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BRIDGE DECK CRACKING

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Abstract - *A crack is a complete or incomplete separation of concrete into two or more parts produced by braking or fracturing. If the induced tensile stresses are higher than the limiting tensile strength of the concrete, the concrete will crack. The biggest problems affecting bridge decks are the deterioration of concrete. Cracks in the deck create a path for water and salts to reach the steel, often leading to corrosion of the reinforcement. The causes of early age cracking are varied but are primarily attributed to effects such as plastic shrinkage, temperature effects and drying shrinkage. This paper discusses about various variables that contribute to bridge deck cracking, evaluation of cracking and methods of repair in detail.*

Key Words: Plastic shrinkage, bridge deck cracking, evaluation of cracking

1.INTRODUCTION

1.1 GENERAL

The biggest problems affecting bridge deck is the deterioration of concrete. The causes of early age cracking are varied but are primarily attributed to effects such as plastic shrinkage, temperature effects and drying shrinkage. The cracking of bridge decks not only creates unsightly aesthetic condition but also greatly reduces durability, leads to a loss of functionality, loss of stiffness, and ultimately the loss of structural safety, resulting in aesthetic conditions that require the premature need for rehabilitation or replacement.

If the volumetric change of concrete due to shrinkage and thermal stresses is restrained, tensile stresses will develop in concrete. If the induced tensile stresses are higher than the tensile capacity of the concrete, the concrete will crack. A crack is a complete or incomplete separation of concrete into two or more parts produced by braking or fracturing. Cracks in the deck create a path for water and salts to reach the steel, often leading to corrosion of the reinforcement.

The basic problem of bridge deck cracking lies in the heating, hydrating, and expanding of young concrete next to older concrete and or fixed members that are cooling and shrinking at different rates which results in cracks in the young concrete. The cracks can be influenced by the material characteristics, casting sequence, formwork, climate conditions, and geometry all of which are time dependent.

2. BRIDGE DECK CRACKING

Based on the orientation of cracking in bridge decks, cracks are commonly characterized into five major categories - transverse, longitudinal, diagonal, pattern or map, and random.

2.1 TRANSVERSE CRACKING

Transverse cracks are the most commonly observed type and typically run perpendicular to the bridge girders but may also appear parallel to the skew near the abutments. These cracks are usually full depth. Cracks widths often exceed 0.002 inch and can reach widths of 0.025 inch, leading to an increased probability of water and chloride ion penetration. The major cause of transverse cracking has been shown to be restrained shrinkage.

2.2 LONGITUDINAL CRACKING

Longitudinal crack run parallel to the bridge girders and generally form directly above the edges of the girders. This type of cracking in ordinary girder type bridges is thought to be due to the presence of steel angles at these locations that are used to secure stay-in-place metal deck pans and cause a stress concentration.

2.3 DIAGONAL CRACKING

Diagonal cracks are commonly associated with bridges with skew, as the cracks are generally observed in areas of the deck with acute angles.

2.4 MAP CRACKING

Pattern or map cracking is a very common form of cracking seen on all types of decks and bridges. Map cracks are often attributed to improper curing. As the deck cures, surface moisture is allowed to evaporate too quickly and volumetric change through shrinkage is incited.

3. VARIABLES CONTRIBUTING TO CRACKING

3.1 MATERIAL PROPERTIES

3.1.1 Cement

In general, the studies have shown that the maximum amount of cement used should be limited to 356 Kg/m^3 (of concrete), which correlates to at 28- 13 day unconfined compression strength near 31 N/mm^2. Several studies have analyzed the effects of varying cement types on deck cracking. It has been accepted that Type II cement helps reduce cracking. Researchers generally believe that Type II cement is successful in reducing cracking due to its reduction in early thermal gradient and shrinkage.

3.1.2 Water cement ratio

Reduced cracking has frequently been linked to a reduction in w/c ratio. Water to cement ratios near 0.4 has been recommended as a maximum.

3.1.3 Air content

While air content is considered quite important in cooler climates to help with freezing and thawing, it has also been found that increased air content can reduce deck cracking in warmer climates. More specifically, a large decrease in cracking has been found when the air content exceeds 6%.

3.1.4 Compressive strength

Increased concrete compressive strength is commonly suggested to be a significant cause of deck cracking.

3.2 SITE CONDITIONS

3.2.1 Ambient Temperature

A significant increase in cracking is when the daily temperature range increases, and therefore the following guidelines have been generated to inhibit cracking. The maximum concrete temperature at placement should not exceed 80°F. The minimum ambient temperature should not drop below 45°F.

3.2.2 Relative Humidity

Plastic shrinkage is related to evaporation rates and concrete bleeding and therefore, it is possible that low humidity will increase evaporation rates and thus increase plastic shrinkage.

3.2.3 Wind Velocity

It is theoretically possible that an increase in wind velocity would increase cracking due to an increase in evaporate rate.

3.2.4 Evaporation rate

The concrete decks are suggested not be poured when a theoretical evaporation rate exceeds 1.22kg/m^2/hr.

3.2.5 Time of casting

Several studies have found that mid-evening or night casting can reduce cracking.

3.3 CONSTRUCTION PROCEDURES

3.3.1 Curing

Adequate and timely curing is a key factor in reducing cracking. In general, transportation agencies suggest at least 14 days of moist curing.

3.3.2 Pour Sequence

It is often difficult to evaluate the effects of pour sequence on bridge decks. In general, when sections of concrete are initially placed, they may be thought of as "cantilever" sections. When these sections are made "continuous," the stresses in each section will redistribute.

3.3.3 Pour Rate

The concrete should be placed at a rate greater than 0.6 span lengths per hour.

3.3.4 Deck Formwork

In general it has been found that there is no significant difference between stay in place (SIP) forms and removable forms in terms of cracking. There may be increased cracking with SIP forms due to a non-uniform shrinkage profile. At the same time, the removable forms allow for an increased drying rate (drying from both sides) which may cause additional cracking

4. EVALUATION OF CRACKING

4.1 VISUAL INSPECTION

Visual inspection provides an initial indication of condition of the concrete to allow information of subsequent testing program.

4.2 DIRECT AND INDIRECT OBSERVATION

The thickness of crack is measured using a comparator or a clear card.

4.3 NON-DESTRUCTIVE TESTING

Non destructive tests can be performed to estimate the presence of internal cracks and voids and the depth of penetration of cracks detectable at the surface. By use of ultrasonic non-destructive test equipment it is possible to detect cracks. A mechanical wave is transmitted to one face of the concrete member and received at the opposite face. The time taken by wave to travel through the member is measured electronically. Pulse velocity can be evaluated if the distance between the transmitting and receiving transducers is known.

4.4 CRACK WIDTH CALCULATION

The crack width in a bridge deck can be estimated by the following expression as :-

$$w = \frac{135}{E_r}\gamma\sqrt{\frac{f_c'}{\rho_g}}\sqrt{d_c^{\,2} + \left(\frac{s}{2}\right)^2}$$

where:

w : Crack width

E_r: Reinforcement modulus of elasticity

γ: Reinforcement bond factor: 1.0 for steel bars, 1.5 for FRP bars

$f_c{}'$: Concrete compressive strength

ρ_g: Reinforcement ratio of the gross section

d_c: Clear cover

s : Reinforcement spacing

4.5 ALLOWABLE LIMIT

According to ACI Committee report 224, crack widths equal to or greater than 0.007 in. (0.18 mm) can reduce durability when bridge decks are exposed to de-icing chemicals (ACI 224R-01 2008). Crack widths should be in the range of 0.25 mm.

5. METHODS OF REPAIR

5.1 EPOXY INJECTION

Concrete cracks are repaired using different techniques and methods, such as epoxy injection depending on how wide, long, and/or deep the crack is. Some of these repairs are completed by using epoxy injections applied directly to the crack. The procedure is different and varies depending on the crack location and whether the concrete cracks are horizontal or vertical.

- Preparing the Concrete Surface
- Installing the Ports
- Injecting the Epoxy

5.2 STITCHING METHOD

It is a rehabilitation technique used at cracks to maintain aggregate interlock and provide added reinforcement to minimize the relative movement of concrete slabs at the cracks.

5.3 OVERLAYS

Overlays may be placed, troweled, screeded, or sprayed in one or more layers onto the concrete surface. This method is used to seal cracks. The overlay method is adopted when large no of cracks are present and treating each crack is expensive.

6. CONCLUSION

One of the biggest problems affecting bridges is the transverse cracking and deterioration of concrete bridge decks. There were a no. of dominant variables that contribute most to cracking in bridge decks as material properties, site conditions, construction procedures, design specifications, traffic and age. Visual inspection and non destructive evaluation methods can be adopted for evaluating bridge deck crack. The repair methods include epoxy injection, stitching etc. From the case study it is concluded that Early-age thermal effects can generate significant thermal stresses in bridge decks. Risk of cracking may be reduced by pouring concrete in late afternoon and applying insulation to the deck after peak hydration. Recommendations for reducing early-age shrinkage cracking are fog mist placements immediately until wet curing media is in place, limiting the cementitious material contents to 356kg/m^3 or less and silica fume replacement to 5%, water cement ratio between 0.42 and 0.45. Additional recommendations for design include increasing the design thickness of decks to 8 inches minimum.

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