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To

All Chief Engineers/Additional Chief Engineers of State PWDs/Union Territories

Sub : Article of interest in Engineering Journals properties of epoxies and their usage in cantilever segmental bridge constructions

Please find enclosed a copy of the extracts from the paper presented by Dr. M.G. Ernani Diaz during the Technical Session, at the New York Congress. These extracts appeared in FIP Notes 52, 1974 and deal mainly with tests carried out on various properties of the epoxies used and their variations with time and other factors. This article may serve as a useful guide in precast-prestressed-segmental construction type of bridges.

Enclosure to letter No. PL-87 (16)/75 dt 1.8.75

GLUEING TOGETHER OF PRECAST ELEMENTS IN BRIDGE CONSTRUCTION

One of the papers presented during the Technical Session at the New York Congress, described the construction work on the Rio-Niteroi Bridge. The paper was presented by Dr. M.G. Ernani Diaz (Brazil) and extracts, dealing with the glueing techniques, are given below :

The extracts deal mainly with the tests carried out on various properties of the epoxies used and their variations with time and other factors.

The Rio-Niteroi Bridge is part of the 13 km long roadway, crossing the Guanabara Bay, between the cities of Rio de Janeiro and Niteroi. For a length of nearly 8 km, over the sea, the superstructure consists of continuous box girders, built in prestressed concrete. The normal spans are 80 m in length and the width of the bridge is 26.6 m.

The prestressed spans were precast as two separate structures, joined together by transverse prestress after erection. Each span of 80 m was formed of 17 precast elements, with a maximum weight of 110 tonnes. The precast elements were cast one against the other, so that each contact surface of an element corresponded exactly to the contact surface of the adjacent element. Joints were formed with Epoxy resin, 1.00 to 1.50 mm thick. The main longitudinal reinforcement consists of cables with approximately straight trajectories. Each box girder normally has 42 cables (12 strands, 12.7 mm diam) as top reinforcement and 14 cables of the same type in the bottom. There are not inclined tendons in the webs, so that all shear must be carried by the stirrup reinforcement and the vertical prestressing bars and, of course, by the diagonal compressive stresses in the webs.

The bridge was erected in about 22 months, with the help of 4 erection gantries. A normal span of 80 m was usually erected in 5 days.

Structural behaviour of the glued joints

Usually in the design of glued bridges it is required that there be no tension stresses in the concrete under service loads. This requirement is important because of the necessary security against formation of bending cracks. In the glued joints, the longitudinal normal reinforcement has no continuity. As a result, at these joints, cracks have a tendency to develop under specific loads, higher than the service loads.

An important problem, is to know how a glued joint can influence a structure in its failure behaviour. There are two aspects to be analysed. One refers to the capacity of the joint to transfer only compression strsses, for instance, in a compression flange of a concrete I beam. In this case the conditions are favourable because the Epoxy glue has a higher compressive strength than the concrete and the stresses are perpendicular to the joint. On the other hand, the transfer of shear stresses in a web of a beam is far more important. This problem must be studied very carefully and the influence of the glued joint on the shear capacity of the beam has to be determined.

In the case of the Rio Niteroi Bridge, where no inclined tendons have been used in the webs, in the plane of the joint the shear must be entirely carried by the vertical components of the diagonal compressive stresses which exist in the web between the cracks, for loads near the failure of the beam. It is important to notice that even with inclined tendons in the webs, in almost all the existing glued bridges with constant depth, the shear must be carried essentially in the same way in the ultimate limit state, in view of the relative small part of the shear carried by the vertical components of the cable forces in that state. For bridges with variable depth, the problem has the same degree of importance because of the high shear stresses in the bridge webs.

Experiment on a model of a glued structure

In order to be able to examine the behaviour of a glued structure up to failure, an experiment was made on a structural model of the bridge to a scale of 1:6. The model represents the part of the bridge near the support and the corresponding 7 precast elements. This part of the structure is critical, because of the relative high values of shear force and moment. The main structural characteristics of the bridge were reproduced, although an I section for the model was adopted. The precast elements of the model were cast exactly as the bridge segments were cast, i.e. cast one against the other. In the contact surface of the web, a key was used in order to provide contact between the elements. The transverse reinforcement in the web of the model corresponds only to that used in the bridge to carry the shear forces, and not to that used to resist the bending moments in the plane of the web.

The failure in the model was due to web-crushing, which occurred prematurely, because the yield strength of the steel in the stirrups had been attained. The conventional tangential stress in the web was 6.8 MN/m2, or 0.23 of the mean cylinder compressive strength of 29.5 MN/m2. The glued joint did not interfere with the trajectories of the inclined web cracks and the web-crushing failure occurred as if the beam were monolithic.

The first detected bending cracks occurred at 93% of the computed cracking load, which was determined as the load which produced a bending stress in the tension flange of 3.9 MN/m2. The bending cracks have a tendency, as would be expected, to build up in the joint zone, where the normal reinforcement has no continuity.

Defining 'r' as the relation between the measured stresses in the stirrups and the theoretical stresses according to the classic Moersch truss theory, a value of 0.642 was obtained for r for the mean value of the measured stresses, and of 0.817 for the maximum measured stresses. This shows that glued joints do not interfere unfavourably with the behaviour of the stirrups. This is to be expected, as the direction of the cracks have not been changed by the joints.

Model for the investigation of a jointed web

For the evaluation of the behaviour of a glued web, it was necessary to provide a model of a web with a glued joint. For the Rio-Niteroi bridge, 3 types of test specimen were used. One type corresponded to a cylinder, 0.30 m high and 0.15 m diameter, with an inclined joint at midheight. This test specimen was used initially, but was abandoned owing to the difficulty of joining the two parts perfectly by a glued joint.

Later, a prismatic test specimen was developed with an X-form. In cross section it is 0.15m x 0.15 and has a height of 0.4 m. In the direction perpendicular to the plane of the joint, two concrete projections are provided, which allow the application of a normal stress to the joint during the glueing operation, which is carried out during the erection of the precast elements of the bridge. In order to allow perfect adjustment between the two parts of the test specimen, two keys were installed at the contact surface. These projections consist of two half spheres 20 mm diameter. Otherwise the joint surface is a plane. In a special series of tests, to reproduce the 3 keys used at the bridge 3 keys were provided at the glueing surface of the test specimen.

In the preparation of the tests specimen, initially one part is cast. After the first one is hardened the other is cast against the first. Before the glueing operation the two surfaces are sandblasted, similar to the sand-blasting of the precast elements of the bridge.

Properties of the cured Epoxy resin

The main properties of the cured Epoxy resin which should be examined for use in the erection of precast elements of bridges are as follows:

a. Behaviour of the cured resin at high temperatures
b. Pot life
c. Resin strength
d. Curing properties
e. Viscosity
f. Thixotropic properties
g. Rating for compression test with glued test specimens
h. Mix-sensibility of the Epoxy resin with the hardener
i. Work conditions for mixing the resin and hardener

It is well known that cured resin is a material, which does not retain its properties under high temperatures. Therefore special care must be given to the investigation of the behaviour of the cured resin at high tempratures, as well as to the study of the creep values for service temperatures. For application at the Rio Niteroi Bridge a product was chosen, which had shown the best qualities in regard to maintaining the values of the modulus of shear, G, at high temperatures.

The strength of the cured resin was measured with the help of a bend test on a prismatic test specimen (40 mm × 160 mm). For the bend test, a point load was applied in the middle of a 140 mm span. The tensile strength of the Epoxy resin system with an age of 6 hours varied very much depending on the air temperature and on the temperature of the mix. These values for a 6 hours old glue and for the work conditions at the bridge site in Rio de Janeiro (variable temprature from 13° to 39°C) varied between 8 MN/m^2 and 20 MN/m^2. The 7 day old cured Epoxy resin presented a mean bending tensile strength of 29MN/m^2.

The variation of the tensile strength with the temperature of the 7 day old Epoxy resin used on the bridge was the following:

Temperature oC 23 36.5 50 65.5
Mean bending tensile strength MN/m^2 30 27.4 25.5 25.4

The variation of the bending modulus of elasticity as a function of the temperature for the same 7 day old Epoxy system can be represented using the following values:

Temperature oC 23 36.5 65.5
Modulus of elasticity GN/m2 6.3 4.46 2.21 1.95

It was shown by Q. Guedes that the splitting tensile strength (40 x 40 x 40 mm^3) is on the average, 28% of the bending tensile strength. (40 x 40 x 160 mm^3) for the above Epoxy system. It was also determined that the bending tensile strength was on the average 51% of the compressive strength (40 x 40 mm^3).

In a compression test on a test specimen having an inclined glued joint, it can be verified that a reduction in the compressive strength always exists in relation to the test values determined in monolithic test specimens. One of the most important required properties of the cured Epoxy resin to be used in segmental bridge construction is to keep this reduction very small. In the case of using a prismatic test specimen with an X-form, the compressive strength measured in test specimens with glued joints, varied from 90% to 98% of the compressive strength measured on monolithic specimens. The relation between the compressive strength measured for prisms with an X-form and the compressive strength measured for cylinders (h=300 mm/150 mm) has a mean value of 0.87. The larger values are obtained for the cylindrical test specimen. For example, the following values for the mean compressive strength utilizing a 7 day old cured resin were obtained.

Measured in monolithic cylindrical test specimen	53.4 MN/m^2
Measured in glued prismatic test specimen (a)	42.8 MN/m^2

Computed for monolithic prismatic specimen (b)	46.4 MN/m²
Efficiency = (a)/(b)	0.92

A very important consideration in the erection of the precast elements is to be able to predict the compressive strength of a glued test specimen, with a low-age cured resin. During erection, it is easy to measure the bending tensile strength of the cured resin, therefore the relationship between the bending tensile strength measured in a prismatic test specimen, using the X shape, was studied. The efficiency of a 7 day old cured resin had a mean value of 0.96. The prismatic test specimen with the X shape allows application of the variable normal stress at the joint during the curing process of the resin. In the erection of the precast elements of the bridge, the next element could be erected 4 hours after the adjacent unit. In this way, the stress at the joint is increased during a period in which the Epoxy system is not completely cured. For investigation of the influence of this fact, an investigation was made of the variation of the compressive strength measured in glued concrete prisms with two different conditions of joint prestress. In the first condition, 15 minutes from the mix-time, the joint was subjected to a compressive stress of 0.15 MN/m2 and the prism was tested after 6 hours and 45 minutes (age of the Epoxy system 6 h 45 min). In the second condition, the joint was compressed to a stress of 0.15 MN/m2 after 45 minutes, the compressive stress was then increased to 10MN/m2 and after 6 hours 45 minutes the prism was tested (age of the Epoxy system 6 h 45 min). It was determined that the compressive strength with the second condition of prestress was 1.29 times greater than the first condition, i.e. an increase of the compressive stress in the glued joint during the process of curing of the resin is not prejudicial.

Because 3 keys exist at the contact surface of the bridge precast elements, a series of experiments was conducted using a prismatic test specimen having 3 keys at the joint. It was shown that the prism with keys at the joints has a mean efficiency of 0.42 even without resin in the joint.

Investigations concerning erection problems

At the beginning of construction, investigations were made to determine if it was necessary to undertake any treatment of the contact surfaces of the precast elements, where a layer of talc and soap had been used to prevent bond between the old and the new concrete. It was seen that the test specimens, without any joint treatment, had compressive strength values which were 78% of the compressive strength values obtained with test specimens with washed and brushed joints. In view of these results it was decided that the contact surfaces would be sand blasted in the construction yard.

The control of the Epoxy system during the erection was done essentially through the determination of the bending tensile stress (40 x 40 x 160 mm³). Three test specimens were prepared for each glued joint using the Epoxy system adopted for the bridge. They were tested near the erection site, along with the erection of the precast elements. The main idea was to control the curing of the Epoxy system and, in case of doubt about the quality of the glue, to stop the erection. In this way, any construction problems associated with a glued joint subjected to the action of high values of forces could be avoided.

The curing process of the utilized Epoxy system in the first hours was very dependent on the air temperature, the temperature of the mix and even the material. In view of the fact that erection went very fast (it was usually possible to erect a precast element every 6 hours) and occurred during the day and night it was essential to control the curing of the Epoxy system, and to check to see if the shear force in any given joint could be carried with sufficient security with the available tensile strength of the cured resin.

Another problem investigated was the influence of wet surfaces on the results of compression tests. Below are the computed efficiencies for a seven day old Epoxy, obtained with the help of glued concrete test specimens with different joint surface conditions:

	Efficiency
wet surface	0.55
humid surface	0.58
humid surface dried with anhydrous alcohol	0.72
humid surface dried with anhydrous alcohol and heat	0.92
surface dried with air spray	0.37

It can be noted that glueing on wet or humid surfaces should not be allowed. Because it is possible that the surfaces could become wet during a rain shower, a process was developed to dry the contact surfaces. This process consists of removing the water on the surface with a cloth, spraying anhydrous alcohol over the surface and burning this alcohol. It was also seen that a delay in the glueing operation had no negative influence on the compression test values. It was feared that water, by capillarity, would come to the contact surface, harming the curing of the glue.

It was also established that, if the contact surface is dry but yellowish, because it has been contaminated by water containing rust (iron oxide), the concrete strength measured in glued test specimens is 90% of that of test specimens with clean surfaces. In this case, the contaminated surface of the precast elements were cleaned by sand blasting at the erection site.

In a few cases, during the erection the contact surfaces were contaminated with oil from the prestressing jacks. It was established that cleaning the oil with anhydrous alcohol and sand blasting the surfaces gave satisfactory results for the compression strength.

Injection of prestressing ducts and joint waterproofing

During the erection, where too much Epoxy is used, the mix is squeezed and can be forced inside the prestressing ducts, preventing the cable threading operation. The recommended technique is to thread a wire brush from the face of the precast element through the ducts and clearing them, immediately after erection.

In cases where the design provides a cable distribution having cables side by side at the glued joints, there will be passage of mortar between the ducts at the joints during grout injection. In this case it is necessary to use simultaneously two injection pumps, to ensure that the two ducts are completely filled with mortar. The design must provide, however, that only the same two cables can touch at the glued joints, because otherwise more injection pumps would be required.

As an additional security against the penetration of water at the joints, the superstructure of the Rio-Niteroi Bridge received a coal-Tar-Epoxy waterproofing membrance at the joints.