Project Summary Report 0-4176-S
Project 0-4176: Development of Precast Bridge Construction Systems
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PROJECT SUMMARY REPORT

Anchorage Requirements for Grouted Vertical-Duct Connectors in Precast Bent Cap Systems: A Summary

During the past ten years, the Texas Department of Transportation has constructed several, high-profile bridge projects using precast bent cap systems. This approach has reduced construction schedules dramatically and has provided safer working environments for bridges over water and in congested urban areas. Grouted vertical-duct connectors have become the preferred detail for the connections between the bent cap and columns (Fig. 1). The geometry is simple and the volume of grout needed to complete the connections is minimized.

The original design recommendations for connections between the precast bent caps and columns were developed during Project 0-1748, in which anchorage of single, epoxy-coated connectors embedded in galvanized steel ducts was studied. As designers and contractors gained experience with this structural system, questions were raised regarding the influence of many design parameters, such as the duct material and the spacing of the ducts, on the response of the connectors. The primary objectives of Project 0-4176 were to understand how design parameters influence the behavior of grouted vertical-duct connectors and to develop appropriate design provisions for these connectors.

What We Did...

Thirty-two pullout tests of large-scale grouted vertical-duct connectors were conducted during the experimental phase of the research. A single connector size (#11) and duct diameter (4 in.) was used in all tests. The primary experimental parameters were: bar coating (epoxy-coated and plain bars), duct material (galvanized steel, high-density polyethylene, polypropylene, and no duct), embedded depth of the connectors ($8d_b$, $12d_b$, and $16d_b$), number of connectors tested simultaneously in tension (one, two, and three), bar eccentricity within duct (centered and eccentric), transverse reinforcement (large spiral around group of connectors, individual spiral around each connector, and no spiral), and clear spacing between ducts ($1D$ and $2D$).

With this many parameters, it was not possible to test every combination of parameters. However, a sufficient number of tests were conducted to determine the general trends in the data. The test data were then used to determine anchorage provisions for this type of connector.

Figure 1 – Construction of Lake Belton Bridge Project using Grouted Vertical-Duct Connectors

What We Found...

The behavior of the connectors is sensitive to the choice of duct material. The initial stiffness and tensile capacity of connectors constructed using galvanized steel ducts were higher than those of comparable test specimens constructed using either polyethylene or polypropylene ducts. The stiffness of the connectors was reduced appreciably after splitting cracks formed in the concrete (Fig. 2). The galvanized steel ducts confined the connector and grout after the splitting cracks formed, but the plastic ducts did not. As a result, those with galvanized steel ducts were able to resist tensile stresses 25 to 35% higher than those with plastic ducts. Specimens constructed using galvanized steel ducts failed when the connector pulled out of the grout. In contrast, most specimens constructed using plastic ducts failed when the connector and a portion of the grout pulled out of the duct. The modification factor β is used to account for the influence of duct material in the final recommendations.

The maximum tensile stress developed in the connectors was also sensitive to the number of connectors tested simultaneously in tension. Increasing the number of connectors from one to two reduced the tensile capacity by 20 to 30%, and a further reduction was observed when three connectors were tested. A cone-shaped volume of concrete surrounding each connector separates from the beam when the connector fails. If the areas of the breakouts overlap, the tensile strength of each connector in the group is reduced relative to that of a single connector. The modification factor γ is used to account for the influence of group effects in the final recommendations. The approach used to calculate γ is similar to that used in Appendix D of ACI 318-05 for cast-in-place and post-installed anchors in concrete.

The tensile strength of the connectors was also sensitive to the placement of the connector within the duct. Specimens with concentric connectors were approximately 15% stronger than specimens with eccentric connectors. Because eccentric placement of connectors is expected in the field, this reduction is included in the final recommendations for all connectors.

Connector response was not sensitive to connector coating or the presence of transverse reinforcement. Slight reductions in capacity were observed when the individual spirals were used, and this detail is not recommended.

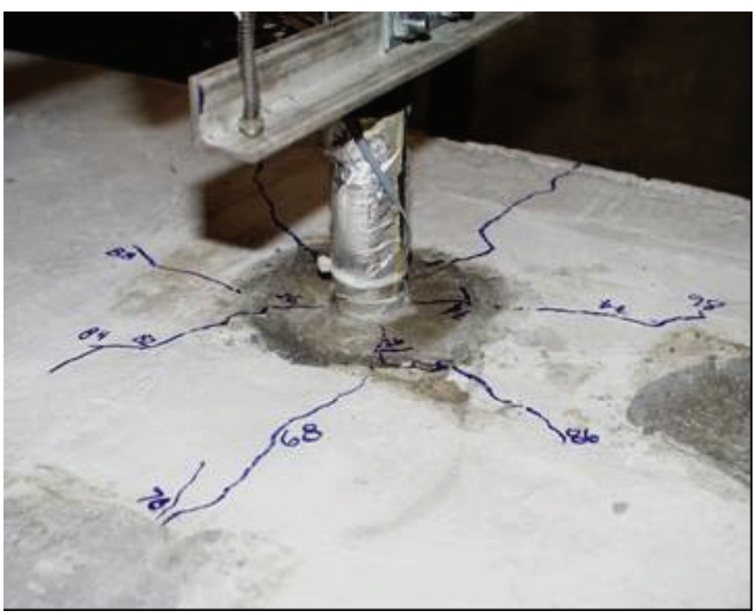

Figure 2 – Widespread Splitting Cracks in Concrete

The Researchers Recommend...

The recommended anchorage design provisions for grouted vertical-duct connectors depends on the following factors: the maximum calculated tensile stress in the connectors for the design load combinations corresponding to strength and extreme event limit states, $f_{s,cr}$; the modification factor for duct material, β; and the modification factor for group effects, γ.

All connectors, regardless of the level of calculated stress, must be embedded a distance $\ell_{e,min}$:

$$\ell_{e,min} = \frac{\beta f_y d_b}{180\gamma\sqrt{f'_c}} \qquad (1)$$

The minimum embedded length should not be less than the larger of $8d_b$ and 12 in., where d_b is the nominal diameter of the connector. This requirement is based on a serviceability limit state and is designed to prevent widespread splitting cracks from forming in the concrete (Fig. 2).

Connectors that are expected to experience tensile stresses under the design load combinations should be embedded a distance ℓ_d:

$$\ell_d = \frac{\beta f_{s,cr} d_b}{45\gamma\sqrt{f'_c}} \qquad (2)$$

In Eq. (1) and (2) the value of β is taken as 1.0 for galvanized steel duct and 1.3 for plastic duct. The value of γ is calculated based on the geometry of the connectors:

$$\gamma = \frac{A_{Nc}}{nA_{Nco}} \qquad (3)$$

where A_{Nco} is the maximum projected failure surface of an individual connector, which is defined as a square with sides of $15d_b$, A_{Nc} is the projected failure surface of a group of connectors, and n is the number of connectors in the group. Calculations are based on the number of connectors in the group that are calculated to resist tensile stresses under the design load combinations. However, a conservative value of γ is obtained if n is taken as the total number of connectors in the group. Values of γ between 0.45 and 0.9 are expected to be representative of current precast bent cap construction in Texas.

Insufficient experimental data were available to determine whether the type of plastic used in the duct or the corrugation pattern had a stronger influence on the design. Therefore, a single value of β is used in the design equations for all types of plastic duct. However, limits are placed on the type of ducts that can be used with the proposed equations. The plastic ducts must be corrugated, the minimum wall thickness is 0.118 in., the minimum rib height is 0.2 in., and the maximum rib spacing is 2.5 in.

For calculated tensile stresses up to 0.5 f_y, the required embedded length for grouted vertical-duct connectors is less than 36 in. for almost all combinations of duct and connector layout. Most precast bent caps currently used in Texas are at least this deep. However, if the calculated tensile stress in the connectors exceeds 0.5 f_y, it may be necessary to increase the spacing between the connectors or increase the depth of the bent cap to accommodate the larger development length needed to satisfy the recommended design provisions.

For More Details...

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The research is documented in the following report:

0-4176-1 *Anchorage Requirements for Grouted Vertical-Duct Connectors in Precast Bent Cap Systems*

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