BART aerial structures, creep and shrinkage control: part II: laboratory testing and field performance

II

BART Aerial Structures, Creep and Shrinkage Control
Part II: Laboratory Testing and Field Performance

La structure aérienne du BART — Contrôle du fluage et du retrait
Partie II: Essais de laboratoire et comportement sur le chantier

BART Hochbahnstrecken — Kriech- und Schwindkontrollen
Teil II: Materialprüfung im Labor und Leistungsfähigkeit des Bauwerks

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The reliability and reproducibility of concrete tests have been questioned since their advent. Test procedures for determining shrinkage and creep characteristics have been used in the United States for many years. However, none of these procedures has attained a degree of acceptability comparable to the standard compressive strength test. In the United States this standard test is defined by the American Society for Testing and Materials as ASTM Designation C 39. The test is performed on a cylindrical specimen 6 inches in diameter by 12 inches high, and at an age of 28 days. The coefficient of variation of the results of this test is about 15 percent when applied to field produced specimens. The results of shrinkage and creep tests show considerably greater variation.

The most widely accepted shrinkage test in the United States is ASTM Designation C 157. This test was developed for use in a laboratory, and its application as a control test to field situations is questionable. In recent years the Division of Highways of the State of California has used a shrinkage test similar to ASTM C 157 as one test for the acceptability of set retarding, water reducing admixtures. The test is applied to determine the laboratory characteristics of a product. Once these have been determined, the product is accepted or rejected and no attempt is made to control its field performance. All of California's work is performed in their own laboratory using their own trained technicians. Such an ideal laboratory situation is enviable, but unrealistic for a private consultant to contemplate.

In the San Francisco area a number of shrinkage tests using a variety of test specifications and different sized specimens have become popular in the building industry. Most of these have been performed by privately owned laboratories. While the general quality of the work done by these laboratories has been good, the reproducibility of the shrinkage results produced by them has been notoriously poor. Part of the fault lies in the fact that large storage facilities with controlled temperature and humidity are extremely expensive. In 1964 the only private facilities available were small make-shift boxes. In addition, no private laboratory had attempted a creep test.

Since BART was committed to using private testing laboratories, it was necessary to develop test procedures and also to stimulate the development of the laboratories to implement them. To accomplish this goal, it was necessary to develop a test which provided enough consistency so that it could be reproduced by several private laboratories. Also, the test had to be simple enough to be economically feasible and sophisticated enough to provide satisfactory results.

It was decided to use a comparison test rather than an absolute value test. That is, the results of the test mix, the concrete proposed by the contractor, were compared with those of a predetermined control mix. This procedure helped to eliminate the differences between the various laboratory facilities and their personnel. Unfortunately, it doubled the work and the cost of each test.

A specific aggregate source was used for the control mix. The aggregate is nearly pure quartz. It is rounded, river-run aggregate with a bulk specific gravity of 2.62, and an absorption capacity of 0.5 percent. The sand produced relative mortar strengths in excess of standard Ottawa sand mortar. Because of the unusually tight control at the source, gradation was maintained within plus or minus two percent with minor rescreening in the laboratory. The cement used was a blend of three local Portland Cements. The cement factor and slump were set at the same values as those of the test mix. Proportions for a typical 7.5-sack control mix with a 3.5-inch slump were as follows:

Material	Quantity
Cement	705 lb
Water	289 lb
Sand	1,342 lb
Coarse Aggregate	1,574 lb

It was decided that because of the time and costs involved in testing, testing would be limited to a qualification test at the beginning of the job and follow-up tests every six months. The specification called for comparisons of compressive strength, modulus of elasticity, shrinkage, and creep as follows:

Property	Performance of Test Mix versus Control Mix (Percent)
Compressive Strength:	
at end of curing cycle	95 minimum
at 28-day age	90 "

Property	Performance of Test Mix versus Control Mix (Percent)
Modulus of Elasticity:	
at end of curing cycle	95 minimum
at 28-day age	95 "
Shrinkage, 14 days after end of curing cycle	130 maximum
Creep, 28 days after end of curing cycle	110 maximum

The overall quality of the concrete, or Class, was specified by cement factor and slump. Provided that the mix was not changed, only standard compressive strength tests were required during construction. The tests for compressive strength and modulus of elasticity are standard ASTM tests and will not be discussed here.

The shrinkage test developed was patterned very closely after ASTM C 157. It specified prismatic specimens 3 inches by 3 inches by 11 inches long. Length changes were measured over the full 11-inch length. Three specimens were required for the reference mix and three for the test mix. The curing procedure used for the test specimens was that method proposed by the contractor for field use. Generally, the contractors used an 18-hour steam curing cycle consisting of 5 hours of set time, 11 hours of steam at 140 degrees Fahrenheit and 2 hours of cooling. The control mix was cured for seven days in a controlled atmosphere consisting of a relative humidity of 90 percent or greater and a temperature of 73.4 plus or minus 3 degrees Fahrenheit. The shrinkage of the control mix and test mix were compared at an age of 14 days after curing.

The creep test was developed with the help of Professor Milos Polivka at the University of California at Berkeley. It specified cylindrical specimens 6 inches in diameter by 16 inches high. Length changes were measured along three 10-inch gauge lines located 120 degrees from one another around the cylindrical surface. Six specimens were required for the reference mix and six for the test mix. Three specimens were to be loaded in the creep frame and the other three were to act as shrinkage adjustment specimens. The curing procedures were the same as those discussed under the shrinkage test. The specimens in the creep frame were subjected to compressive stress of 1,200 pounds per square inch. After adjustments for elastic strain and shrinkage strain, the creep strain of the control mix and test mix were compared at an age of 28 days after curing.

About 3,000 girders were cast for the job. The majority of these were produced by a single contractor at a precasting yard which was completely rebuilt for the job. The girders were cast in steel forms on a concrete bed.

The concrete was placed by a belt conveyor and vibrated internally and externally. The fresh concrete was steam-cured and the girders were stressed in place before storing at the yard. Stressing was done with 1-1/4-inch diameter high strength alloy steel rods. The girders were transported to the job by truck and placed by crane. Field control consisted of the compressive strength tests discussed previously and controlling the camber of the steel forms.

The camber of the forms was shown on the contract drawings for each girder. These camber dimensions were originally calculated on the basis of the properties of the control mix. After the first 100 girders had been placed in the field, a survey was made of the amount of camber in each girder. The survey indicated that the finished girder camber varied by plus or minus 3/4-inch from the average camber. It also showed that the average girder camber was approximately 1/2-inch greater than the calculated camber. Camber surveys made at different ages indicated that elastic and shrinkage strains were higher than anticipated while creep strains were lower. No attempt was made to explain the discrepancy between the calculated camber and observed camber, but the specified form camber was lowered to produce the desired finished product.

While it might be argued that the field control, mainly compression tests, did not constitute field control of the elastic and inelastic strain properties, the finished product results indicated otherwise. Before track was laid on the structure, a profile of the girders was made. On one four-mile section which was studied in detail, the mean difference between calculated and observed cambers was less than 1/8-inch while the standard deviation was less than 1/4-inch.

The resulting structure will provide a safe and comfortable surface for the passengers of the 1970's to travel throughout the San Francisco Bay Area at speeds of 80 miles per hour.

SUMMARY

The reliability of concrete testing has long been questioned. Test procedures for shrinkage and creep characteristics are usually too time consuming and expensive to apply to field applications. The field performance of the BART aerial structures provides evidence that the tests developed for BART were effective in solving these problems.

RESUME

On a longtemps discuté de la validité des essais sur le béton. Les procédés des essais de fluage et de retrait sont généralement trop longs et coûteux pour être utilisés sur le chantier. Le comportement sur place des poutres de la structure aérienne du "BART" prouve que les essais développés pour le "BART"'ont résolu ces problèmes de manière efficace.

ZUSAMMENFASSUNG

Die Zuverlässigkeit von Betonprüfungen hat immer schon in Frage gestanden. Kriech- und Schwind-Untersuchungen für individuelle Betonbauwerke sind normalerweise zu zeitraubend und zu teuer. Die Leistungfähigkeit von BART's aufgestelzter Fahrbahn beweist, dass die speziell für BART entwickelten Prüfverfahren erfolgreich waren und dazu beigetragen haben, Kriech- und Schwind-Probleme vorteilhaft zu lösen.

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