Third Godavari Bridge : Quality control measures

A. K. Sinha

A number of measures are taken to ensure quality in the construction of the third Godavari Bridge. The article highlights quality control measures taken in each activity of construction.

The third Godavari Bridge consists of unique bow string girders having a span of 94.00m. The length of the main bridge is approximately 2.74 km and there are 28 spans. The bridge has been designed by Bureau BBR, Switzerland, and checked by the Railway's proof consultant Leonard, Andrae & Partners, Germany. Very stringent quality control is exercised because the structure has been designed as per the international codes like DIN codes etc., and very high standard of construction quality is assumed.

Quality control measures

The arena of quality control extends right from the procurement of material and site planning to the last stages of the construction activity including even the maintenance of the structure.

Quality control is therefore exercised in each activity, right from the time of procurement of various materials to the final stages of construction. In order to exercise the steps properly, it is very important to monitor/predict the construction activities and requirement of materials. For this, a PERT network has ementeen developed for the complete bridge. Each activity of this network (like casting a segment of an arch) is further broken down to minute activities. So, every activity of the main network, has a detailed network of its own. The PERT network is made on the software HTPM (Harvard Total Project Manager) and depending on the actual progress the main network is updated every month. The computer indicates the requirement of materials/other resources in future.

Procurement/usage of materials

Various construction materials ranging from normal concreting materials like stone aggregate, sand etc., to the high quality construction materials like shrink sleeves, fatigue tested high tensile steel, high quality pot bearing components etc. are procured. The important quality control aspects being exercised regarding materials are brought out below :

High tensile steel wire

7-mm diameter high tensile steel wires having an ultimate tensile strength (UTS) of 1570 N/ mm^2 are used. Wire samples are taken in a random manner from each consignment and tested for various properties at the reputed laboratories. Specification of HTS wire which has to be adhered to is as follows:

1.	Tolerance in diameter	:	7mm ± 0.05 mm
2.	Minimum UTS	:	1570 N/mm^2
3.	Minimum percent of elongation at rupture	:	5 percent
4.	Proof stress (0.2 per cent)	:	1,335 N/mm^2 (min)
5.	Reduction in area due to necking	:	30 percent (min)
6.	Minimum bend radius	:	4 diameter (min)
7.	Modulus of elasticity	:	$2.01x10^5$ N / mm^2
8.	Relaxation test	:	1000 hour relaxation at 0.7 UTS not more than 8 percent.

HTS wires used in the DINA-hangers are subjected to the dynamic tests, in addition to the above. During testing the wire is subjected for a stress range of 200 N/mm^2 for 2 million cycles. Bureau BBR, Switzerland, have also done exhaustive tests both for single wires and cables, totalling over 70 tests and they have worked out the upper stress level and the stress range including maximum number of load cycles to which the cables can be subjected.

Also, it is ensured that the coiling of wires during handling is done in such a manner that the minimum radius of curvature is not less than 2 m. This is also ensured for the cables which are manufactured and despatched to the site. Any permanent bend/kink is rejected while manufacturing the cables. The wires are duly oiled and packed in hessain cloth during transport. After opening, the coil is given a coat of washable anti-corrosive liquid immediately to prevent onset of corrosion. The coils are stored in air tight sheds to prevent corrosion.

Chemical composition is checked on random basis. The range of the values is as given below :

1. Carbon : 0.90 percent
2. Manganese : 0.85 percent (max) - 0.76 percent (min)
3. Silica : 0.90 percent (max) - 0.60 percent (min)
4. Phosphorus : 0.35 percent (max) - 0.15 percent (min)
5. Phospherus : 0.05 percent
6. Sulphur : 0.05 percent

HDPE pipe, shrink sleeves, etc.

DINA hanger consists of 49 parallel fatigue-tested HTS wires concealed in HDPE pipes. For manufacturing DINA hangers and pot bearings, various high quality materials are required like very thick HT plates, shrink sleeves, HDPE pipe, Syntheso grease (imported) and fatigue-tested HTS wire.

The HDPE pipe is tested for tolerances in diameter and thickness upto 0.1 mm. The strength is tested at a temperature of 80°C by inducing water pressure inside the pipe for 170 hours. The hoop stress should be 4 N/mm^2 and the long-term internal pressure creep test, which is of prime importance and which determines the service life of HDPE pipe is also done as per DIN 8075. Other than these tests, elongation at break, Brinell hardness, Merl flow index, weldability test etc., have also been done as per DIN 8075.

The shrink sleeve is used at the joint of two HDPE pipes to give them continuity of strength. The shrink sleeves are tested for their tensile strength of 244 kg/cm^2 and the extent to which they may shrink after heating, thereby developing a firm grip.

Cement

Special quality cement confirming to IRS T-40 grade is used for this work and the cement consignments are tested on random basis as per the IRS code. Other than the usual tests the fineness (by Blaine's method) is seen which should be more than 3,700 cm^2/gm. The cement is properly stacked and stored in air-tight sheds, earmarked for it and the sheds are kept sealed unless cement is required to be issued.

Sand

Locally-available sand from river Godavari has been found to be suitable for the concreting purposes. At various intervals sieve analysis of the sand is done for checking gradation of the sand for the zone as per IS:383 and fineness modulus of sand. The bulkage of sand versus moisture content graph is also developed for rapid determination of moisture. The moisture is also checked by rapid moisture meter.

Coarse aggregate

Coarse aggregate is procured from the quarry belonging to the Railways so that the quality of the coarse aggregate remains consistent and does not vary because of variation in the source. Hard granite aggregate is used and it is machine crushed in a fully automatic crusher in two sizes of 20mm and 10mm maximum. These are used by mixing in 70:30 proportion. Size of coarse aggregate is monitored every month for the gradation by conducting sieve analysis including determination of flakiness index, elongation index, absorption of moisture etc., as per I.S. specifications.

Also, all-in-aggregate sieve analysis is conducted at frequent intervals to control the gradation of aggregate. The results are plotted on graph and any deviation is corrected by adjusting the crusher or altering aggregate ratio marginally.

Water

River water from Godavari has been found suitable for the concreting and grouting purposes. Whenever the turbidity increases during flood season, the water is stored well in advance in large storage tank and only clear water is drawn from the upper layers. Also, following tests are conducted regularly.

Chlorine test : It is determined by Chlorotex Reagent by adding 5ml to 50ml of water and comparing with the standard colour pattern.

pH value : pH value is determined by using Indikrom papers which when dipped in water indicates pH value by colour comparison. The pH value of water should not be less than 6.

Also, concentration of acid/alkali in ppm is determined by titration.

Concrete quality control

Concrete mix design

The concrete grade as per the drawing is M45 for arch, and M42 for other structures. The mix design of concrete has been carried out in an exhaustive manner by following the method of British Road Note-4 method. An approximate proportion of

Table 1. The minimum and maximum cube strength results alongwith standard deviation and characteristic strength of concrete for third Godavari bridge at Rajahmundry as on June 30, 1995

Aassumed standard deviation (As per IS:456:1978) in kg/cm^2	=	70.000
Assumed characteristic strength of concrete as per design in kg/cm^2	=	450.000
Number of cubes tested	=	3707
Minimum cube strength in kg/cm^2	=	398.700
Maximum cube strength in kg/cm^2	=	706.800
Average cube strength in kg/cm^2	=	571.840
Standard deviation of concrete in kg/cm^2 (Actual)	=	26.360
Characteristic strength of concrete in kg/cm^2 (actual)*	=	526.505
Calculation for the maximum, minimum and average cube strength results and for drawing histogram bar chart for 28-day cube strength results		
Value of minimum cube strength result	=	398.700 kg/cm^2
Value of maximum cube strength result	=	706.800 kg/cm^2
Value of average cube strength result	=	571.840 kg/cm^2
Number of results falling in first interval	=	3
Number of results falling in second interval	=	1
Number of results falling in third interval	=	1
Number of results falling in fourth interval	=	150
Number of results falling in fifth interval	=	713
Number of results falling in sixth interval	=	1649
Number of results falling in seventh interval	=	1035
Number of results falling in eighth interval	=	120
Number of results falling in ninth interval	=	25
Number of results falling in tenth interval	=	10

Total number of results for all intervals	=	3707

mix was arrived at using this method and trial tests were conducted for different cement content and water-cement ratio. Also, the ratio of coarse aggregate and fine aggregate was varied keeping the above two parameters constant. The ratio of mixing two types of coarse aggregates 10mm down and 20mm down was also varied keeping the above three factors constant. Therefore, numerous trial test cubes were tested for the above parameters and finally the proportion was arrived at as 1 :1.258 : 2.142 with cement content of 500 kg/ m^3 for water-cement ratio = 0.38 adopting a mix of 20mm : 10mm coarse aggregate in 70 : 30 proportion.

Monitoring of strength of concrete

The required number of concrete cubes are taken as per clause 14.2 of IS:456, for testing, duly covering all components of structure on rotation basis. The concrete cubes are tested for 3 days, 7 days'and 28 days in the concrete testing machine of 300t capacity available at the site.

In order to get the overall idea of quality of the concrete, the cubes are taken from each arch segment at 3 places, that is, rear portion, mid and front portions. Similarly, for starting stub and tie-girder also, the cubes are taken in random manner, so as to know the quality of each component.

The strength of concrete is monitored by testing the cubes. During concrete mix design the value of standard deviation was assumed as per IS code and similarly, other assumptions were also made. To cross check these assumptions and to monitor the strength -- the test cube results are fed in the computer and the statistical analysis is carried out by using a programme developed at site to determine the histogram of 28 days results of test cubes. The latest histogram drawn for 28 days cube strength results is shown in Fig 1. The minimum test cube strength is reported alongwith the maximum cube strength. Also, the mean (50 percent) average test cube strength result and the actual standard deviation as per the Formula $\sqrt{\frac{\sum[xi - x\ (AVE)]^2}{n-1}}$ are calculated with the help of computer. This exercise is done every month and reported.

Till date, 3,707 test cubes have been tested for 28-day results and the minimum test cube result found is 398.70 kg/cm^2 and the maximum 706.80 kg/cm^2 alongwith mean result of 571.840 kg/cm2. The latest actual standard deviation calculated with the help of computer is 26.360 kg/cm^2 as against the assumed standard deviation of 70 kg/cm^2. Also, the actual characteristic strength of concrete, that is, the value below which 5 percent of the test cubes fall (95 percent confidence level) is calculated and updated regularly and the latest value of actual characteristic strength of concrete (f_a) is 526.505 kg/cm ^{2} as against the required 450 kg /cm^2. The computer analysis of above are appended in Table 1.

The green concrete is tested for compaction factor with the standard compaction testing machine along with determination of wet density. Also, permeability tests are conducted for 28-day cured concrete cylinders.

Acceptance criteria of concrete

IS:456-1978 is followed for checking the acceptance criteria of concrete. This is done with the help of a computer by checking each test cube result as per provision. Till date, three test cube results have been found to be less than 450 kg/cm^2 strength, this is much lower than the allowed number (3,707 x 5/100) and, therefore, satisfactory. Following is the method followed for acceptance.

Assumed characteristic strength of concrete (f_a) = 45 N/ mm^2
Assumed standard deviation (a) = 7 N/ mm^2

Check for individual test cube results

Let any test cube result = f_a N/mm^2

Let characteristic strength = f_a N/mm^2

Let f_a - f_{ck} = f

If f > 0 = > O.K. (sample result is accepted)

$f < 0 =>$

Then, $f_a \not< f_{ck}$ = 1.35 or 0.80 f_a, which ever is greater, otherwise the sample result is not acceptable.

Let, average strength of all samples = f_{ave}

Then, $f_{ave} \not< f_{ck} + \left(1.65 - \frac{1.65}{\sqrt{n}}\right) x\sigma$. However; the concrete is not acceptable if $f_{ave} < f_{ck} + \left(1.65 - \frac{3}{\sqrt{n}}\right) x\ \sigma$.

These checks are applied for results as on June 30, 1995.

1. Latest average strength of all sample = (f_{ave}) = 58.350 N/mm^2
   Number of results = 3,707
   Assumed standard deviation (σ) = 7.00 N/mm^2
   So, $f_{ck} + \left[1.65 - \frac{1.65}{\sqrt{n}}\right] x\ \sigma = 45 + \left[1.65 - \frac{1.65}{\sqrt{3707}}\right] x\ 7.00$ = 56.36 N/mm^2
   Whereas, latest f_{ave} = 58.35 N/mm^2 > 56.36 N/mm^2
   Hence, O.K.
   The graphical representation of the above is shown Figure 2.

2. Sample results lower than f_{ck} , that is, 45 N/mm^2
   The lowest cube resut (f_{a1}) till date = 39.87N/mm^2
   Now $f_{a1} - f_{ck} = f$ = 39.87 – 45 = 5.13 N/mm^2 so, f < 0
   Now f_{ck} – 1.35 σ = 45 – 1.35 x 7.0 = 35.55 N/mm^2
   and 0.80 f_{ck} = 0.80 x 45 = 36.00 N/mm^2
   Greater value = 36 N/mm^2
   No cube test result < 36 N/mm^2
   The lowest test result = 39.87 N/mm^2 which is more than 36 N/mm^2. Hence, O.K.

Quality control measures for other activities

Care taken during manufacturing of prestressing cables

For manufacturing cables, the cutting length of wires is determined by an electronic distomat by measuring the actual span length of the particular span for which cables are to be manufactured. Then the determined cutting length is marked on the cutting bench to an accuracy of 0.5mm again by the distomat. The wire is given a standard pull during cutting to eliminate sag. The temperature correction is also applied depending on the prevailing temperature at the time of cutting of wires. The wires are preferably cut in the night when the ambient temperature remains quite stable. All the wires should be parallel to each other without any inter-twining. To ensure this, each wire is given a colour code so that a particular wire passes through its nominated hole in both anchor heads thereby ensuring separation and parallelism. Also, before passing wires from the anchor head holes, the bunch of wire is combed by a combing device to eliminate the mixing of wires.

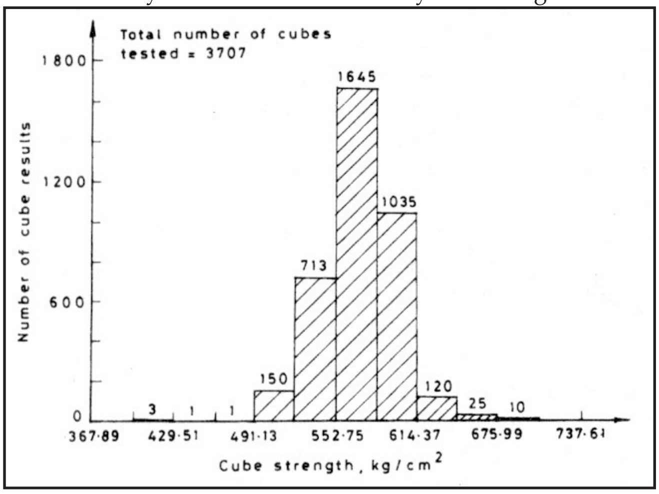

Figure 1. Histogram for 28-day cube strength results

The button-heads are achieved by pressing the end of wire hydraulically which results in a predetermined bulge in the form of a button head. The accuracy of a button head is also checked by slide callipers and gauge etc. to ensure the following specification :

1.	Height of button head	: 7.10mm to 7.30mm
2.	Diameter of the button head	: 10.30mm to 10.40mm
3.	Eccentricity of button head	: > 0.35mm (max.)
4.	No. of cracks	: Nil.

After manufacturing, the cables are coiled by automatic coiler for transportation. This ensures uniform curvature in the coil.

Care taken during DINA hanger manufacturing

The DINA hangers are BBR, Switzerland, manufactured at Bangalore as per specifications. Here also cutting length of wire is determined by electronic distomat and standard pull is given to the wire through spring. The tolerance of button head which is here trapezoidal in shape is checked by means of go-and-no-go gauge and callipers with regard to the diameter, height and eccentricity. Normal care taken during manufacturing of other cables is taken here also with regard to parallelism etc. The hanger is concealed in HDPE pipe, the lengths of which are joined by the fusion method of welding at 125°C and after cooling the joints are tested for flexural strength.

An epoxy compound is injected into anchor heads at both ends with the help of compressed air and proper filling at correct pressure is checked finally. The annular gap between 110mm and 125mm diameter HDPE pipes is filled with imported PE (poly ethylene) tape in which electrical wires are embedded and when a current of 7 amperes is passed through the wires the tape fuses to seal the gap in an effective manner.

Finally, the shrink sleeve (a sleeve which when heated shrinks) is used to bind the two lengths of HDPE pipes duly over-lapping on each side. The shrink sleeve is shrunk by heating and proper shrinking is ensured by measuring the shrunk length and the shrunk diameter and comparing them as per specification. The shrink sleeves are tested for pull test and hoop stress capacity by random sampling. Finally, the DINA hangers are loaded for transport ensuring again that the radius of curvature is not less than 2m anywhere.

Manufacturing of the bearings

Four types of pot bearings are used in this bridge, namely, free to slide in both directions, free to slide in longitudinal direction, free to slide in transverse direction and fixed. These are manufactured in Bangalore as per the specifications of Bureau BBR, Switzerland. Various components used in the manufacturing of bearings are procured and assembled at BBR(I) factory, Bangalore. For the pot bottom which is 107mm thick, HT plate was imported from West Germany, because as a quality control measure two plates of lesser thickness were not allowed to be joined together by welding. The dimensional tolerance of all the components of bearings are ± 0.10mm (max), the lay out of the bearing is such that any increase/decrease in dimensional tolerance would render the assembly of the bearings impossible. The following components of bearings are checked for dimensional tolerances.

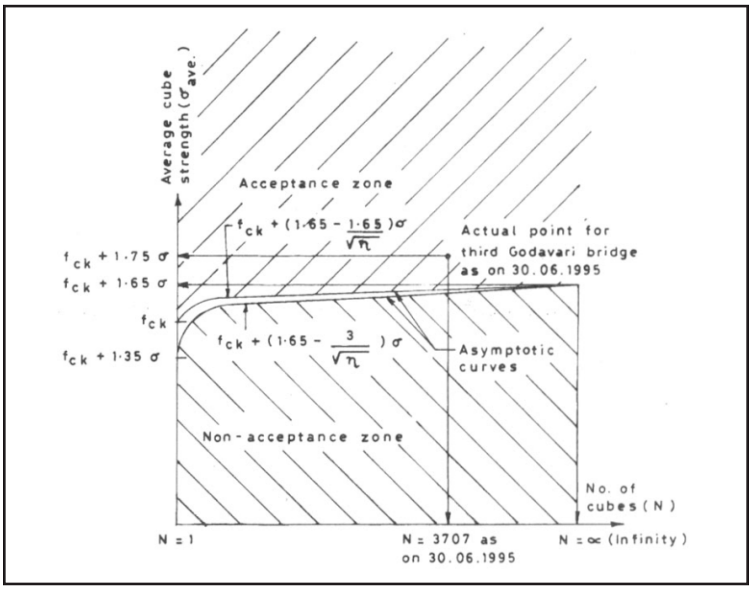

Figure 2. Comparison of the graphical representation of acceptance criteria of concrete

1. Pot bottom (HT plate)
2. Elastomer pad
3. Brass rings
4. Pot cover
5. PTFE sheet with circular recesses
6. Guide bar
7. Sliding plate with ultra smooth stainless steel plate attached to the bottom.

The above components are also checked for their specified hardness by means of an equotip apparatus for steel material and by shore hardness tester for elastomer pad. The equotip hardness is being measured by L.D. number ranging from 400-500. A steel sheet of very high smoothness is attached to the bottom of the sliding plate and the smoothness of the steel sheet is measured electronically at the factory just before assembling because till then the steel sheet is kept under cover so as to avoid any dirt particles settling on it.

Syntheso grease (imported) applied on the PTFE sheet is very smooth and does not harden or form a cake even after a long time.

Care taken during concreting

Semi-automatic weigh batching plants are used for producing the concrete. Before every concreting operation, the rapid moisture meter is used to determine the moisture content in fine and coarse aggregate and the water is adjusted accordingly. Also, the bulkage of sand is read out from the graph of moisture content versus bulkage of sand (developed at site for the particular sand being used). The moisture content in the coarse aggregate is measured by rapid moisture meter and water is adjusted accordingly. Minor and final adjustments of water content is done after actual vibration of the concrete is taken up.

The concrete is transported and placed within few minutes by means of a crane to avoid setting. The vibration of concrete is done using needle vibrators, shutter vibrators to give a uniform and thorough vibration and to eliminate any sort of honey-combing.

Retarder-cum-plasticiser is used to increase workability and delay the setting, thereby eliminating any cold joints.

Care taken during surveying

The survey is conducted using sophisticated survey instruments like T-3 theodolite, electronic distomat, N-3 level, all station instrument etc. The old bridge is used as a base-line for conducting survey, on which, GTS bench mark is also available. The GTS bench mark level is used to cross check any disturbance at other levels marked for survey purpose due to movement of trains. The perpendicular distance between the pier of old bridge and the new bridge is measured by an electronic distomat at all locations. Also, the spans of the old bridge and new bridge are measured by electronic distomat upto an accuracy of 1 mm. Thereby, a grid is made and plotted to enable further survey works. The survey of the arch requires three dimensional survey and is carried out from the old bridge whereas alignment is controlled from new bridge itself. The correct geometry of the arch as per the drawing is ensured within a tolerance of lmm both in the level and in alignment.

Before casting any segment of arch, the alignment and both X co-ordinate and Y co-ordinate are checked. Also, before undertaking the actual concreting of the segment the DNA inserts are fixed in the arch keeping the shutters at the theoretical level so as to ensure true verticality of the DNA inserts. This is because after concreting, the segment comes back to the theoretical level and then DNA anchors will be truly vertical. Therefore, X and Y co-ordinates are ensured within 1 mm of accuracy including the alignment of the arches. Also, any correction whatsoever in the alignment of the arches are fed to calculate the revised X and Y co-ordinates and viceversa. The verticality of the DINA anchors is also cross checked by means of the theodolite frequently. The location of the DINA anchors in X-direction, Y-direction and Z-direction is ensured upto a tolerance of 1mm. Each segment of the arch is controlled with respect to X, Y and Z co-ordinates at three points to ensure a correct profile of the arch.

For placement of bearings on the pedestals, for determination of level of various prestressing cable duct anchors, for determining the level of springing point of arch and for determining the level of scaffolding of tie-girder including concreted portions, a high precision level instrument of N-3 type is used. The accuracy of the instrument is 0.01 mm.

The correct level of bearing is ensured at not less than 5 points including the centre of bearings. In order to determine the correct level of anchors during casting of starting stub, N-2 type instrument is used to an accurancy of 2 mm. For tiegirder concreting the tie-girder scaffoldings are given a positive precamber as per drawing and these levels are checked using N-3 level upto an accurancy of 0.01mm. The flexing of tie-girder during concreting stages is monitored by taking these levels on DINA mild steel pipe. Also, flexing of arch during this period is monitored and verified as per the design.

All the above survey works are carried out in the morning hours as far as practicable in cool temperature and care is taken to cross check results either by placing the instrument at different locations or by the method of intersection using two instruments at a time. Extensive use of walkie-talkies is made during survey works to avoid any mistake due to lack of communication. Also, recently an All Stations Instrument, that is, Eletronic Distomat fused with Electronic Theodolite has been procured to conduct the survey works with even a higher accuracy of 0.5 seconds. This instrument has a memory card which records all results automatically thereby obviating any mistake due to wrong entry. Also, this instrument applies correction automatically whenever the vertical axis of the instrument is not truly vertical. It also calculates horizontal distance, vertical distance, reduced level etc. Also, it is possible to do survey of hidden points. The instrument feeds/retrieves data directly from computer.

Quality control measures during prestressing of cables

The prestressing cables are stressed by means of a hydraulic jack of suitable capacity, operated by an electrically-operated hydraulic pump. In this project electrically operated hydraulic pumps have been imported from Switzerland, and these pumps are having a pumping capacity of 1.5 to 2.5 litres per minute. The pressure is read by means of a pressure gauge attached to the pump, the least count of which is two bars. For accurate stressing like final stressing, an accurate pressure gauge called Wiga meter is used, the least count of which is 0.1 bar. The Wiga meter is a sophisticated instrument and is imported from Switzerland, and is electrically operated. The jacks used for prestressing works are double-acting type which enables to execute the work in less time to avoid any variation of temperature. To reduce prestress loss, the second cycle of prestressing is taken up after one month.

Double-end two cycle stressing is adopted to ensure that the prestress is distributed over the complete length and also to reduce the loss due to steel relaxation, creep, shrinkage and friction. The actual elongation of cables is checked against theoretical elongation. For final stressing the elongation is given priority while during intermediate stressing (during construction stages) the force is given priority. This is done with a view to uniformly distribute the prestress force all along the length of the tendon. During construction the tendons are stressed to balance various forces (like arch thrust) and hence no force is given priority.

Care taken during grouting of cable ducts

The grouting is undertaken in the early hours of morning to ensure that the grout temperature is below 33°C. If needed, ice is added to water. Cement used is not older than 2 weeks from the date of manufacturing and it is seived through 300 microns sieve. Expanding type retarder is added to enhance flowability, to retard initial setting time, to reduce bleeding and eliminate shrinkage.

Every duct is checked for water tightness by pumping water at 7 bars. Any seepage/leakage is sealed and the duct is rechecked until all such places are properly sealed. For sealing, high strength admixure is used which is also waterproof. After the grout is completely filled in the duct a stagnating pressure of 7 bars is given for at least 2 minutes to ensure that any crevices, are filled up properly.

Electrical, mechanical systems are checked by actual running of the systems so as to minimise any failure during the operation. Also, an air-compressor of 10 bars capacity is kept ready to wash any duct, if needed. During grouting ambient temperature, water temperature, grout temperature, flow cone test, bleeding test and expansion test are conducted.

Conclusion

It is evident that stringent quality control measures are taken at all stages of construction to ensure a sound structure. This is proved amply by the results obtained during the load test conducted for the first span in January, 95. The results showed that the actual deflection of arch and tie-girder was in fact less than the theoretically computed results. During the load test the structure behaved almost exactly at it should have, thereby establishing the soundness of the structure.

A.K. Sinha, Deputy Chief Engineer, South Central Railway, Rajahmundry - 533101.

(Source: ICJ July 1995, Vol. 69, No. 7, pp. 408-413)