Combined Shear and Tension on Grouted Base Details

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Braced structures with large height-to-width ratios, i.e., transmission towers, water towers or industrial equipment support towers, when subjected to lateral loads, often have resultant uplift and shear forces transmitted to their foundations. The base details must transmit combined tension and shear from the column to the foundation. For ease of construction, the columns are often set with base plates shimmed 1 to 2 in. above the top of the foundation; the shimmed volume is later grouted to complete the base detail.

The two major codes governing steel and reinforced concrete construction do not specify design formulas for grouted anchor bolt-base plate connection details.

The Uniform Building Code,[1] representative of general building codes, states bolts shall be solidly embedded in plain or reinforced concrete, and the connection shall be designed so that the tension or shear on every bolt is not greater than a value defined in their tables.

Previous investigators have studied anchor bolts embedded in concrete subjected to combined shear and tension, but have not included the effects of the grout.

Shoup and Singleton[2] conducted an experimental investigation of headed concrete anchors to determine the optimum relationship between the head diameter, shank diameter, and shank length. Headed studs welded to a steel plate and embedded in concrete were subjected to separate tension and shear tests, and design recommendations were suggested. Hughes[3] did work similar to Shoup and Singleton and arrived at similar design recommendations.

Conrad[4] studied the loading characteristics of several types of grouted anchor bolts, using three different types of grout, and concluded non-shrink grout gave results of most value. Separate tests were conducted to determine the tensile and shear capacities of the grouted bolts, but no test was made for combined loading.

Ollgaard, Slutter and Fisher[5] studied the shear strength of stud connectors in lightweight and normal-weight concrete and concluded the shear strength was primarily influenced by the compressive strength and the modulus of elasticity of the concrete.

McMackin, Slutter and Fisher[6] tested headed steel anchors under a variety of combined loading conditions and presented formulas for estimating the capacity of headed anchor studs in tension, shear, and combined tension and shear. The tests were sponsored by the Nelson Stud Welding Company.

Nelson Stud Welding[7] conducted extensive tests on the use of headed studs embedded in concrete. Interaction curves were obtained to express the combined loading effects of studs subjected to combined tension and shear for lightweight and normal-weight concrete, and for full or partial embedment.

The Prestressed Concrete Institute,[8] has interaction curves based either on the concrete capacity or the stud capacity for combined tension and shear loading on headed studs.

The results of several of these investigations are shown in Fig. 1.

This study consists of a test program to determine the additional effects of the grout layer.

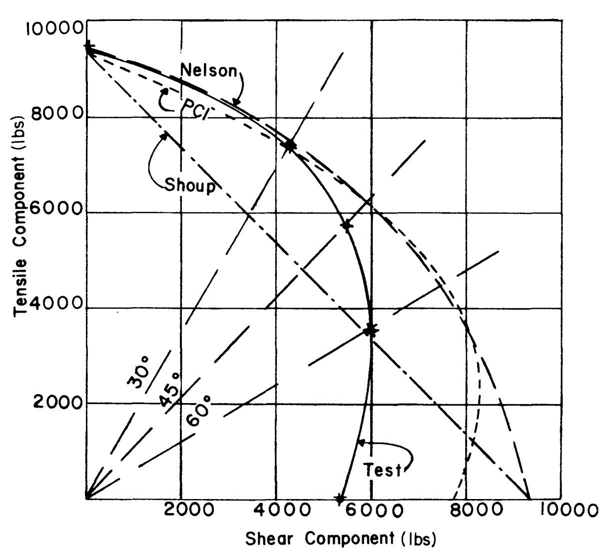

Fig. 1. Interaction curves and test results

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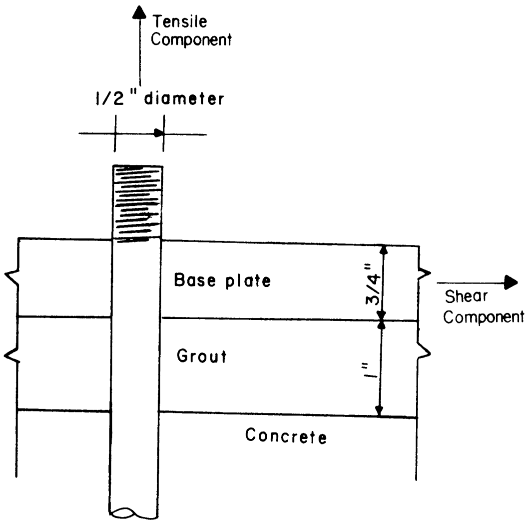

Fig. 2. Test details

Fig. 4. Grout failure; load applied at 45°

TEST PROGRAM

The base detail tested consisted of a ¾-in. base plate, 1-in. grout and ½-in. diameter anchor bolts anchored in concrete. See Fig. 2. A total of 15 specimens were tested. Resultant forces were applied at 0, 30, 45, 60, and 90 degrees to the vertical; three specimens were tested at each of these angles.

Commercially available anchor bolts conformed to ASTM A307 and base plates to ASTM A36. Yield and ultimate stresses for the anchor bolts averaged 47,000 and 67,000 psi, respectively. Nuts were turned to snug tightness and then turned an additional half-turn.

Commercially available nonshrink, nonmetallic grout with 28-day compressive strength of 8000 psi conformed to Corps of Engineers Specification CRD-C588-76. The 1-in. grout thickness is representative of current construction practices.

Concrete had 28-day compressive strengths of 3000 and 4000 psi.

All specimens were tested to failure. As load was applied, the first failure observed was separation between the grout and base plate. Second failure was spalling or splitting of the grout around the anchor bolt, as shown in Figs. 3, 4, and 5 for loads applied at 30, 45, 60 degrees to the vertical, re-

Fig. 3. Grout failure; load applied at 30°

Fig. 5. Grout failure; load applied at 60°

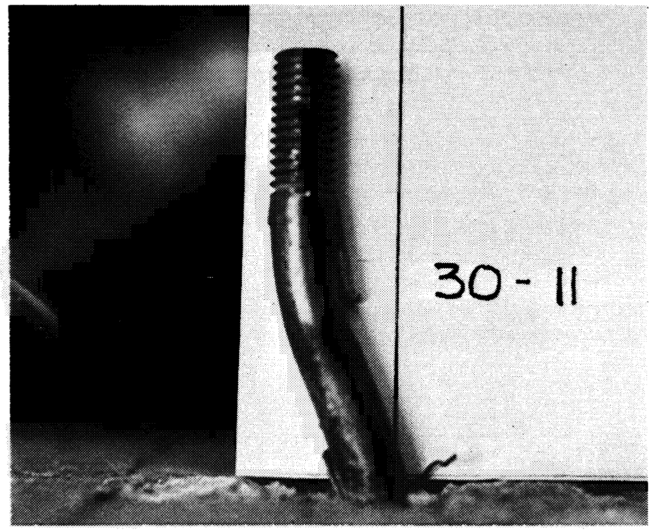

Fig. 6. Anchor bolt failure; load applied at 30°

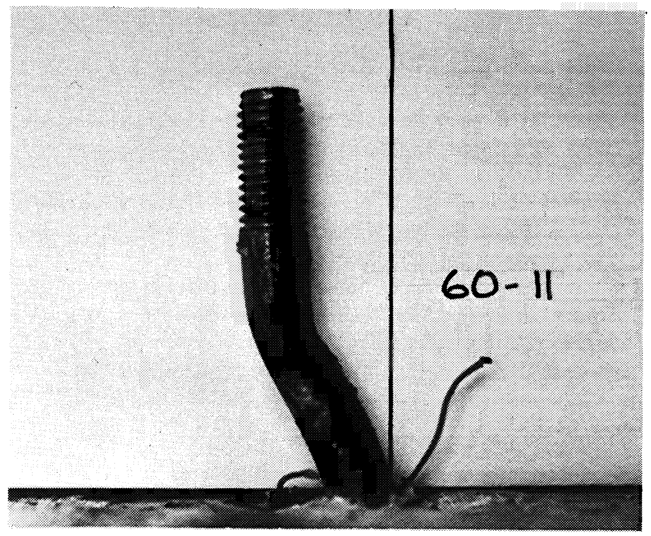

Fig. 8. Anchor bolt failure; load applied at 60°

spectively. Final failure was yielding of the anchor bolt. Figures 6, 7, and 8 show final deformed shapes for loads applied at 30, 45, and 60 degrees to the vertical, respectively. No failures were observed in the concrete.

TEST RESULTS AND ANALYSIS

The average experimental tensile and shear force components are plotted in Fig. 1. The yield capacities for Specimens 0, 30, and 45 agree with values obtained from the references, but as the shear component becomes larger, the values obtained from the test program are smaller, compared to those of the other investigators.

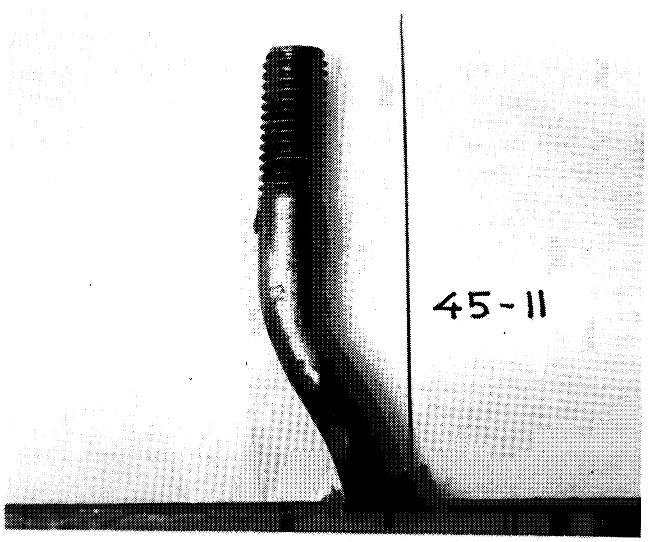

Fig. 7. Anchor bolt failure; load applied at 45°

The shear component induces slip between the base plate and grout, thus inducing moment in the anchor bolt. As the magnitude of the shear component is increased, grout failure occurs, resulting in a larger length of exposed anchor bolt. The moment applied to the anchor bolt is thus amplified by both increased shear and increased effective length. Accordingly, the capacity of a grouted anchor bolt is less than that of an anchor bolt embedded directly in concrete.

The capacity of the base detail is dependent on both grout failure and anchor bolt yielding failure. The splitting type grout failure indicates that the size (in plan dimensions) of the grouted area is as important a consideration as is the 28-day strength. The reverse curvature of the yielded anchor bolt indicates a degree of end fixity is attained at the base plate and at the concrete foundation.

Allowable tensile and shear forces permitted by the Uniform Building Code (representative of design practices) are conservative.

SUMMARY AND CONCLUSIONS

This test program indicates the interdependence of grout and anchor bolt in determining the capacity of a grouted base detail subjected to combined shear and tension. Existing interaction equations based on bolts embedded directly in concrete are not applicable to the grouted condition when the shear component becomes predominant.

Designing anchor bolts as fixed-end members subjected to moment and tension requires further experimentation to determine the effective length and end fixity. Size (area and thickness) effects of the grout, as well as strength, will influence effective length. Initial tightening and size of anchor bolt, as well as size and thickness of base plate, will influence both effective length and end fixity.

REFERENCES

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