Texas A&M Transportation Institute

PROJECT SUMMARY

Texas Department of Transportation

0-5997: Structural Assessment of "D" Regions Affected by Premature Concrete Deterioration

Background

Reinforced concrete bridge piers in Texas have shown signs of concrete deterioration in the form of map cracking within a few years after construction. The pattern cracking is associated with the deleterious effects of alkali-silica reaction (ASR) and delayed ettringite formation (DEF) within the concrete over time. The effects of premature concrete deterioration caused by ASR and/or DEF on the structural performance, in particular the end regions of structural elements known as disturbed or D-regions, is unknown. It is also not known how to take these effects into account in a commonly used design office analysis technique such as the strut-and-tie (SAT) method.

What the Researchers Did

This research established the effect of ASR/DEF deterioration on the load-carrying capacity of bridge piers. The researchers designed an experimental program where a total of four large-scale C-shaped specimens representing cantilever and straddle pier bents were built. The constituent materials for the mix were chosen such that they promoted ASR, and during curing, the concrete temperature was elevated above 170°F to promote DEF. Specimen 1 was the control specimen and was stored under a controlled environment; Specimens 2, 3, and 4 were conditioned outdoors with supplemental water to accelerate the ASR/DEF deterioration mechanisms. Data from the three specimens were gathered on a regular basis to monitor the progression of internal concrete and steel strains, and surface strains. Specimens 2, 4, and 3 were conditioned for nine months, two years, and five years, respectively, and then destructively tested to assess their load-carrying performance compared to Specimen 1.

The researchers investigated the viability of applying SAT analysis to the deteriorated specimens. Owing to the complex nature of ASR/DEF deterioration and the various effects that it had in weakening the cover concrete, confining the core concrete, and yielding the reinforcement, due to progressive swelling strains, it was not possible to incorporate the effects of ASR/DEF deterioration in the SAT modeling technique. Moreover, SAT only satisfies force equilibrium and is intentionally formulated as a lower-bound design method of analysis; the critical mode of failure is often elusive to a designer. The researchers developed and validated the Compatibility Strut-and-Tie Model (C-STM) that is intended for the nonlinear analysis of shear-critical reinforced concrete structures. The new C-STM approach was then applied to the experimental C-beam specimens. Based on field observations and measurements, material property modifiers were proposed to

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incorporate ASR/DEF effects in the C-STM analysis.

Additionally, as a means to assess the expansion strains caused by ASR/DEF-related expansion, a minimalist semi-empirical analytical model was developed, validated, and applied to the C-beam specimens.

What They Found

Researchers found the following:

- Field measurements showed that ASR/DEF-related expansion could cause yielding of reinforcement, and surface strains as large as 6 percent were observed.
- When testing, failure in all specimens was in brittle shear through the beam-column joint, due to insufficient transverse joint shear steel and inadequate anchorage details in the form of properly hooked hoops.
- A stiffening and strengthening effect attributed to swelling of concrete was observed in the specimens with ASR/DEF deterioration, which put the reinforcing steel into a beneficial state of active prestress. For a *heavily* deteriorated specimen, considerable hidden steel corrosion was discovered when the cover concrete spalled during the destructive test.
- Considering the complex nature of ASR/DEF-related expansion, the transient analysis model developed is able to simulate the expansion strains with good accuracy.
- C-STM was used to model each specimen in this study, was shown to simulate quite well the overall force-deformation behavior, and identified the final mode of failure in the D-region.

What This Means

The findings indicate that:

- *Slight*, *moderate,* or *heavy* amounts of deterioration caused by ASR/DEF-related expansion in reinforced concrete may not, by itself, cause any reduction in the structural load-carrying capacity of the structure. The apparent stiffness of the structural response may also increase with an increase in the extent of damage because of the confining effects caused by the expansion of the concrete core.
- A structure with *heavy* ASR and/or DEF damage may be embrittled and prone to a sudden failure.
- Cracks induced by ASR/DEF-related expansion act as a pathway for moisture ingress into the structure. This may trigger and accelerate the corrosion of reinforcement in an otherwise sound structure, which may adversely affect the load-carrying capacity.
- The semi-empirical expansion model can simulate the expansion strains caused by ASR/DEF-related expansion.
- The C-STM is a robust analysis technique that can model structures without and with the effects of ASR/DEF-induced deterioration.

While it is evident from this study that deterioration caused by ASR/DEF expansion may not adversely affect the load-carrying capacity of the structure, corrosion could be a major concern and warrants further investigation.

For More Information

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