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BEHAVIOR OF EPOXY-GROUTED DOWELS AND BOLTS USED FOR REPAIR OR STRENGTHENING OF RC STRUCTURES

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SUMMARY

The use of epoxy adhesives to install reinforcing bars or threaded bolts in existing concrete elements is growing rapidly. Epoxy materials are available for a variety of installation and construction conditions. A number of different tests using epoxy grouts have been conducted at The University of Texas and are summarized here. The results provide guidance for designers opting for the use of epoxy materials in seismic repair or strengthening work.

INTRODUCTION

In repairing or strengthening reinforced concrete structures in seismic zones, new structural elements must be attached to the existing structure. Two often-used techniques involve (1) the addition of concrete and reinforcement to increase the size of columns and/or beams or to provide structural wall elements to a moment resisting frame, or (2) the addition of a steel bracing system that increases or provides alternate lateral capacity. In both cases the new materials must be attached to the existing structure to provide the type of monolithic action generally assumed in design of the retrofit scheme. A reasonably simple method to make the attachments involves the use of epoxy resins to grout reinforcing bars or bolts into the existing concrete elements. A series of tests have been conducted in which grouted bars or bolts have been studied. The following studies were carried out:

1. Pullout tests of reinforcing bars grouted into holes cleaned in different ways or in different positions.
2. Interface shear tests (new concrete cast against old concrete) with grouted dowels crossing the interface.
3. Tests of steel elements attached to concrete using grouted bolts.
4. Cyclic lateral load tests of a 2-story, 2-bay, 2/3 scale frame that was strengthened by increasing the column size or by attaching a structural steel bracing system to the frame with grouted bolts.
5. Tests of infill walls attached with bars grouted to existing frame.

PULLOUT TESTS

A total of 101 reinforcing bar dowels were tested (Ref. 1). The parameters studied include the hole cleaning method, embedment length, bar size, and grouting position. The test apparatus and procedure were designed to permit concrete failure cones to develop without restraint from the loading apparatus.

The data show the ineffectiveness of light cleaning. The most promising method was cleaning with a stiff bottle brush. Almost all concrete dust in the hole had to be removed (especially from the walls of the hole) for the cleaning method to have any significant impact on the load carrying capacity of the epoxied dowel. The maximum loads per unit embedment length for several cleaning methods (#6 bars) are plotted in Fig. 1. The most effective anchorage was achieved by cleaning with a stiff bottle brush.

Figure 2 shows the results of tests using different types of epoxy and three different grouting positions. All tests were for #6 bars with six-inch embedment. Nearly the same strength was achieved using a variety of epoxies and following manufacturer's guidelines for mixing and placing.

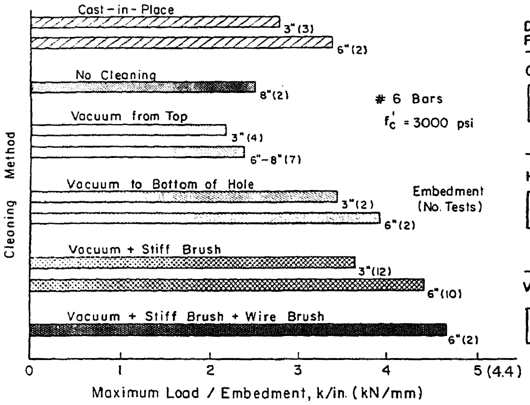

Fig. 1 Effect of cleaning method on pullout capacity

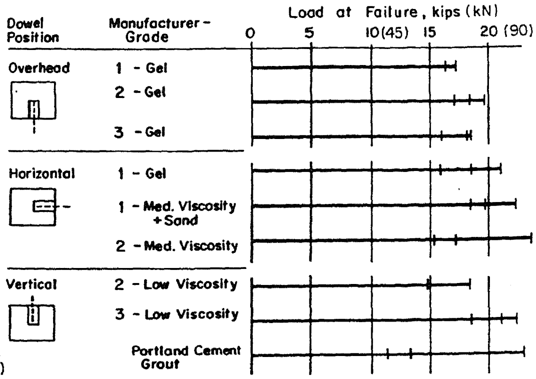

Fig. 2 Comparison of epoxy type and grouting position, #6 (19mm) bars, 6- in. (150 mm) embedment

INTERFACE SHEAR TESTS

The main objective of the interface shear tests (Ref. 2) was to investigate the strength and load-deflection characteristics of the interface connection between old and new concrete typical of that used in repair and strengthening of existing reinforced concrete structures. Variables included the compressive strength of the concrete, reinforcement detailing across the concrete interface, and interface surface preparation. The test specimen is shown in Fig. 3. The interface area was 36-in. x 10-in. (0.9m x 0.25m). Several concrete surface preparation techniques including sandblasting, chipping, shear keys and smooth surfaces were considered. Reinforcement details across the concrete interface include number of dowels, embedment length, and dowel layout. Other variables included concrete strength, casting procedure of the wall and base block, and wall reinforcement details. Specimens were subjected to repeated cyclic loadings at various load levels up to failure. Thirty-three specimens were tested. Shear-stress across the interface was plotted against displacement. To compare test results, an envelop curve of the cyclic load-displacement curves was constructed. The tests indicated that the following parameters significantly influenced the interface performance:

- Dowel embedment length (Fig. 4) and number of dowels (Fig. 5) – shear strength increased with increased embedment and number of dowels but not in a linear manner.
- Concrete surface roughness – roughened surfaces reached higher strengths than plain surfaces; however, the degree of roughness, chipping, keying, sandblasting did not result in significant difference in peak strength (Fig. 6).
- Wall and base block reinforcement details – had no discernible influence on strength. The concrete strengths of the base and the wall appeared to influence the shape of failure surface but the influence on shear strength was not consistent.

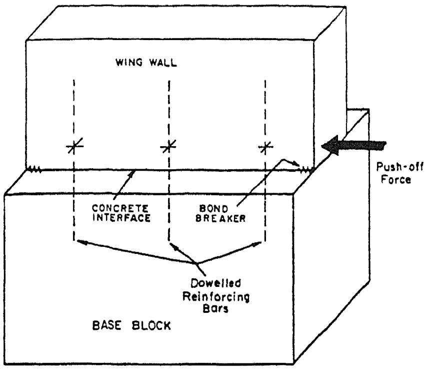

Fig. 3 Interface shear test specimen

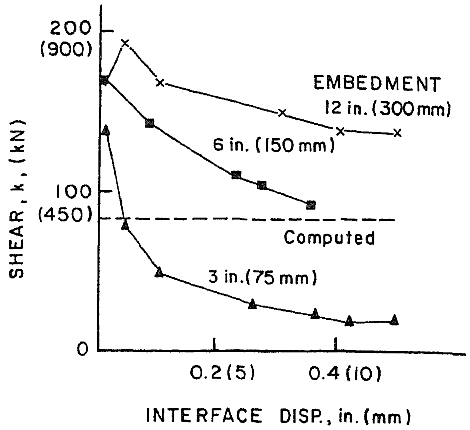

Fig. 4 Effect of dowel embedment length, load-slip envelopes.

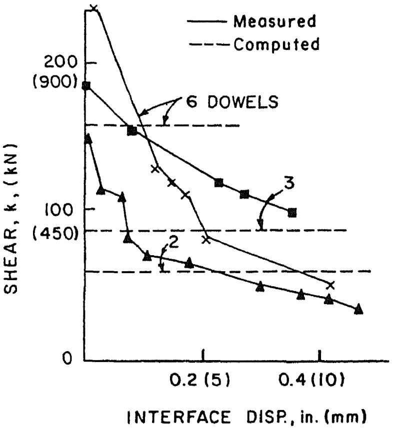

Fig. 5 Effect of number of dowels, load-slip envelope

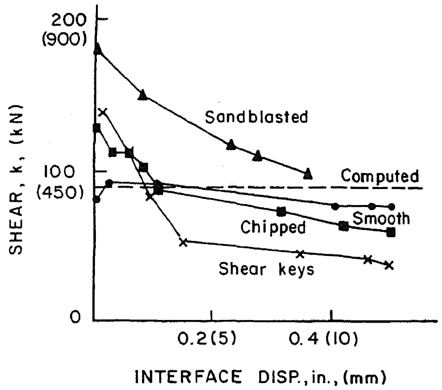

Fig. 6 Effect of surface treatment load-slip envelopes

In Figs. 4, 5 and 6, the computed shear strength based on ACI shear- friction equations is shown. It can be seen that the peak strength was always greater than computed values. However, after cycling and larger slip values, shear dropped below the computed strength. It should be noted that the shear-friction theory is based on the reinforcement crossing the interface reaching yield. Expect for dowels with a 12-in. (200 mm) embedment, none of the shorter 3- or 6- in. (75 or 150 mm) dowels were embedded sufficiently to develop yield. In spite of this, the measured peak shear strength exceeded computed values.

STEEL ELEMENTS ATTACHED TO CONCRETE

Six specimens were tested to investigate the capacity of steel to concrete connections (Ref. 3). The steel element was loaded in tension. The test specimen configuration is shown in Fig. 7. The main variables studied include the number of anchor bolts and concrete-steel interface surface preparation. The anchor bolts were cut from the same stock of 3/4-in. (19 mm) mild steel threaded rod. All but one specimen had 6-in. (150 mm) embedment. Each anchor was tightened to the same torque using a torque wrench. The specimen was subjected to repeated cycling. A load-slip relationship was obtained

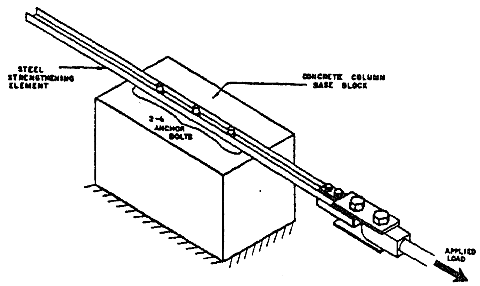

Fig. 7 Steel to concrete connection test specimens

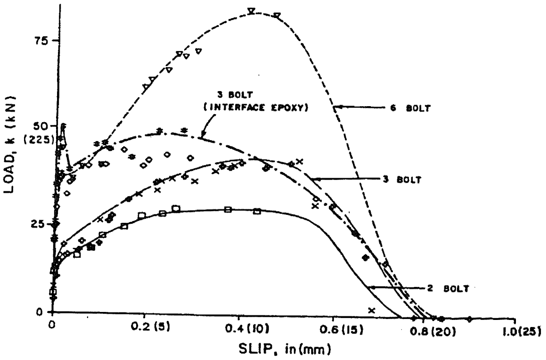

Fig. 8 Load-slip envelopes for steel to concrete connections.

for each and a load-slip envelope was constructed. The envelopes are a composite of load-slip curves in both loading directions (Fig. 8).

The stiffness of all the specimens in the elastic range was nearly the same. After slip occurred, stiffness decreased causing large deformations upon application of significant loads. Connections with interface epoxy show a 25% reduction in the load resisted after slip reached 0.015 in. due to failure of the epoxy interface. Interface epoxy increased maximum load per bolt in the elastic range more than three times and a higher load was maintained up to nearly 0.5-in. slip. Overall, connections with interface epoxy clearly performed better. The measured percentage of applied load resisted by each bolt are shown in the bar graphs in Fig. 9.

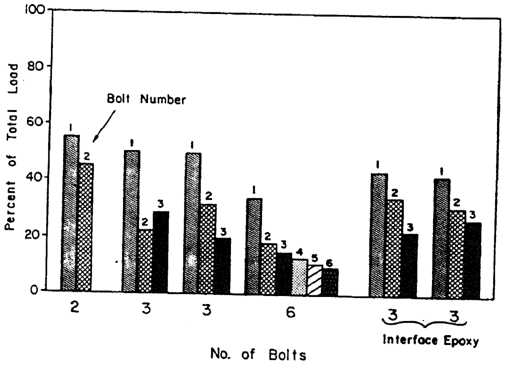

Fig. 9 Estimated load carried by bolts - after first slip

Once relative movement between steel and concrete began, most of the load was resisted in bearing. In every test the lead bolt resisted the greatest load. Remaining load seems to be divided between consecutive bolts based on their distance from loaded end. When no interface epoxy was used, the lead bolt resisted more load than the other bolts in all cycles. In tests with interface epoxy, the load was distributed to bolts almost evenly. Surface epoxy improved connection behavior even after the interface fractured. By filling gaps between the anchors and the bolt hole, loads were distributed between bolts in proportion to distance from loaded end. Once slip began, the bolts with interface epoxy shared load more equally than in the other tests.

STRENGTHENED FRAMES

The key to evaluating any repair or strengthening scheme is the overall performance of a structure. A framing system shown in Fig. 10a was identified as having high potential for damage in an earthquake. The frame consists of deep spandrels at floor level and short columns between the spandrels. The columns are not heavily reinforced and are likely to fail under large lateral deformations. Since only the columns are weak, two relatively simple strengthening schemes were considered (Ref. 4). First, the columns were converted into stiff strong elements by adding a new concrete column wall at each column (Fig. 10b). The new concrete is shown in Fig. 11. New concrete was attached to the existing frames with grouted bars. The second scheme, shown in Fig. 10c, consisted of using an exterior steel frame with lateral resistance provided by diagonal steel members. Because the diagonal steel elements introduced a vertical force component into the columns, channel sections were anchored to sides of columns with grouted bolts.

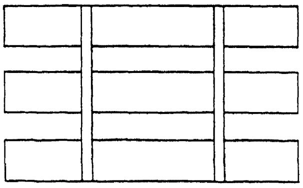

Fig. 10a Unstrengthened frame

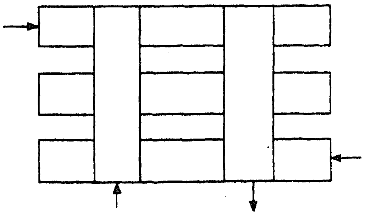

Fig. 10b Column strengthening

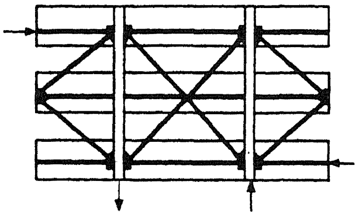

Fig. 10c Diagonal steel bracing

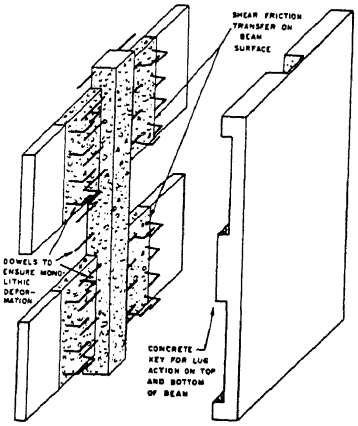

Fig. 11 Details of column enlargement

The test specimens were 2/3 scale models of the prototype. The 2/3 scale permitted placement of the structure on the strong floor-wall system available. The scale was sufficiently large to permit grouted anchor details to be duplicated accurately in the test structure. Loading was applied through the upper floor at points near the columns. The new columns permitted the flexural capacity of the beams to develop. The frame failed in a ductile manner. Adhesive bond and dowel action provided adequate load transfer between the reinforced concrete piers and the original frame. Steel diagonal braces improved the performance of the reinforced concrete model. The grouted bolts performed very well. Virtually no slip was observed between the concrete and the steel members. Epoxy was placed so that it filled the gaps between the holes and other bolts.

INFILL WALLS

The use of shotcreted infill walls to strengthen nonductile single- story portal frames has been studied with 2/3-scale specimens (Fig. 12). A full infill, an infill with a door opening centered in the frame, and an infill with a window opening centered in the frame were tested (Ref. 5). Although the addition of each wall type improved the lateral force resistance of the frames, the capacity of two of the frames was controlled by tensile failure of the compression splices in the boundary elements (columns) resulting from overturning forces on the walls. Failure started in the column splices and spread across the wall along the top of the dowels grouted into the foundation beam. In all cases the grouted dowel performed very well. The dowels along the columns and at the top registered very low strains. At the bottom of the wall, failure occurred at the end of the dowel, not at the interface between the wall and floor. The tests would indicate that a smaller number of dowels could have been used at the sides and top without significantly changing behavior.

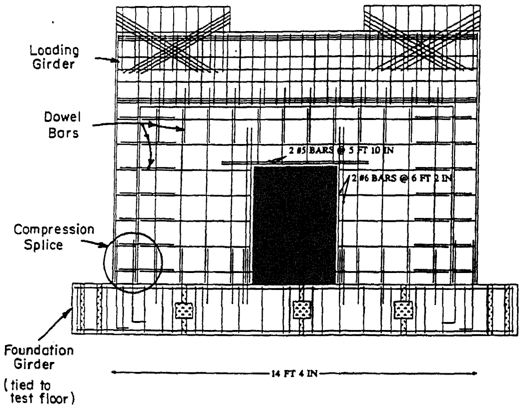

Fig. 12 Infill wall tests

CONCLUSIONS

Epoxy-grouted reinforcing bars and threaded bolts provide:

1. A reliable, relatively quick method for providing continuity between existing and new elements.
2. Quality control in terms of adequate cleaning prior to grouting is essential.
3. Dowels generally provide more capacity than determined using code provisions for shear friction or for development.

ACKNOWLEDGEMENTS

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