Task 4 - Field Durability of Reinforced Normal Weight, Lightweight, and High Strength Concretes.

This task is the central work unit of the entire program. It comprises the majority of field testing and covers the greatest range of concrete materials and mixture design techniques of all tasks. One hundred and two specimens and 54 controls will be exposed to both warm and cold salt water environments for 12 years.

Objectives

The objectives in this task are to determine the effects of cement type; w-c ratio; steel type; steel stress; cover; the use of fly ash, silica fume, and ground blast-furnace slag cement replacements; and the effects of warm and cold water environments on the durabilities of reinforced normal weight, lightweight, and high strength concretes. Further, it is the objective of the task to determine to what extent the various cements and mixture proportions influence the corrosion of the reinforcement as a function of the chloride penetration and carbonation phenomena.

Approach

The task is divided into 3 areas: normal weight, lightweight, and high strength concrete studies. In all 3 areas, specimens will be beams 11 in. by 12 in. by 93 in. long (279.4 mm by 304.8 mm by 2.36 m), will contain conventional reinforcement and stirrups, and will have the steel stressed by loading pairs of beams together in stainless steel loading yokes

Normal weight specimens--The variables for the normal weight tests include specimens made with 4 types of cement (Type II, Type I blended with fly ash, Type I blended with ground blast-furnace slag, and Type I blended with silica fume), 4 w-c ratios (0.3, 0.4, 0.5, and 0.7), 4 reinforcing steel variations (ASTM A615 grades 60 and 75, A767, and A775), 4 steel stress levels (20, 35, 50, and 60 ksi (137.89, 241.32, 344.74, and 413.69 MPa)), and 3 steel covers (3/4 in., 2 in., and 3 in. (19.1 mm, 50.8 mm, and 76.2 mm)).

The use of the different cements constitutes one of the basic reasons the program was first initiated. No major warm and cold water exposure program has been conducted since the work done by the Corps of Engineers in the 50's, 60's and 70's and the availability of these new additive materials provides great incentive to document how they affect concrete durability. The use of w-c ratios in the range of 0.3 to 0.5 are normal for construction and good durability, and are used to add to the knowledge of concrete mixtures in this usable range. The higher w-c ratio of 0.7 is included to study the effects of a high w-c ratio in the presence of the cement replacement materials.

The steels (conventional, galvanized, and epoxy coated) are being tested to determine their performance coupled with the cements and mixture designs used in the program.

Since all structural members in regular use are under some level of stress, the study of four steel stress levels is undertaken to find out more about the relationships of steel stress, steel corrosion, and concrete deterioration. The higher stress levels in the study are designed to intentionally crack the concrete. This condition will potentially allow greater amounts of salt and water to enter into the cracks and will have an effect on the durability of the member. It is anticipated that all stress levels will give data that will enhance our understanding of the relationships between stress levels and steel corrosion. While 2- and 3-in. (50.8 mm, and 76.2 mm) covers are recommended in reinforced concrete members exposed to severe environments, a 3/4-in. (19.1 mm) cover is being included here to hasten, and provide additional insight into the corrosion process.

Latex modification of concrete is another area of improvement to concrete durability which has developed within the past 15 years. The potential to exclude water and salts from the pore structure of the concrete by this modification is considerable, and long term exposure will benefit our knowledge of its effects. As a result, 6 normal-weight latex-modified beams will be exposed at each of the two exposure sites.

Under the normal weight division of this task, 46 stressed beams and 16 unloaded controls will be exposed at the warm water site, and 28 stressed beams and 16 controls will be placed at the cold water site.

Lightweight specimens--Use of lightweight concrete has increased substantially in the last two decades, and this program offers an opportunity to study the long-term durability of this type of concrete. Eighteen specimens (6 stressed beams and 3 unloaded controls at each of the warm and cold water sites) will be exposed in this part of the task.

The variables for the lightweight tests include specimens made with type II cement, 3 w-c ratios (0.3, 0.4, and 0.5), 3 types of steel (ASTM A615, A767, and A7-75), 3 steel stress levels (20, 35, and 50 ksi (137.89, 241.32, and 344.74 MPa)), and 2 steel covers (2 in. and 3 in. (50.8 mm and 76.2 mm)). The aggregate which will be used in the beams is expanded shale.

High strength specimens--Pozzolan, slag, and silica fume additives coupled with low w-c ratios have helped increase the strength of reinforced concrete design considerably. More and more companies are turning to higher strength concrete to increase load carrying capacity and reduce mass. The probability of these concretes having increased durability under severe marine exposure is also good. In this part of Task 4, 32 beams (8 stressed beams and 8 controls at each of the 2 exposure sites) will be studied.

The variables for the high strength tests include specimens made with 4 types of cement (Type II, Type I blended with fly ash, Type I blended with granulated blast-furnace slag, and Type I blended with silica fume), 2 w-c ratios (0.3 and 0.4), 3 types of steel (ASTM A615, A767, and A775), 3 steel stress levels (20, 35, and 50 ksi (137.89, 241.32, and 344.74 MPa)), and 2 steel covers (2 in. and 3 in. (50.8 mm and 76.2 mm)). The reinforcement in these beams will consist of two No. 11 bars in the tensile zone, and 2 No. 4 bars in the compressive zone. The concrete will be designed to have 9,000 psi (62.08 MPa) compressive strength.

Output

Exposure of beams is expected to begin in 1991. On a yearly basis, inspection trips will be made to both sites. Visual inspection will be made on each specimen and pulse velocity measurements will be made to document deterioration not visible to the eye. Core testing of the control specimens will be made in each alternate year to document progress of chloride penetration and carbonation depth.

Yearly progress reports will be written on the performance of specimens under this task. At the end of the 12 years of exposure, a number of the beams will be returned to the FAU and UNB laboratories for petrographic examination and post-mortem examination. A final report will be issued detailing the findings of this long-term study in 2004.

Task 5 - Effect of High Slump on the Durability of Reinforced Concrete.

Objective

Before the advent of water-reducing admixtures, high fluidity in a concrete mixture was generally achieved by increasing the w-c ratio. Much has been written about the tendency of cement to settle in fresh concrete with high w-c ratios. Problems such as pockets of water forming beneath the reinforcing and coarse aggregate particles, reduced bond between steel and concrete, and excessive corrosion on the reinforcement have been cited. With the development of water reducers, and more recently high-range water-reducers (HRWR), it is now possible to obtain high slump without the addition of water that increases the w-c ratio. The long-term effects of this development have yet to be sufficiently explored. The main objective of this task is to study the effects of high slump, achieved using HRWR's, on the concrete beneath the reinforcement.

Approach

Six beams and 6 controls, identical in size to those described under Task 4, will be exposed at the warm water site only. The variables used in this task will be similar to those used in the normal weight concrete of Task 4. An HRWR will be used to increase the slump from the 3 in. (76.2 mm) used throughout the rest of the program, to 9 in. (228.6 mm).

There will be 3 cement types studied (Type II, Type I with a pozzolan added, and Type I with a blast-furnace slag added); 2 w-c ratios (0.4 and 0.5); 3 steel types (ASTM A615, A767, and A775); 3 covers over the steel (3/4 in., 2 in., and 3 in. (19.1 mm, 50.8 mm, and 76.2 mm)); and 3 stresses in the steel (20, 35, and 50 ksi (137.89, 241.32, and 344.74 MPa)).

Output

The beams in this task will also be exposed for 12 years, and will undergo yearly visual and pulse velocity examinations. There will be yearly progress reports written as well as a final report published in 2004.

Task - 6 Field Durability of Post-tensioned Prestressed Concrete.

Objective

To date, the majority of the exposure research on prestressed concrete has been done on beams made with conventional concrete mixtures. There have been very little long-term exposure studies conducted using pozzolans, slags, and silica fume in conjunction with conventional Portland cement. Additionally, there is still disagreement over whether tendons in post-tensioned concrete members should be bonded or left unbonded.

This task has been designed to study prestressed concrete members with the objective to determine the effects of the cement type, w-c ratio, anchor type, anchor protection type, presence or absence of tendon bonding, grout type, and concrete stress levels on the durability of post-tensioned, prestressed concrete beams.

Approach

There will be 18 beams and 6 control beams exposed at both the warm and cold water exposure sites under this task. The beams will be I- beams in cross-section, as shown in Fig. 3. They will be 10 in. wide by 16 in. deep (254.0 mm by 406.4 mm) at the ends, and have the dimensions in the figure in the central part of the member. Their length will be 96 in. (2.34 m). The ends of the members will have a hollowed-out cavity where the end anchorages will bear on the concrete, and where different types of end-anchorage protection will be employed. The tendon eccentricity from the neutral axis of the beam will be based on the stress level in the concrete. To provide data on the effectiveness of bonded versus unbonded tendons after stressing, both types of systems will be implemented.

The 18 beams and 6 controls at each site will cover the following different material variables: 2 types of cement (Type II and Type III); 3 w-c ratios (0.3, 0.4, and 0.5); 2 types of prestressing tendons, each plain and epoxy coated, to make 4 different conditions of tendon exposure (ASTM A416 (7-wire stress-relieved strand), ASTM A416 with epoxy coating, ASTM A722 (single, high-strength steel bar), and ASTM A722 with epoxy coating); 2 different anchors (plain stress type and an epoxy coated stress type); 2 types of corrosion protection to the anchors (conventional concrete plug in the cavity and a low permeability concrete plug); 3 conditions of protection to the tendons (ungrouted, conventional grout, and silica fume grout); 2 types of tendon ducts (metal and polyethylene); 2 tendon stress levels (high = 170 ksi (1172.12 MPa) and low = 85 ksi (586.06 MPa)); and 2 types of conventional reinforcement (ASTM A615 and A775).

The conventional reinforcement will have 2 in (50.8 mm) cover, and will serve an additional function in the exposure program. All of the bent stirrups shown in Fig. 3 will be epoxy coated. Half of them will have had their epoxy coating applied before the bars were bent, and the other half will have been bent before the epoxy is applied. There has been some controversy over the effectiveness of epoxy coated rebars which have subsequently been bent potentially disrupting the integrity of the coating. This study will address that problem.

Output

These beams will be exposed for 12 years beginning in 1991. There will be yearly examination of the beams and yearly progress reports issued. At the end of the exposure period, 11 of the beams will be returned to the laboratories for petrographic examination and post-mortem examination. A final report on this task will be published in 2004.

Task - 7 Resistance to Freezing of Reinforced Concrete of Low Water-Cementitious Materials Ratio.

Objective

Much of concrete durability in cold climates is related to its resistance to deterioration from freezing and thawing of water in its pore structure. Mixture design practices and additive materials which modify the pore structure, and lower the permeability of the concrete increase its durability to freezing and thawing by preventing water from entering the pore system. Practices such as lowering the w-c ratio, increasing the cement content, and filling the pore cavities with small diameter particles such as silica fume help accomplish this.

Additionally, the strength of very low w-c ratio concrete is very sensitive to entrained air content. Minimum changes in the volume of entrained air can drastically change the strength achieved.

The objective of this task is to determine the freeze-resistant behavior of concretes of very low w-c ratio, with and without the addition of silica fume, and with and without air entrainment.

Approach

Since this task requires freezing temperatures, it will be limited to the cold water site. Twelve beams loaded to American Association of State Highway and Transportation Officials service load conditions (30) and 12 unloaded control beams will be exposed. The beams will have the same dimensions as the Task 4 beams, will all be made with type II cement, have a w-c ratio of 0.3, a slump of 3 in. ± 1 in., (76.2 mm ± 25.4 mm), and 3/4 in. (19.1 mm) maximum size marl aggregate. The beams will be reinforced with ASTM A615 steel.

Since the strength of low w-c ratio concrete is sensitive to the volume of air entrainment, the beams in this task will be designed to identify the minimum levels of air content necessary for durability. By making specimens with 0, 3.5, and 7.0% entrained air, with and without silica fume, and with various periods of air drying prior to installation at the exposure site, the highest strength can be achieved without compromising the freezing and thawing resistance of the concrete.

The variables in this task will be the cover over the steel (3/4 in., 2 in., and 3 in. (19.1 mm, 50.8 mm, and 76.2 mm)), the addition of silica fume (none, or 8% cement replacement by volume), the amount of air entrainment (none, 3.5% ± 1%, or 7.0% ± 1%), and 2 different curing environments (7-day moist curing followed by 3 months drying or continuously moist cured until exposure begins at 97 days age).

It is speculated that the curing environment will play a role in the durability of the beams. The pore structure of concrete moist cured for 7 days followed by dry curing for 90 days will be different from that continuously moist cured for 97 days. As a result, the ingress of water and salts through this pore structure will also be different.

The presence or absence of silica fume and air entrainment will also change the physical properties of the pore system. The data gathered from the various combinations of these two additives will enhance the knowledge of the freeze-resistant behavior of concretes modified with these materials.

Output

These beams will be exposed for 12 years beginning in 1990, and continuing through 2002. Yearly field examination will be conducted, as well as the writing of annual progress reports. Two beams will be brought back to the laboratory at the end of the exposure period for flexural testing, petrographic examination, and post-mortem examinations. A final report will be written for this task in 2003.

Task 8 - Electrochemical Aspects of Reinforcement Corrosion.

Objective

A critical feature of the proposed exposure program is the corrosion assessment of embedded steel in the concrete specimens. Until recent years, monitoring of corrosion activity in the field has been largely limited to visual observation of the specimens. Equipment and corrosion measuring techniques were not available or were not suitable for field use. Under this task, laboratory measurement techniques and new monitoring techniques will be used in the field to monitor the progress of steel corrosion.

The objectives of this task are threefold. One is to identify the presence of corrosion activity in the test specimens at both the warm and cold water sites. A second is to quantitatively determine the corrosion rates which occur for various combinations of mixture design and depth of cover. The third is to evaluate the value of short-term data acquired from accelerated test methods in predicting long-term field behavior.

Approach

This task has no specimens of its own. The field specimens from Tasks 2 through 7 will be monitored to provide data for this task. The scope of this task includes periodic non-destructive monitoring of the specimens during their exposure period for rate of corrosion, and post-exposure destructive testing to determine the net corrosion damage.

Under the non-destructive field monitoring, several corrosion monitoring techniques will be evaluated for incorporation into the annual inspection protocol. Before being placed at the field sites, commercially available reference electrodes will be cast into selected specimens from Tasks 2 through 7. Leads from these electrodes and from the reinforcement will be routed through the concrete to a water-tight port mounted in the end of the specimen. This port will allow corrosion potential measurements and corrosion rate measurements to be made without compromising the integrity of the specimen. This should permit "time-to-corrosion" to be determined for the various specimens. Consideration is also being given to inclusion of linear polarization probes into selected specimens for determination of instantaneous corrosion rate.

During the field monitoring portion of this task, visual inspection of the specimens will be conducted to document cracking, spalling, and staining of the specimens. The terminology which will be used to describe the severity of these phenomena will be kept consistent with those used in the previous work done by the Corps of Engineers (1-12) such that these, and past test data can be better compared.

In Task 2, the accelerated exposure specimens will be monitored on a monthly basis rather than the yearly routine which will be followed in the field exposure tasks. Both the full and half size specimens will receive corrosion potential measurements and corrosion rate measurements.

The second part of this task involves destructive determination of corrosion to the reinforcement. This will include recovery of the embedded steel, logging of the severity of the corrosion, measurement of the remaining dimensions of the steel (reinforcement, tendons, ducts, and anchorages), and comparison of these dimensions with initial values (recorded during specimen fabrication). This will permit determination of net weight loss, and hence corrosion as a function of a particular study parameter. The data from the long-term corrosion to the reinforcement will be compared to that predicted from the short-term accelerated studies to confirm or deny the validity of the latter as a tool in predicting concrete durability.

Output

This task will start in conjunction with Task 3, "Accelerated Testing of Rebar Corrosion", and will run throughout the program. Yearly interim progress reports will be written, and a final report detailing the corrosion findings of all tasks in the program will be published in 2004.

Task 9 - Microstructural and Microchemical Analysis of Concrete Cores from Current and Previous Programs.

Objective

Much of the valuable information from the processes which take place when concrete is exposed to a deteriorative environment are observed on the microscopic level.

The beneficial effects of silica fume occur in the matrix of the cement paste, as well as in its pore spaces. Fly ash and ground blast furnace slags affect the chemical composition of the concrete and are best observed under high magnification. Corrosion products, hydration products, and microstructural changes in the steel and concrete are all processes which must be observed under the microscope to gain the full advantage of their information.

The objective of Task 9 will be to determine the effects of the various service environments on the chemistry, mineralogy, and microstructure of the concretes in the program.

Approach

As with Task 8, the data for this task will be obtained from the specimens of Tasks 2 through 7. During the annual inspection, cores from the control beams of each task will be taken and returned to the laboratory for microstructural and microchemical analysis. Core samples will be wrapped and sealed at the field sites to preserve their as-cored conditions, and when prepared for laboratory testing, care will be taken to avoid altering the microstructure or the chemistry of the concrete by the examination preparation procedures.

Tests which will be conducted include: permeability of the concrete, chemical composition testing, conventional petrographic tests, microscopic analyses for freezing and corrosion damage, and tests for pH levels of the cement. The microscopic techniques which will be used will include: conventional microscopy (10X - 100X), transmitted light microscopy (100X - 500X), scanning electron microscopy (SEM) (>500X), energy dispersive x-ray testing in conjunction with the SEM, and chemical techniques to study such criteria as carbonation and chloride penetration. Special attention will be given to the interfacial regions at the steel/concrete contact surface so that the corrosion products can be identified and the microstructural changes in the steel and concrete can be examined.

Output

Yearly progress reports will be written as data are received from other field and laboratory tasks, and a final report published in 2004.