PROGRESS REPORT ON THE USE OF LOW-SHRINK CONCRETE, EPOXY INJECTION FILLING OF CONCRETE CRACKS AND BORON LOADED CONCRETE IN THE ACCELERATOR HOUSING

REPORT TO STANFORD LINEAR ACCELERATOR CENTER - ABA NO. 96
STANFORD UNIVERSITY SUBCONTRACT S-136
UNDER AEC CONTRACT AT(04-3)-400

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July 7, 1964

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SYNOPSIS

Basic design considerations for the Accelerator Housing require the housing to have maximum structural integrity and minimum cracking of concrete. The use of low-shrink concrete and epoxy injection filling of concrete joints was considered essential to fulfill these design requirements. Experience to date indicates that utilizing low-shrink concrete materials in conjunction with carefully controlled concrete placing and curing procedures has been an efficient and economical means for meeting design criteria and has achieved highly satisfactory results. Likewise, the use of special epoxy injection techniques has been a satisfactory and suitable method for adequate sealing and repair of concrete joints and cracks.

Specified sections of the Accelerator Housing require concrete containing
to minimize effects on
a Boron additive to minimize radiation effects on the concrete. Boron frit added directly to the concrete mix has been used for this purpose. Additional tests have been conducted with another Boron additive, Colemanite, which will be specified for use in Target Area concrete sections having special radiation requirements.

INTRODUCTION

One of the most critical construction features of the Stanford Linear Accelerator project is the two-mile long concrete housing in which the accelerator tube will be mounted and aligned. The following report has been prepared to summarize progress and the reasons for the use of low-shrink concrete, epoxy injection filling of concrete joints and Boron additive concrete for the Accelerator Housing. The report first discusses the basis for the selection and application of these materials and then presents a brief summary of results to date.

The housing is a reinforced concrete enclosed structure designed as a continuous beam throughout its 10,000 foot length, with no expansion joints. Inside dimensions are 10 feet x 11 feet with 1½-foot thick walls, a 2-foot thick floor and a 2-foot thick ceiling. About 40,000 cubic yards of concrete were used for the housing construction. Twenty-three feet of highly compacted earth fill is placed over the housing which also rests on bedrock or select earth fill to minimize future settlement.

LOW-SHRINK CONCRETE AND EPOXY INJECTION

Design Tolerances

During the design stage of the Accelerator Housing, various means were studied in an attempt to find an economical method of producing and maintaining the alignment tolerances required for effective operation of the accelerator. The foundation conditions vary along the length of the accelerator, both in their geologic material and in the use of cut and fill sections. The cut sections occur where the material is excavated to obtain the required housing elevation; other areas required compacted engineered fill sections to provide the proper elevation for the housing.

The housing alignment tolerances during the proposed operating life of the accelerator were set at ± 0.01 inches in any 40 foot length during any 90 day period; no more than 1/4 inches displacement in the 10,000 foot length during any 90 day period; and ± 12 inches in the vertical or horizontal direction during the total life of the project. ABA studies concluded that, in order to meet these stringent requirements, it was essential to adopt a method of maximizing the structural integrity of the concrete housing by minimizing cracking in the concrete to the greatest extent consistent with eoonomy, and by "glueing" construction joints together. (These studies are summarized in Report ABA-68.) Concrete with low shrinkage characteristics, high strength, and good resistance to cracking was required.

Test Program

Many factors affect concrete cracking. Among these are the amount of drying shrinkage, the type of aggregate, the type of cement, the temperature during placing, the control of temperature range during curing and the control of temperature after curing. To ascertain the effects of aggregate, type of cement and the effect of water reducing admixtures on shrinkage, a research and testing program was instituted with the University of California. Professor Raymond Davis was retained as a consultant in this program. Test results and conclusions are contained in the Concrete Housing Report by Professor Davis dated 15 June 1963, and Test Results of Concrete Studies by the University of California, dated 12 June 1963.

The program results indicated that concrete made with granite aggregates such as those produced near Watsonville or American River gravel shows an appreciable reduction in shrinkage from concrete made with the usual local aggregates. The tests also indicated that the use of a high-grade crystalline limestone resulted in definite decrease in shrinkage. In addition, the concrete made with either of these aggregates showed a material reduction in the thermal coefficient of expansion. Concrete made with granite aggregate, a good grade sand such as Felton or Monterey sand, and a low-heat type cement, i.e., Type II cement, showed a reduction in shrinkage of approximately 60% and a reduction in thermal coefficient of expansion of about 40% when compared to concretes made with local aggregates. Concrete made with the limestone aggregate, good grade sand and low-heat cement showed slightly greater reduction in shrinkage and in thermal coefficient of expansion than the granite-aggregate concrete.

The testing program also disclosed that there was no significant difference in the shrinkage of concrete made with either type of water reducing admixture (hydroxylated carboxylic acid type or lignosulfonic acid type). Either admixture could be used without detrimental effects.

In general, the use of granite or limestone aggregates produced concrete with a much higher strength than concrete made with local aggregates and a similar cement factor. Also, these concretes developed higher early tensile strength; the increased early tensile strength tends to minimize cracking caused by sudden temperature drops during curing. As a consequence, a saving of slightly more than one sack of cement per cubic yard of concrete was realized. The tests showed that a low cement factor, from 4.5 to 5.5 sacks per cubic yard for 4000 psi concrete, could be maintained by using the largest size aggregate which could be properly placed, by good gradation of the aggregates, by maintaining a minimum slump consistent with proper placement, by using air entrainment and a water-reducing admixture, and by placing the concrete at a low temperature.

Other Considerations for Concrete Placing and Curing

Further analyses indicated that the Accelerator Housing could be constructed with construction joints at about 80-foot centers without intermediate cracking, provided that the temperature of the concrete could be controlled during placing and curing, and after curing.

In reviewing the possible construction procedures for maintaining control of the temperature during placing, curing and post-curing of all concrete until backfill was in place, some of the alternatives considered were::

a) placing concrete in the shade;

b) evaporative cooling;

c) curing compounds, both pigmented and clear;

d) lowering concrete placing temperatures;

e) cooling by use of ponded water.

It was concluded that the most efficient and most economical curing procedure for the housing would be the use of a fog-spray over the exposed concrete resulting in cooling by evaporation. Further, it was found desirable to cover the concrete with a 5/8" fiberboard (placed on a damp-proofing membrane previously applied) having a reflective outer surface to protect the concrete from changes in ambient temperature. The fiberboard would also serve to reflect solar heat and to protect the membrane during backfilling. Once the first 18 inches of backfill were placed, the concrete temperature would remain relatively constant until the accelerator operation commenced.

Epoxy Material for Injection into :Concrete Cracks and Joints

A survey was made of possible materials for "glueing" together jointed sections. Tests and field experience indicated that cracks in concrete could be filled by an epoxy-type material injected directly into the joints Methods have been developed to apply this material quite economically. The tests also indicated that concrete sections filled with epoxy attain approximately the same strength at the joints as do other portions of the concrete.

Specifications

To obtain the desired results indicated in the tests and analyses, the specifications included the following:

1. Concrete Aggregates: Concrete shall have a maximum shrinkage of 0.025% at the age of 35 days after molding when tested in accordance

with ASTM C157 as modified (modification mainly involves size of molded sample), and a thermal coefficient of expansion not to exceed 4.5 millionths per degree Fahrenheit.

2. Portland Cement: Shall conform to ASTM C150, Type II, with the following modifications:

   (a) Tricalcium aluminate content shall not exceed 6%.

   (b) Tricalcium silicate content shall not be less than 42% nor more than 50%.

   (c) Specific surface as measured by the air permeability test shall not vary more than 10% from the average of previously submitted samples.

   (d) Mortar cube strengths shall not be less than the following:

Age	Strength
3 days	1,250 psi
7 days	2,300 psi
28 days	4,500 psi

   (e) Cement shall all be supplied from the same mill unless a change in source is approved by the Manager.

3. Water Reducing Admixture: Shall not produce more than a 15% increase in shrinkage after 21 days of drying when tested in accordance with ASTM C157 as modified. Admixtures containing calcium chloride or any corrosive agent shall not be used.

4. Air-Entraining Admixture: Shall comply with ASTM C260 and the air content of the freshly mixed concrete shall be not less than 3½% nor more than 5%.

5. Temperature of the Concrete as Placed: Shall be not more than 60°F or less than 40°F.

   From May 15 to October 15, concrete placement shall be limited to the hours between 4:00 p.m. and 4:00 a.m.

6. Curing and Temperature Control:

   (a) Specified to maintain water for hydration of concrete as well as to reduce the range in temperature of the concrete during curing.

   (b) The concrete shall be kept wet by a fog spray system which will keep all surfaces to be cured continuously wet so as to promote evaporative cooling of the concrete.

   (c) This curing shall be maintained for a minimum of 14 days after placing of the concrete.

7. Dampproof Membrane and Protective Cover:

   (a) Within 24 hours after completion of the water curing, the contractor shall start to apply a protective membrane as specified.

   (b) Immediately following the application of the membrane, a 5/8" thick fiberboard with a white exterior surface shall be applied over the membrane. The purpose of this fiberboard with the reflective surface is to minimize the heat gain from the sun and to provide insulation of the concrete prior to backfilling.

8. Epoxy Injection:

   (a) Epoxy shall be a 100% solids epoxy adhesive with aromatic type curing agent such as M-Phenylenediamine.

   (b) Epoxy shall be injected as specified and core test results as taken by the Manager shall indicate a minimum 90% penetration for satisfactory completion of epoxy filling of all joints.

<u>Concrete Construction and Field Results</u>

The contractor constructed a concrete mixing plant on the job site and also installed an ice plant with a 20-ton per day ice making capacity. A granite aggregate, Felton sand, modified Type II cement, and an admixture meeting the specifications were used by the contractor.

Concrete was placed within the time specified and at a maximum temperature of 60°F. Construction joints were carefully cleaned (sandblasted) to ensure good bondage to fresh pours. Required patching was generally completed within 24 hours after stripping of concrete forms. Curing was accomplished by a continuous fog spray system. The curing water was drained away by the subdrain system provided with the housing. The temperature of the concrete was measured at the time of placing, by means of resistance thermometers after placing and during the curing period until the structure was backfilled. After curing, an adhesive sealer was used to coat the exterior surfaces and polyvinyl chloride dampproofing membrane was wrapped around the sides and top of the housing surface. (The membrane had been previously placed under the housing floor prior to placing of the concrete). Then the fiberboard was positioned over the sides and top of the surface and, finally, the earth fill was placed and compacted to the required density.

The construction results have indicated that the methods used generally kept the concrete temperature within a range of 25°F to 30°F above the placing temperature. Concrete placed to date has developed minor cracks only at construction joints except for two small areas where thicker slabs (4 feet thick) were necessary due to larger spans; here the temperature of hydration was such that the temperature range was between 40°F and 50°F above the placing temperature.

Epoxy Injection Techniques

The construction joints in the housing (on about 80' centers) have been filled with epoxy under pressure. In applying the epoxy, first the contractor manually spread a mixture of the epoxy mix stiffened with asbestos fiber over the surface of the joint. At about 2-foot intervals, a small open space, called a "port", was left and sealed with tape. After about 24 hours, the contractor removed the tape and injected the epoxy into the ports at a pressure ranging from 50 psi up to 150 psi using an injection nozzle. The joints along the walls and floor were injected first and the epoxy was then injected into ceiling joints about one day later. After injecting the epoxy, penetration was gauged by volumetric measurements and by noticing the epoxy appearing at adjacent ports.

Core samples taken have indicated that the epoxy injection has achieved the desired penetration and sealing of joints.

BORON-LOADED CONCRETE

Certain sections of the Accelerator Housing adjacent to the positron radiator require a boron additive for further neutralization of radiation effects on the concrete. Studies and laboratory tests indicated that a boron frit (an artificially compounded calcium borate) containing approximately 16% elemental boron could be used without retarding the set of the concrete mix. This frit was added at 100 pounds per cubic yard of concrete. Three hundred cubic yards of concrete containing boron frit were placed.

A subsequent test program was conducted using washed and screened Colemanite (a naturally occurring calcium borate) as a boron additive. The test results showed that Colemanite can be used as a satisfactory boron additive. When adequately washed and screened, it does not seriously retard the concrete set. Also, Colemanite is more economical than boron frit. Forthcoming project construction will specify washed and screened Colemanite as a boron additive where required in concrete sections.

SUMMARY AND CONCLUSIONS

The preceding text has outlined the design basis, testing program, specifications, and field methods followed for the use of low-shrink concrete, epoxy injection of joints in concrete and boron-loaded concrete. Experience to date, with about 80% of the housing construction complete, indicates that the low-shrink concrete placed and cured in accordance with controlled procedures has achieved highly satisfactory results; the entire concrete program has provided an efficient and economical means for meeting design criteria and tolerances. Epoxy injection has been an adequate method for sealing and repairing concrete joints. Likewise, the boron additive has been used where required in concrete sections. Forthcoming Target Area construction will specify and utilize the materials and techniques discussed in this report.

Complete reports and analyses will be prepared by ABA upon completion of the project concrete work, covering all features of the concrete program and presenting data and field results obtained.

AETRON-BLUME-ATKINSON

INTEROFFICE MEMORANDUM

July 9, 1964

To: G. G. Bawden

From: Roland L. Sharpe

Subject: ABA Report for AEC "Construction Problems" Publication

As requested in your June 8, 1964, memo, attached are eight copies of Report ABA-96, covering information on low-shrink concrete, boron additive concrete and epoxy injection of concrete cracks.

Roland L. Sharpe

Roland L. Sharpe
Technical Director

RLS/JRB/cb

cc: J. R. Boyle

Enclosures: ABA-96 (8)

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