTION:

4.1 Among various available instrumentation techniques, Cathodic protection is the only technique which can stop the corrosion of the reinforcing / pre-stressing steel. **It controls corrosion by applying an external source of direct current (DC) to the surface of the embedded steel. Cathodic protection supplies an external energy to the steel surface to prevent the formation of ferrous ions by forcing all reinforcing steel to function as a current receiving cathode. There are two types of cathodic protection systems available i.e. i) Impressed current system and ii) Sacrificial anode systems**

4.2 Impressed current system: It is the most widely employed one. This system requires the following components:

i) External DC power source (Rectifier)
ii) Current distribution Hardware (Anode)
iii) Completed Circuit (Wiring)
iv) Evaluation and control devices (Probes, Reference Cells, Controller)
v) Conducting Electrolyte (Moist Concrete) and Protected Metal (Re-bar/pre-stressing cables) inherent in the structure.

4.3 Sacrificial Anode System: Sacrificial anode cathodic protection system utilise zinc anodes placed in saw cut slots in the decks or on the deck and followed by an overlay. A natural galvanic potential exists between the zinc and steel re-bar. Cathodic protection current, using this natural voltage, flows from zinc to the re-bar. No external power is needed. Several evaluation projects have met with only limited success.

4.4 In India, Cathodic protection for concrete structures is only at research stage. Central Electro-chemical Research Institute (CECRI) Karaikudi provides services in the field of Cathodic protection. For more details refer to chapter no. 9 of RDSO's report no. BS-14 (revised) of June, 2001 on "Durability of Concrete Structures".

5.0 CONCLUSION:

It will not be incorrect to state that the instrumentation of bridges is still at a primitive stage in India. But it is the time to make beginning. Therefore, instrumentation on some of the bridges can be adopted, as a trial, to pave way for future. Lot of bridge construction activities are going on in Northern

Railway on Jammu-Udhampur-Katra new BG line; a beginning can be made there.

REFERENCES

1. “Assessment of instrumentation for concrete bridges” by Dr. M.G.Tamhankar.

2. “Instrumentation and monitoring of New Yamuna bridge at I.T.O., New-Delhi” by V. K. Ghanekar, K. N. Agarwal, G. K. Sahu and J. K. Goyal.

3. “Construction of Airoli bridge across the Thane Creek” by A.R.Jambekar.

4. “Experimental procedures to measure internal strains in concrete physical models” by SD Butt, J.E.Gale, G.D.Dillabough and P. Lemessurier

5. “Strain Gages- Back to Basics” by Peter K.Stein.

6. RDSO report No , B.S. 14 (revised) titled as ‘Durability of concrete structures’.

7. Catalogues & Literature from following firms:

   i). PROCEQ SA, Switzerland.
   ii). James Instruments Incorporation, USA.
   iii). Colebrand Ltd. U.K.
   iv). Slope Indicator Co., USA.
   v). Sensors & Measurements Enterprises, Lucknow.
   vi). Gage Technique International Ltd., England.
   vii). Advanced Technology and Engineering Services, New Delhi

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