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AN UPDATE ON EVALUATION TECHNIQUES AND REPAIR MATERIALS FOR CONCRETE BRIDGE STRUCTURES

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AN UPDATE ON EVALUATION

TECHNIQUES AND REPAIR MATERIALS

FOR CONCRETE BRIDGE STRUCTURES

Deterioration of reinforced concrete is a common problem for bridge structures located in a marine environment. This paper presents a review of the principle causes of reinforced concrete distress, the basic steps to evaluate structure conditions, including nondestructive methods, plus recent advances in concrete repair method and products.

I. CAUSES OF DISTRESS

A. Corrosion

The most common distress of reinforced concrete is corrosion of embedded steel reinforcement. Chloride ions are considered to be the major cause of the corrosion. Ocean salt waters provide a ready source of chloride ions and are thus one of the harshest environments for a reinforced concrete structure. Concrete normally provides reinforcing steel with excellent corrosion protection. A high alkaline (high pH) environment in concrete results in the formation of a protective film around the steel which protects it from corrosion. Chlorides can break down the protective alkaline barrier and, if oxygen and moisture are present, electrochemical corrosion will occur. The subsequent oxidation of iron (the anode) and the production of rust along the bar results in a volume expansion which induces substantial stresses on the surrounding concrete with cracking, delaminations, and spalling resulting. The distress process is progressive in that cracks and spalls facilitate entry of chloride, water, and oxygen to the concrete thus accelerating corrosion rates. The major factors which affect the corrosion of reinforcement are:

1. Permeability and denseness of the concrete.

2. Depth of cover.

3. Availability of oxygen and rate of oxygen diffusion.

4. Degree of water saturation of the concrete.

5. Concrete carbonation.

B. Sulfate Attack

The sulfates in seawater are moderately aggressive to concrete. Sulfate attack involves the reaction of sulfate with hydrated lime (formed during cement hydration) producing gypsum. This results in solid volume expansion with subsequent cracking and disintegration of the concrete surface. Good quality concrete practices including the use of cements low in tricalcium aluminate (C_3A) content with low water-cement ratios will prevent sulfate induced distress.

C. Carbonation

Hydrated portland cement will chemically react with the carbon dioxide in the atmosphere. In addition to reducing the alkalinity of the concrete (thus promoting corrosion) carbonation increases the shrinkage of concrete on drying and tends to promote surface crack development. Again concrete quality plus consolidation and curing determine the extent of carbonation. For good concrete, carbonation is a very slow process which does not penetrate deeply. Also high humidity reduces carbonation rates.

D. Cracking

In addition to the previously discussed corrosion and chemical reactions which crack hardened concrete other common causes of cracks include:

1. Drying shrinkage.

2. Differential thermal stresses in a structure.

3. Construction and service loading conditions.

4. Errors in design and detailing including improper jointing and insufficient reinforcement.

II. CONDITION SURVEY

The key element of a successful repair and restoration project is a specialized condition survey and evaluation to collect and assess data and select appropriate repairs. The condition survey would normally include a visual inspection plus nondestructive and destructive testing. The elements of the condition survey are discussed in detail in the following paragraphs.

A. Visual Inspection

A careful examination by an experienced materials engineer or technician is conducted to identify extent, severity, and locations of distress. The guidelines given in ACI 201.1R-68, ACI 345-82 and AASHTO are useful to categorizing and logging distress. Photographic documentation of typical conditions is and essential aid to the evaluation process.

B. Nondestructive Testing

Nondestructive testing techniques are available to obtain estimates of strength, uniformity of strength, the thickness of a wall, detect internal cracks or voids, locate rebar, and establish rebar cover and bar size. The more common NDT methods include:

1. Pachometer - This is a magnetic device used to locate rebar and, if bar size is known, estimate concrete cover. The equipment is usually effective for depths of cover up to 8 inches.

2. Ultrasonic Pulse Velocity and Pulse Attenuation - This equipment emits an energy wave through the concrete and measures the velocity of the wave plus the attenuation of the signal between the transmitter and receiver. Velocities can be correlated with compressive strength and overall concrete quality obtained from cores. Attenuation is indicative of cracking or voids. The standard test method is described in ASTM C 597. Ultrasonic equipment must be operated and interpreted by experienced personnel since results are affected by moisture, reinforcing steel, and embedded items. The equipment is easily portable and

up to 200 tests points can be checked in a day.

3. Rebound, Pullout, and Penetration Tests - All of these devices give an indication of uniformity and strength of the concrete near the test surface. The rebound hammer has a spring loaded ram which drops a small weight upon an impact face and then measures the rebound of the weight. The pullout test measures the force required to pull an embedded metal insert and the surrounding section of concrete from the concrete mass. The penetration test determines the penetration of a steel probe which is shot into the concrete. All of these NDT techniques require correlation with compressive strength data from cores or cylinders to establish reliable indicated strength values. These NDT methods are fast and simple and relatively inexpensive.

4. Radiography - Gamma radiography can be used to detect size and location of rebar. The technique can also be used to indicate crack plane or discontinuities parallel to the plane of the radiation. The equipment is expensive and testing is a slow process, thus limiting this technique to very specific situations.

C. Destructive Testing and Core Sampling

A core program includes sampling the in place concrete at locations and performing tests to identify desired properties of the concrete. Most sampling programs are biased in that samples are generally located at reasonably good and at distressed areas. The selection of sampling areas and the number of samples require careful evaluation by the engineer in order to define a test program which will supply the required information and meet the budget and time constraints of the owner. Tests which are commonly performed on core samples include:

1. Compressive Strength as per ASTM C42.

2. Petrographic Analysis. Petrographic analysis can identify mineralogy of the aggregates, voidage and air content, evidence of chemical attack, alkali-aggregate reactions, degree of carbonation, presence of residual cement and mineral admixtures, and the compounds present in the hydrated cement.

3. Chloride content and pH are typically performed at various intervals from surface downward to the rebar depth.

4. Density . Density variations can be indicative of changes

in materials plus changes in strength.

III. EVALUATION AND REPAIR OBJECTIVES

Careful evaluation of the condition survey and test results is necessary to select proper, and durable repair procedures. The repairs will normally be selected to accomplish one or more of the following objectives:

1. Restore or increase stiffness or strength.

2. Improve functional performance.

3. Improve watertightness by sealing cracks and porous surfaces.

4. Improve appearance.

5. Replace corrosion damaged concrete and reinforcing steel plus minimize future corrosion distress.

Important constraints which will impact upon the selection of repair procedures include costs, desired life of the repairs, and site specific conditions such as available construction time and traffic maintenance requirements.

IV. REPAIR PROCEDURES AND MATERIALS

Repairs to concrete normally include patching, crack sealing, and surface sealing.

A. Patching

The important characteristics of a concrete patching material are elasticity, dimensional stability, and bond or adhesion. Compatibility with the existing substrate regarding pH, expansion coefficient, and permeability are important factors affecting the success of corrosion repair areas.

Polymer concrete and polymer modified portland cement concretes are probably the most common repair materials. A wide variety of polymers have been used. The properties of polymer concrete are largely related to polymer/aggregate ratios and the polymer. Since most polymers have coefficients of thermal expansion 2 to 3 times that of normal concrete, aggregate fillers and depth of patching need to be considered during the selection process. Some of the more common polymer concretes and their properties are:

1. Epoxy mortar - High strength, excellent chemical resistance, some shrinkage during hardening, short pot life (generally 10 - 30 minutes).

2. Methyl methacrylate acrylic mortar or concrete - Rapid strength gain with ultimate strength similar to normal concrete, some shrinkage, initial set is accelerated at temperature over 70°F.

3. Latex modified mortars or concrete.

   a. Polyvinyl acetate - Improves strength and abrasion resistance, not resistant to acids or alkalis, questionable performance under high moisture condition.

   b. Styrene Butadiene Rubber - improves strength and flexibility, good resistance to alkalis and acid but can by attacked by organic solvents. Internal film that forms when coalesced can be destroyed by finishing of the surface.

Silica fume concrete is being used with increasing frequency in severe environments. Silica fume is a by-product of the reduction of high-purity quartz with coal in electric arc furnaces in production of silicon and ferrosilicon alloys. The fume, which has from 70% to 90% silicon dioxide, consists of spherical particles about 100 times smaller in diameter than the average cement particle. Silica fume acts as a "super pozzolon" reacting with lime during hydration of the cement to form cementitious calcium silicate hydrate. Because of the fumes extreme fineness and high silica content the pozzolanic action is very effective. Replacement of cement with 5 to 20 percent silica fume can substantially increase concrete strength, reduce permeability, and increase resistance to sufates and chloride ion penetration. Compressive strengths in excess of 10,000 psi and permeability less than that of latex modified concrete have been reported . Silica fume mixes require significant mix adjustments including increases in air entraining agent dosage, use of water reducers to negate increased water demand, and longer mixing time. Early strength gain (0 to 3 days) is similar to normal concrete. Bleeding is greatly reduced by the addition of silica fume, thus moisture loss protection to prevent plastic shrinkage cracks is necessary.

B. Crack Sealing

The selection of an appropriate crack sealing procedure is a function of the cause and the active or dormant state of movement at the crack. Active cracks are those which experience current movement from thermal loadings, foundation settlement or other forces. Dormant cracks are cracks where there is no movement or the cause of cracking has been eliminated. Such cracks are usually shrinkage or load induced.

1. FLEXIBLE SEALING

Active cracks can be routed out, cleaned, and filled with a suitable field-moulded flexible sealant to function as a joint. High performance flexible sealants include polysulfide, polyurethane, silicones, and low modulus epoxy materials. Each of these materials has particular characteristics such as chemical resistance, extensibility, and setting properties which must be considered for each specific application.

2. ROUTING AND SEALING

Routing and sealing can be used on cracks that are dormant and of no structural significance. This repair is not applicable for sealing cracks which will be under significant hydrostatic pressure. Epoxy compounds and urethanes are premium sealants.

3. EPOXY INJECTION

Cracks as narrow as 0.05mm can be bonded by injection of epoxy. However unless the crack is dormant, cracking is likely to reoccur near or away from the repaired area. Epoxy injection requires a high degree of skill and temperature conditions may impose construction constraints. In addition it is very difficult to seal cracks which are moist or actively leaking water. Pot life of the epoxy, viscosity, crack width and injection pressures all affect the depth of penetration and rebonding.

C. SURFACE SEALERS

Waterproofing barrier systems to prevent the intrusion of chloride from seawater and other deleterious chemicals are being used with increasing frequency. Of particular note are silane based penetrating sealers which have high water repellency and chloride screening properties. The silanes do not alter concrete appearance and reportedly do not impede water vapor permeability during drying of the interior of the concrete. This is an important property, particularly near splash or tidal zones where the concrete is subject to frequent drying and wetting. Penetrating urethane sealers do alter the surface appearance (adds luster) and usually results in some surface buildup and reduction in water vapor transmission. Urethane sealers offer excellent water repellency but have not performed as well as the silanes as a chloride ion barrier in some research studies. Urethane coatings usually require a dry substrate. Epoxy sealers have excellent chemical resistance and resistance to chloride ion migration. The epoxies generally result in surface buildup and harden the concrete surface. Water vapor transmission is reduced and the potential for blistering of the coating increases, especially if solids content of the epoxy is high.

This is by no means a complete listing of all the considerations or products available to the engineer who is planning repair of a concrete bridge. The technology is evolving rapidly, with new products being introduced at a fast pace. It is likely that useful lives of structures will be extended more easily and more cost effectively in the future.