Proceedings of Ninth World Conference on Earthquake Engineering
August 2-9, 1988, Tokyo-Kyoto, JAPAN (Vol.VII)

12-4-17

GUIDELINES FOR EPOXY GROUTED DOWELS IN SEISMIC STRENGTHENING PROJECTS

Loring A. WYLLIE, Jr.[1]

[1]Structural Engineer, H.J. Degenkolb Associates, Engineers

SUMMARY

Epoxy grouted dowels or threaded rods are frequently used in seismic strengthening and repair projects to attach new concrete or structural steel shapes to existing concrete members. Guidelines have been lacking beyond epoxy manufacturer's recommendations on details of installing epoxy grouted dowels and design values to use. This paper, based on recent research and literature surveys, attempts to give designers guidelines for the use of epoxy grouted dowels to transmit tension or shear from new concrete members to existing concrete and to attach new structural steel members to existing concrete.

INTRODUCTION

Frequently, it is necessary to strengthen existing concrete structures for improved seismic performance, either after a damaging earthquake or in preparation for a future event. This work always involves attaching new concrete or steel bracing members to the existing concrete members. Epoxy grouted dowels are ideal for this task due to the strength and ease of installation of epoxy resins to anchor dowels or threaded rods. The usual objections of epoxy due to its tendency to creep under sustained loads and its loss of strength when subjected to heat are not concerns in most seismic strengthening projects. The short term loading on dowels from seismic loading precludes creep concerns and since dowels are grouted within the concrete mass, there is sufficient insulation to protect the epoxy from heat sources such as fires.

The research that has led to these guidelines is part of a joint research project between The University of Texas at Austin and H.J. Degenkolb Associates of San Francisco. Combining the talents of consulting structural engineers and University researchers has resulted in a well balanced and meaningful research in the area of repair and strengthening of concrete structures. Reference 1, presented at this Conference, describes in more detail the experimental work that was part of this research project and part of the basis of these guidelines.

EPOXY DOWEL INSTALLATION

Proper installation techniques of epoxy dowels are very important and essential for good performance. Holes should be drilled to the proper depth as discussed later in this paper and 1/4 inch (6mm) oversized from the nominal diameter of the reinforcing bar. This will provide sufficient space for the deformations of the reinforcing bar to fit in the hole. For threaded rods connecting to new structural steel members, the hole should be only 1/8 inch (3mm) oversized. The hole should be kept to the minimum feasible diameter. Once the hole is drilled, it is imperative that the hole is thoroughly cleaned of all drilling dust and powder. Whereas air jets or vacuums are helpful, they are usually not sufficient alone. It is necessary to use a wire or stiff-bristle bottle-type brush to brush the drilled surfaces of the hole and remove all drilling powder. If this dust or powder is not removed, the epoxy will bond to the powder rather than the concrete and slip will occur.

There are many epoxy products available and many are suitable for installing epoxy dowels. The normal fluid epoxies are suitable only for vertical holes drilled downward. Epoxy gels which do not flow are most suitable for this work as they can be installed in all hole orientations, vertical downward, vertical upward and horizontal. The epoxy should be mixed in accordance with the manufacturer's recommendations and installed in the lower third to half of the hole with a caulking gun or similar device that places the epoxy in the end of the hole without air voids. The dowel should then be inserted and rotated, then wedged in place with a wooden wedge or golf tee to hold the dowel in place until the epoxy sets. It is important that the dowel not be pumped in and out of the hole during installation as air voids might be formed in the vacuum created when the dowel is pulled outward.

It is important that job specifications and instructions to workmen are very clear on the procedures to be followed in installing epoxy dowels. Most workmen are convinced they can do this work without special instruction, and they are unaware of important issues unless they are clearly explained to them.

EPOXY DOWELS IN TENSION

The performance of epoxy dowels in tension is dependent on proper installation, sufficient embedment depth and sufficient spacing between adjacent dowels. Installation should be in accordance with the preceding section. Spacing should be at least an embedment depth apart. It is often better as well as more economical to use bigger dowels at greater spacings than lots of small dowels at close spacing.

Once installation techniques are mastered, the other key element for epoxy dowels in tension is providing sufficient embedment length. Embedment depth should be sufficient to develop the strength of the dowel. A reading of current building codes for concrete construction (Reference 2) would infer the dowel must be installed in a hole equal to a full development length. Tests by numerous researchers have shown that a shorter embedment length is sufficient for epoxy grouted dowels (Reference 3). The embedment length should be sufficient to develop the strength of the dowel. ACI 318-83 development lengths are nominally based on 1.25 times yield of the steel, or for Grade 60 steel (410 Mpa), 75 ksi (520 Mpa). For the purpose of this research, recognizing the importance of preventing anchorage failures to provide ductile performance, a criteria of embedment length sufficient to develop 100 ksi (690 Mpa) ultimate stress for Grade 60 (410 Mpa) reinforcing steel seems appropriate. Therefore, these guidelines are based on providing embedment sufficient to develop 100 ksi (690 Mpa).

Reference 4 provides a detailed discussion of previous research and the results reported in Reference 3. Figure 1 plots test data from Reference 3 against an expression by Eligehausen (Reference 8) developed from a linear regression analysis of over 2,000 expansion anchor pull-out tests. The agreement is impressive. Table 1 summarizes the desired minimum embedment lengths for epoxy dowels, installed or described before, to develop ultimate strength of the reinforcing. It is important to note that the data on which Table 1 is based is limited to a range of concrete strengths and bar sizes. Suggestions in the shaded area are offered for bars larger than #6 (18mm diameter) and in concrete of 6000 psi (41 Mpa) except for #6 bars (18mm) for which data does exist. More research is needed to confirm embedment depths for these larger bars and higher concrete strengths. For bars properly embedded to the recommended depths, ultimate bar strength in tension should be achievable. For important tension elements, such as chords of new shear walls into basement walls or other critical tension elements, it would be a prudent exercise of engineering judgment to increase these embedment depths 25 to 50% for that particular usage.

EPOXY DOWELS IN SHEAR

Epoxy dowels resisting shear forces are possibly more prevalent than pure tension situations. The attachment of infilled walls or new shear walls to existing concrete frames always requires a shear transfer between new and old concretes. To study this mechanism of shear transfer, a series of 33 test specimens were tested for cyclic shear along an interface between old and new concrete (Reference 5). Variables included the number of epoxied dowels, their embedment depth, the surface preparation of the old concrete including no preparation, sandblasting, chipping shear keys and roughening with a chipping gun, relative concrete strengths and reinforcing details. In addition to Reference 5, more discussion of the interpretation of these experiments is included in Reference 4.

The research has confirmed that shear transfer across an interface between new concrete and old concrete should be treated as shear friction in accordance with ACI 318-83 (Reference 2). For seismic exposures, the existing concrete surface should be thoroughly roughened by heavy sandblasting or chipping. Dowels should be installed to provide an area of shear friction reinforcement according to Reference 2 and should be epoxied in holes in the existing concrete according to Table 1. It is important that the dowels be embedded for full development per Table 1. Tests (Reference 5) showed that roughened surfaces are most important to limit slip and dowels with full embedment are needed to maintain load after slip occurs.

The experiments also illustrated several fine points of shear transfer that common sense would confirm. For example, in one specimen too much epoxy was placed in the holes and when the bars were inserted, puddles of epoxy about 4 inches (100mm) surrounded the dowels and this excess epoxy was not removed. This specimen, considering its variables, achieved a strength significantly below corresponding specimens with slightly different conditions. This test illustrated the need to insure that all extra epoxy is cleaned off the interface, as the most effective region of the interface to transfer shear is close to the dowels.

EPOXY GROUTED THREADED ROD FOR ATTACHING STRUCTURAL STEEL MEMBERS

Epoxy grouted threaded rods are suitable to attaching new structural steel bracing elements to existing concrete. For shear transfer of loads from a structural steel member to existing concrete through epoxied threaded rods, several guidelines should be followed. All procedures for installation are similar to reinforcing steel dowels except for hole diameters which should only be 1/8 inch (3mm) larger than the nominal rod size.

Tests (Reference 6) performed as part of this project confirmed that the threaded rod should be installed in accordance with Table 1, although variation of embedment depth was not included in the test program and further research may confirm that shorter lengths are sufficient. Reference 6 did confirm an excellent technique for dowel installation. Holes were drilled in the proper location and they were cleaned and prepared. The structural steel members were prepared with oversized holes (rod diameter plus 3/16 inch) (plus 4.5mm) and placed in position against the concrete. The epoxy was placed and bolts installed, with some of the epoxy filling the space between the oversized hole on the structural steel and the threaded rod. The result was that this epoxy in the space between the rod and steel, despite its low modulus, did help spread out the loads more or less uniformly to the bolts and prevent one bolt from taking all the load before cracking of the concrete began. This appears to be a desired procedure for dowel installation and one that should be followed to provide tolerance for installation without welding washers or similar exercises. If the epoxy had sand added to increase its modulus of elasticity, this detail might be even more effective, although tests have not been performed to test this suspicion.

For threaded rods in shear installed as described, all cyclic test specimens eventually failed by shearing the threaded rods. Thus, it appears that rods installed as described and to the embedment depths specified in Table 1, can be designed to ASTM A307 bolt values in shear as specified in the AISC Specifications (Reference 7). In other words, the threaded rod is as strong as a machine bolt in shear connecting two pieces of steel.

COMBINED SHEAR AND TENSION LOADS

No tests have been conducted in this program nor reviewed in the literature for combined shear and tension loadings. Since the shear loading for concrete dowels is based on shear friction which depends on the clamping force of the dowels across the interface, an addition of the demands for tension and shear (as shear friction reinforcement) would seem appropriate. A more favorable interaction expression should be possible for threaded rods attaching structural steel to concrete, although the author is not aware of experimental evidence to establish this relationship.

INSPECTION

Proper inspection of epoxy grouted dowels is essential as the effects of workmanship have a significant effect on dowel capacity and performance. Since epoxies are proprietary products of somewhat unique chemistry, project specifications should require the epoxy manufacturer to submit evidence that the epoxy to be used is suitable for the work. This can be verification that the epoxy conforms to AASHTO Designation T237-72I (slant shear test) or that dowels or rods embedded a certain depth in concrete fail the dowel or rod.

Of great importance is proper field inspection of the epoxy dowel installation. The dowel installation should be observed periodically, both for cleanliness of the holes, proper epoxy mixing and proper dowel installation. Holes should be clean enough that a finger inserted in the hole comes out clean without any powder or concrete dust. After the epoxy has set, a sampling of the dowels or threaded rods should be tested in tension with a calibrated jack. The test load should be one-quarter to one-third the yield strength of the dowel or rod so as not to damage the dowel for usage. A sampling frequency can be established based on number and sizes of dowels, number of shifts dowels are installed, importance of the installation and number of dowels which fail this test. The author has used this approach on various construction projects and the test easily discovered improperly installed dowels when specified procedures were not followed.

CONCLUSIONS

Based on a test program at the University of Texas at Austin and published literature, the following conclusions can be given as guidance for designers using epoxy grouted dowels in seismic strengthening projects:

1) Epoxy grouted dowels can successfully be used for seismic strengthening projects. Holes should be drilled 1/4 inch (6mm) larger than nominal reinforcing bar diameter or 1/8 inch (3mm) larger than threaded rod nominal diameter. Holes must be thoroughly cleaned with a stiff brush to remove all drilling dust.
2) Epoxy dowels for tensile loadings should be installed as described and to a minimum embedment given in Table 1.
3) Epoxy dowels for shear should be designed as shear friction per Reference 2 with installation as for tension with the concrete interface thoroughly roughened by sandblasting or chipping. Threaded rods for shear attachment of structural steel to concrete should also be installed per Table 1 with design values as for ASTM A307 bolts in steel per Reference (7).
4) Inspection of epoxy dowels should include a tension test on an appropriate sampling to a load of one-quarter to one-third of the yield strength of the dowel.

ACKNOWLEDGMENT

This work was sponsored in part by Grant CEE-8201187 and CES-8515837 of the National Science Foundation. The author appreciates this support. Opinions and conclusions are those of the author and not necessarily those of the Foundation.

REFERENCES

1. Jirsa, J.O., "Behavior of Epoxy-Grouted Dowels and Bolts Used for Repair or Strengthening of R.C. Structures," Proceedings, 9WCEE.
2. ACI Committee 318, "Building Code Requirements for Reinforced Concrete," ACI 318-83, American Concrete Institute, 1983.
3. Luke, Philip C.C.; Chon, Carlos; Jirsa, J.O., "Use of Epoxies for Grouting Reinforcing Bar Dowels in Concrete," PMFSEL Report 85-2, Ferguson Structural Engineering Laboratory, University of Texas at Austin, September 1985.
4. H.J. Degenkolb Associates, "Connections to Existing Concrete for Seismic Rehabilitation," to be published in 1988.
5. Bass, Robert A.; Corrasquillo, Ramon L.; Jirsa, J.O., "Interface Shear Capacity of Concrete Surfaces Used in Strengthening Structures," PMFSEL Report 85-4, December 1985.
6. Wiener, David F., "Behavior of Steel to Concrete Connections Used to Strengthen Existing Structures," M.S. Thesis, University of Texas at Austin, August 1985.
7. "Specification for the Design, Fabrication and Erection of Structural Steel for Buildings," American Institute of Steel Construction, November 1978.
8. Eligehausen, R. and Pusill-Wachtsmuth, P., "Stand der Befestigungstechnik in Stahlbetonbau", IABSE Surveys, S-19/82, 1982 (in German).

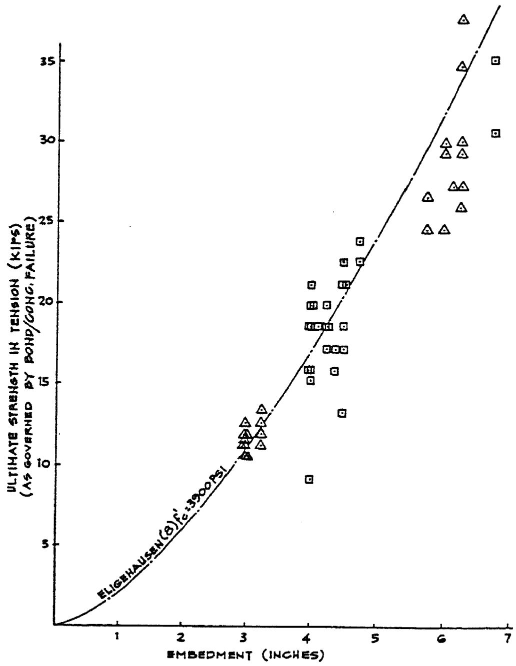

Figure 1. Tension tests of epoxy dowels (Reference 3) plotted against expression for pull-out strength of expansion anchors from Reference 8.

BAR SIZE	CONCRETE STRENGTH 2000 PSI.	4000 PSI.	6000 PSI.
4	6	5	4
5	8	7	6
6	10	8	7
7	12	10	8
8	14	12	10
9	16	14	11

GOOD DATA FOR THIS VALUE

MORE TESTING NEEDED AT THIS CONC. STRENGTH LEVEL

MORE TESTING NEEDED AT THESE BAR SIZES

Table 1. Recommended embedment depth (inches) for development of Grade 60 reinforcing bars installed with epoxy resins in accordance with proper procedures, 1 inch = 25 mm. Bar sizes are U.S. Standard (#4 = 12 mm ø, #6 = 18 mm ø, #8 = 25 mm ø).