# FIELD TESTS OF EPOXY GROUT AND EXPANSION ANCHORS
Supplement to Research Report No. R-579

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ABSTRACT: Static field tests of epoxy grouted anchorages were conducted to supplement previous laboratory tests, and to determine to what extent concrete would fail by spalling when bars were grouted in holes of various depths. Expansion anchorages were also tested. In both instances, effect of proximity to the pavement edge was studied. Allowable shear-bond stresses were determined for the epoxy anchorages.

KEY WORDS: epoxy, epoxy resins, grout, grouting, anchor bolts, anchorages, bridge rails, shear stress, bridges/structures/, reconstruction, renovating, widening.

# FIELD TESTS OF EPOXY GROUT AND EXPANSION ANCHORS
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Early in 1966, the Research Laboratory Division conducted laboratory tests on epoxy and cement-type compounds for grouting. Results were published in May in Research Report No. R-579.

The purpose of the laboratory tests was primarily the evaluation of the grouting material, not the concrete. Since the laboratory pull-out tests were done in a universal testing machine, concrete blocks were supported by the machine head, over an area that approached within a few inches of the bar that was being pulled out. This prevented the possibility of large, spall-type failures in the concrete.

This report covers subsequent field tests conducted to determine to what extent the concrete would fail by spalling when bars were grouted in holes of various depths, using epoxy-polysulphide grout. Grout used in the field tests was the same type used in the laboratory; viz., epoxy-polysulphide grout meeting Federal Specification No. MMM-G-650a, Grade B, dated June 1964.

Several 3/4-in. Bethlehem K-1 expansion anchors were also included in the field tests, some having holes filled with epoxy above the expansion shell. These tests were included because this type of anchorage has been used on highway projects in the past, and also to determine the effect of setting such anchors near the edge of a concrete slab.

## Equipment

The first step in the program was the design and construction of a reaction frame of 80,000-lb capacity for use with a pair of 20-ton hydraulic rams to pull the specimens from the pavement. The finished frame, with pump and rams, is shown in Figure 1. The frame spans roughly 3-1/2 ft between supports. The two rams were coupled to a single hydraulic pump, with a 10,000-psi pressure gage in the line. The hydraulic system was calibrated by placing the rams in a universal testing machine, and determining the load-pressure relationship. Typical threaded test bars used in the pull-out tests are shown in Figure 2. The lower bar has a 3/4-in. thread to fit the Bethlehem expansion anchors. The bars for epoxy anchorages were intended to approximate the strength of ASTM A 15 hard grade rebars.

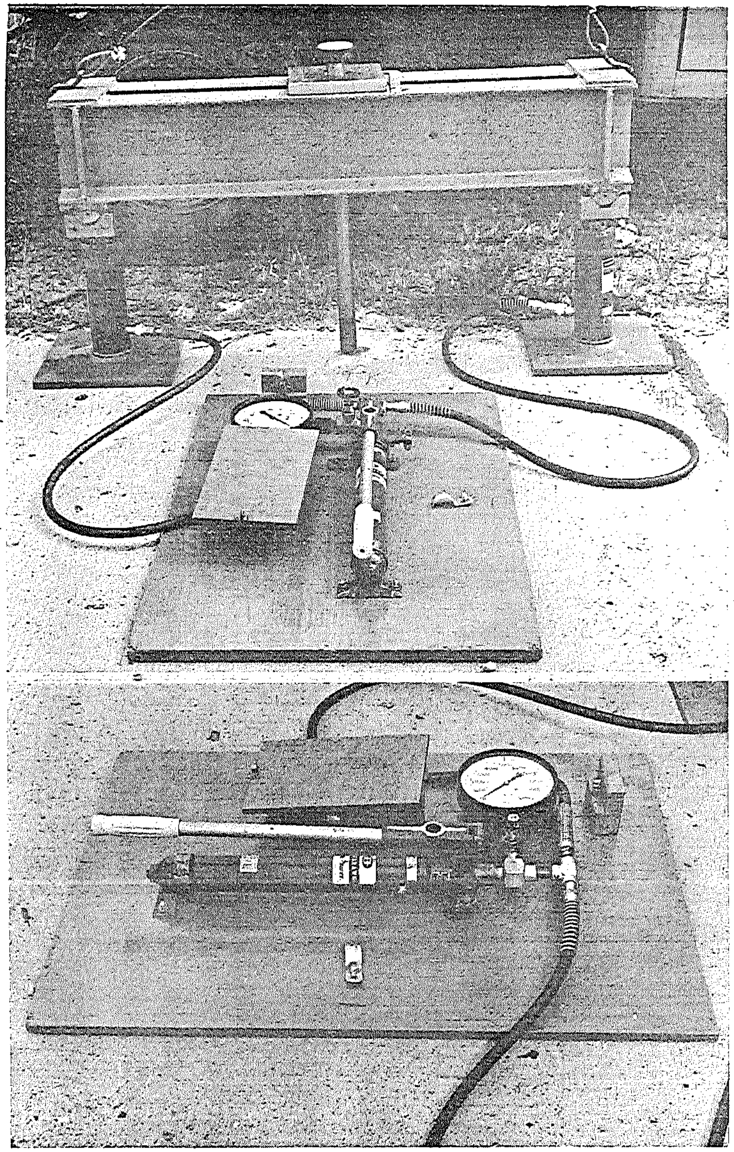


Figure 1. Reaction frame and hydraulic system (top) with 80,000-lb capacity. Hydraulic pump (bottom) has 10,000-psi gage.

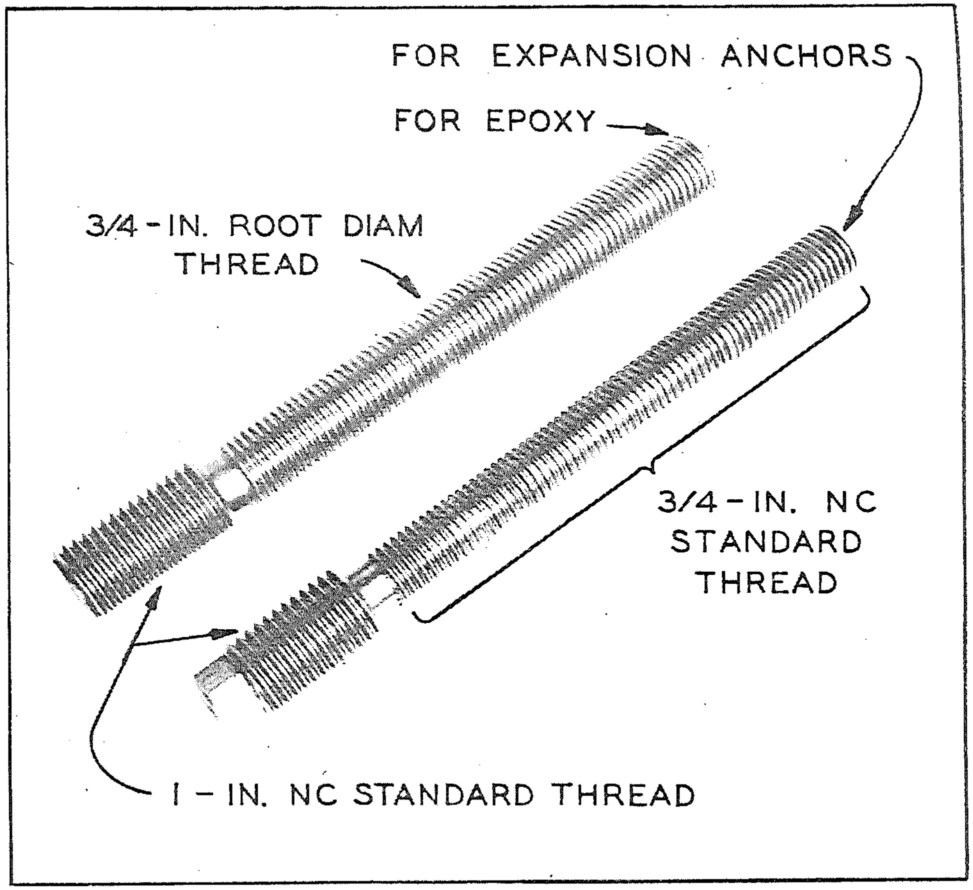



Figure 2. Typical test bars, with 1-in. standard thread to fit load frame drawbar.

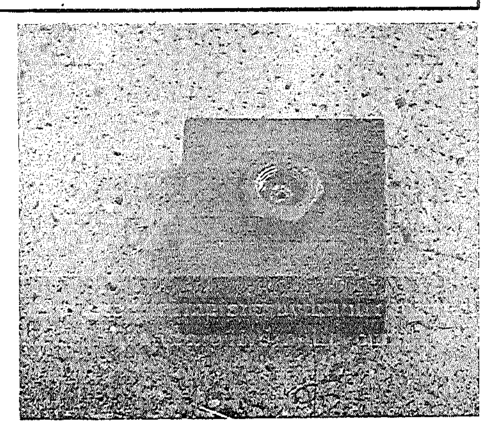


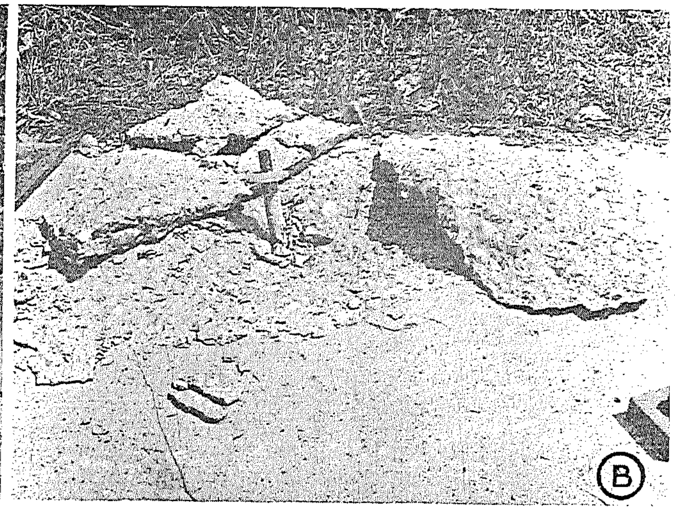
Figure 3. Typical epoxy grouted anchorage; hex nut resting on steel channel gives proper depth and alignment.

Test specimens were grouted into a 9-in. reinforced pavement slab at the abandoned weigh station near Fowlerville. Five 4-in. diam cores were cut from the concrete for strength determination. Tests run in the laboratory indicated compressive strengths of 5,150 and 5,250 psi for the slab in which the first series of tests was made, and 5,800 to 7,900 psi for the slabs used in the second series. Test holes were drilled in the pavement with a 1-1/4 in. diam carbide bit and an electric roto-hammer. The first series of test holes was prepared without extensive instructions to the crew, to determine what effect this might have on an installation and what range of pull-out loads might be encountered. Holes were cleaned by brushing without water, and some dust was left on the walls at the time of grouting. Failures in the first series of pull-out tests indicated that the cleaning had been insufficient in some cases. The second series of holes was then prepared by the same crew, with more extensive instructions. Holes for the second series were flushed out with water, cleaned with a tight fitting cylindrical bristle brush and water, and then allowed to dry before grouting. In both series, grout was poured into the test holes, and bars were then dropped in slowly. Proper depth and alignment were maintained by a hex nut threaded onto the top of the bar, resting on a small section of steel channel (Fig. 3). All expansion anchors were torqued to 75 ft-lb when installed, as recommended by the manufacturer. Epoxies were allowed to cure for a minimum of five days, at air temperatures above 70 F.

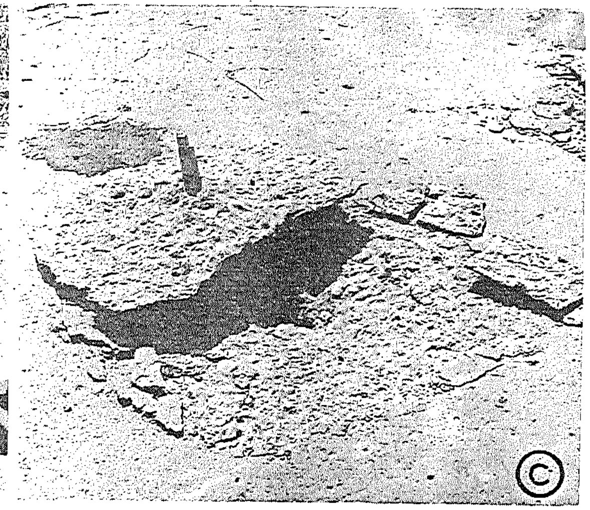
## Epoxy Grouted Bars--Discussion of Test Results

In the first test series, 14 threaded bars were grouted into the pavement at various depths and edge distances as indicated in Table 1. After curing, the test bars were pulled from the pavement, with the results given in the same table. Nominal epoxy-concrete shear bond stresses at the time of failure--the nominal shear-bond stress is equal to the failure load divided by the cylindrical surface area of the concrete hole--ranged from 650 to 1,300 psi, and averaged about 950 psi. This is considerably lower than the results obtained in the laboratory tests, which averaged about 1,800 psi. Some specimens failed in the manner shown in Figure 4a, at relatively low shear-bond stress, pulling out only a small amount of surface concrete and showing no epoxy-steel bond failure near the end. This indicated that some test holes were not adequately cleaned by the dry brushing method used. The strongest specimen of Series 1 (Figure 4b) developed 1,300-psi nominal shear-bond stress at failure, pulled a large piece out of the concrete, and showed some epoxy-steel bond failure. A specimen typical of the average anchorage strength in this


650 psi

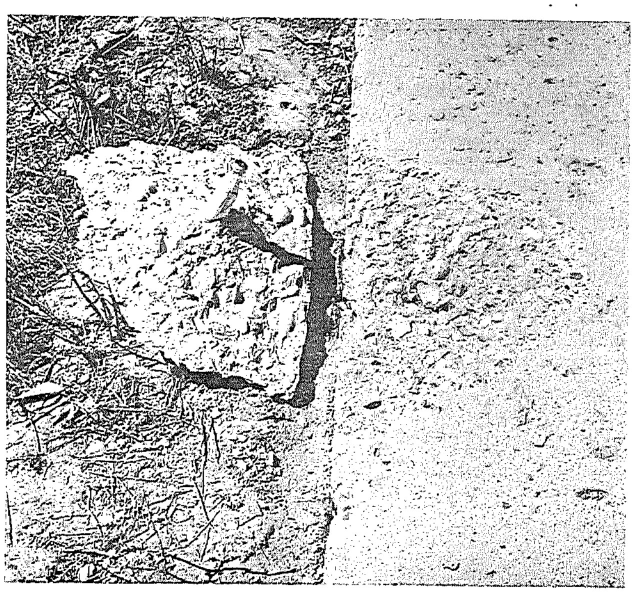



1300 psi




910 psi

Figure 4. Series 1 specimens in 7-in. holes included a) one with small amount of concrete failure and considerable shear bond failure, indicating poor bond due to dust in hole (left); b) strongest specimen, with large concrete spall and some epoxy-steel bond failure (center); and c) typical failure of average strength anchorage (right). Psi values given are nominal epoxy-concrete shear-bond stress at failure.



1100 psi

Figure 5. Series 2 specimens, set 7 in. deep and 7 in. from the pavement edge. Withdrawal of the entire epoxy plug (right) indicates poor bond at the bottom of the hole. Psi values given are nominal epoxy-concrete shear-bond stress at failure.

1150 psi





R-620

## TABLE 1
## SUMMARY OF TEST RESULTS*

| | Sample No. | Distance From Edge, in. | Hole Depth, in. | Epoxy Concrete Bond Area, sq in. | Ultimate Load, kips | Epoxy-Concrete Shear Bond Stress, psi | Tensile Bar Stress, psi | Type of Failure | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Surface Spall Depth, in. | Epoxy-Concrete Bond, in. | Epoxy-Steel Bond, in. |
| Test Series 1 | 1 | Far | 3 | 12-1/2 | 14 | 1,100 | 32,000 | Large surface spall, full depth. | | |
| | 2 | Far | 3 | 12-1/2 | 11-1/2 | 900 | 26,000 | 2 | 1 | -- |
| | 3 | 5 | 5 | 20-1/2 | 19 | 950 | 43,000 | 2 | 3 | -- |
| | 4 | 5 | 5 | 20-1/2 | 16 | 800 | 36,000 | 2 | 3 | -- |
| | 5 | 10 | 5 | 20-1/2 | 17 | 850 | 39,000 | 2 | 3 | -- |
| | 6 | 10 | 5 | 20-1/2 | 17-1/2 | 850 | 40,000 | 2 | 3 | -- |
| | 7 | Far | 5 | 20-1/2 | 21-1/2 | 1,050 | 49,000 | 2 | 2 | 1 |
| | 8 | Far | 5 | 20-1/2 | 19 | 950 | 43,000 | 3 | 2 | -- |
| | 9 | 7 | 7 | 29 | 19 | 650 | 43,000 | 1 | 6 | -- |
| | 10 | 7 | 7 | 29 | 25-1/2 | 900 | 58,000 | 2 | 5 | -- |
| | 11 | 14 | 7 | 29 | 36-1/2 | 1,250 | 83,000 | 3 | 1 | 3 |
| | 12 | 14 | 7 | 29 | 38 | 1,300 | 86,000 | 3 | 2 | 2 |
| | 13 | Far | 7 | 29 | 31 | 1,050 | 70,000 | 2 | 5 | -- |
| | 14 | Far | 7 | 29 | 26-1/2 | 900 | 60,000 | 3-1/2 | 2-1/2 | 1 |
| Test Series 2 | 1 | Far | 4 | 16-1/2 | 20-1/2 | 1,250 | 47,000 | 1 | 2-1/2 | 1/2 |
| | 2 | Far | 4 | 16-1/2 | 20-1/2 | 1,250 | 47,000 | 1 | 2-1/2 | 1/2 |
| | 3 | 5 | 5 | 20-1/2 | 28 | 1,350 | 64,000 | 1** | 4 | -- |
| | 4 | 5 | 5 | 20-1/2 | 28 | 1,350 | 64,000 | 1-1/2 | 2-1/2 | 1 |
| | 5 | 7-1/2 | 5 | 20-1/2 | 25-1/2 | 1,250 | 58,000 | 2-1/2** | 2-1/2 | -- |
| | 6 | 7-1/2 | 5 | 20-1/2 | 30 | 1,450 | 68,000 | 1 | 2 | 2 |
| | 7 | Far | 6 | 24-1/2 | 29 | 1,200 | 66,000 | 2 | 3 | 1 |
| | 8 | Far | 6 | 24-1/2 | 28 | 1,150 | 64,000 | 2 | 4 | -- |
| | 9 | Far | 6 | 24-1/2 | 44 | 1,800 | 100,000 | 3 | 2 | 1 |
| | 10 | 7 | 7 | 29 | 32 | 1,100 | 73,000 | 3** | 3 | 1 |
| | 11 | 7 | 7 | 29 | 33 | 1,150 | 75,000 | 3** | 4 | -- |
| | 12 | Far | 8 | 32-1/2 | 48 | 1,500 | 109,000 | 2-1/2 | 2-1/2 | 3 |
| | 13 | Far | 8 | 32-1/2 | 43 | 1,300 | 98,000 | 4 | 3 | 1 |
| | 14 | Far | 8 | 32-1/2 | 36-1/2 | 1,100 | 83,000 | 2-1/2 | 5-1/2 | -- |

*Threaded bars with 3/4-in. root diam grouted in 1.3-in. diam holes cleaned by dry-brushing in Test Series 1 and by water in Test Series 2.

**Spall to edge

test series is shown in Figure 4c. The second series of test installations was then made, using a more thorough cleaning method, with brushes and water. Results of the second test series are also given in Table 1. Typical failures of the deeper anchorages were similar to Figures 4b and 4c. Nominal epoxy-concrete shear bond stresses at failure ranged from 1,100 to 1,800 psi and averaged more than 1,300 psi, a considerable improvement over the results of Series 1. Some of this increase in pull-out strength may have been due to the concrete used for Series 2, which was somewhat stronger than for Series 1. However, little benefit could have been derived from the stronger concrete, if the epoxy-concrete bond had been insufficient to transfer the load to the concrete. Several anchorages were set at various distances from the edge of the slab to determine the extent to which edge distance would affect the mode of failure. Results have been included in the tables. Edge distances in all cases equaled or exceeded hole depth. Although the concrete did spall to the edge in some cases, nominal shear bond stresses at failure were comparable to some other specimens that were located far from the edge. In no case did the concrete split out to the edge for the full depth of the anchorage. Samples from Series 2 that were set 7 in. deep and 7 in. from the edge are shown in Figure 5. Nominal shear bond stresses at failure for these two specimens were 1,100 and 1,150 psi.

Failure of the longer specimens was characterized by surface spalling at or near the maximum load, followed by withdrawal of the lower portion of the anchorage for some distance at a somewhat lower load which gradually dropped as the contact length decreased. In only one case did the concrete spall to the full depth of the anchorage, and that was at a test depth of only 3 in.

Minimum ultimate tensile strength for ASTM A 15 hard grade rebars is 80,000 psi, corresponding to a load of about 35,000 lb on a nominal 3/4-in. bar. The table shows that two 7-in. deep anchorages exceeded this load in the first series of tests, while one 6-in. deep anchorage and all three 8-in. deep anchorages in the second series of tests exceeded 35,000 lb.

## Epoxy Grouted Bars--General Discussion

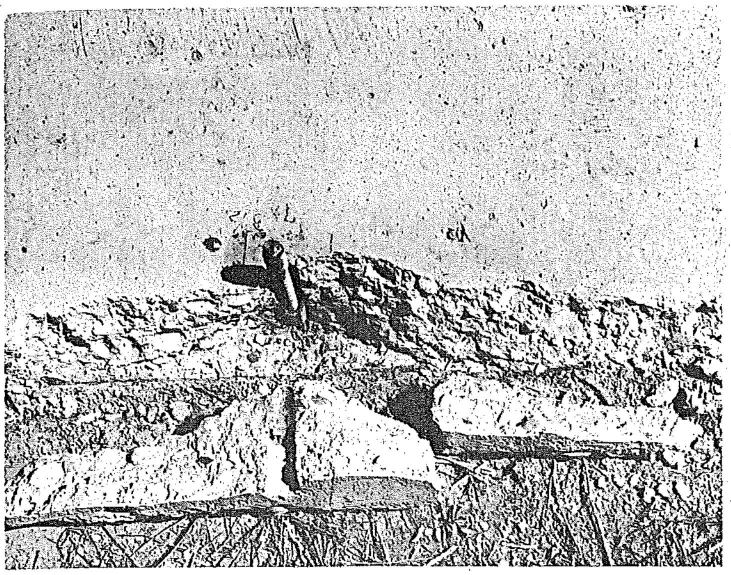
An expression for theoretical critical depth, $h_c$, required to prevent full depth conical spall failures of the concrete, was presented on page 4 of Research Report No. R-579. Several simplifying assumptions were made in the development of $h_c$ and are stated in that report. The field tests reported here have shown that epoxy grouted anchorages, of the type tested, do not fail by full depth conical spalling when depths are sufficient to develop the major portion of bar strength (Figs. 4b, 4c, 5). Since failures did not occur in the manner postulated, the values of $h_c$ listed in Table 1 of Research Report No. R-579 cannot be directly compared with the test results. The scope of the field tests was not sufficient to develop a general theory for the type of failure encountered. Maximum hole depths were limited to 8 in. by the thickness of the slab and only one hole diameter was used. However, the results do indicate that the anchorage resistance of the concrete is sufficient to develop the required loads in 3/4-in. diam bars, when the design of the anchorage is based on allowable shear bond stresses at the grout-concrete and grout-steel interfaces. It does not seem unreasonable to assume that similar results would be obtained with 1-in. diam bars designed on the same basis. Therefore, although the calculated values of $h_c$ in Research Report No. R-579, cannot be directly compared to the results of the present tests, the values do seem reasonable in light of these results.

Table 8 of Research Report No. R-579 recommended 9-in. hole depth for 3/4-in. bars in nominal 1-1/4 in. diam holes, and 14-in. hole depth for 1-in. bars in nominal 1-1/2 in. diam holes. These recommendations were based on development of the minimum ultimate strength for hard grade rebars, using 1,000-psi nominal shear bond stress at the grout-concrete interface. This seemed to be a reasonably conservative figure, based on laboratory tests. However, in view of the Series 1 results, which could be somewhat representative of field conditions, it may be advisable to increase the specified hole diameters by 1/4-in. This lowers the required shear-bond stress to about 800 psi for the development of the minimum ultimate bar strength. The larger diameter would also allow more clearance for cleaning the holes. Expansion of the hole diameter to much more than twice the bar diameter is not recommended, since the shear-bond stresses at the steel-grout interface would then govern the design.

Bethlehem Expansion Anchors--Discussion of Test Results

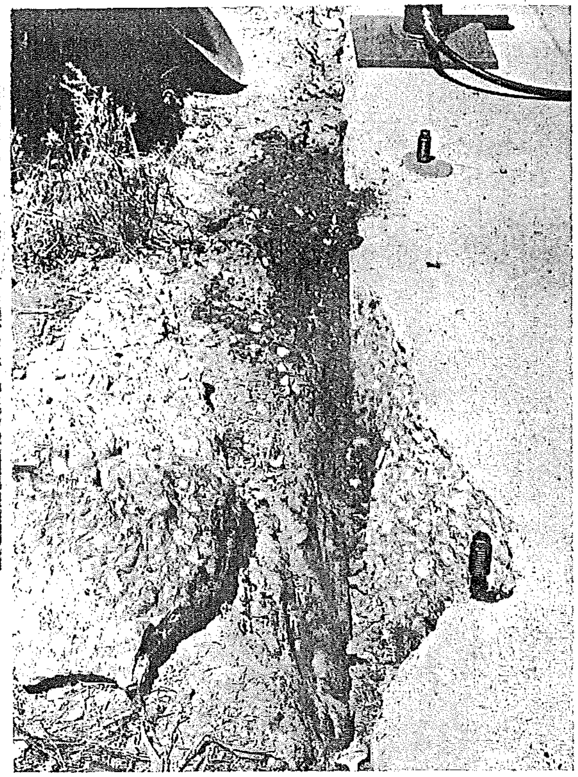
Twelve 3/4-in. Bethlehem K-1 expansion anchors were included in the field tests, with the results given in Table 2. All of the anchors were set in nominal 1-1/4 in. diam holes, 7 in. deep. Various edge distances were tried, as shown in the table, to establish the minimum distance required to develop the full strength of the anchor bolt. Anchors set at 3-1/2 and 5-1/2 in. from the pavement edge failed as shown in Figure 6, by spalling out full depth to the pavement edge. One anchor set 6 in. from the pavement edge failed by breaking a large corner off the slab (Fig. 7a), even though the distance to the transverse pavement joint was about 1-1/2 ft. This indicates that caution is required in selection of locations for such anchors near joints or corners. Another anchor with 6-in. edge distance, set far from a transverse joint, developed the full strength of the bolt without damage to the slab (Fig. 7b). Anchors set in the interior of the slab developed the full strength of the bolt and failed in the same manner shown in Figure 7b.

Four specimens had holes filled with epoxy grout after the expansion anchor had been set. This was done because such anchorages have been specified on highway projects in the past. One such anchorage with 5-1/2 in. edge distance developed the strength of the bolt, while a similar anchorage failed by spalling full depth. Both are shown in Figure 8. Neither

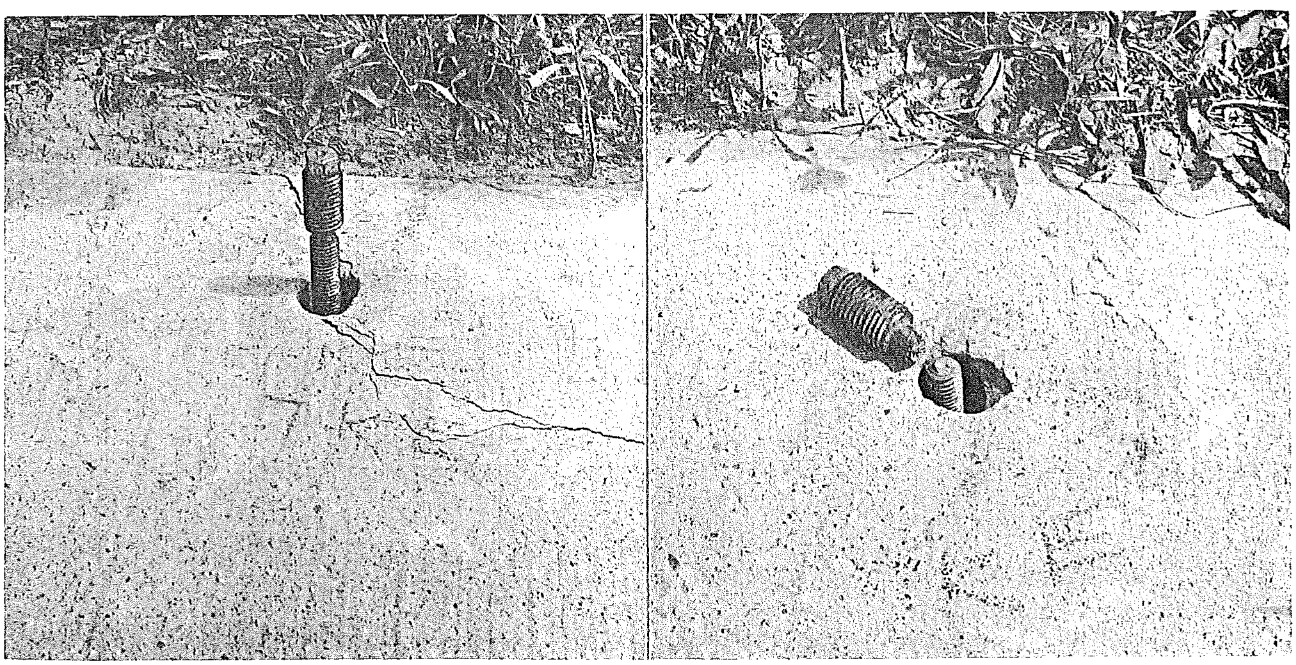


7-in. Deep
3-1/2 in. From Edge

Figure 6. Two expansion anchors spalled full depth to the pavement edge.



7-in. Deep
5-1/2 in. From Edge

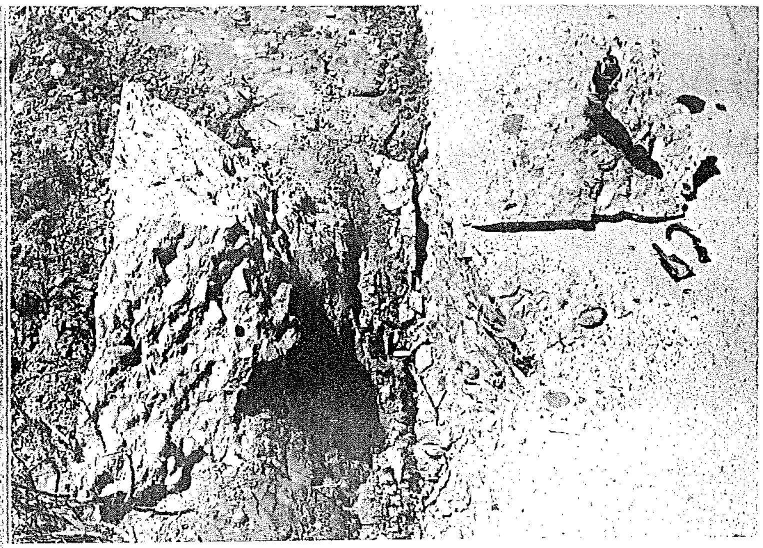


7-in. Deep
6 in. From Edge

7-in. Deep
6 in. From Edge

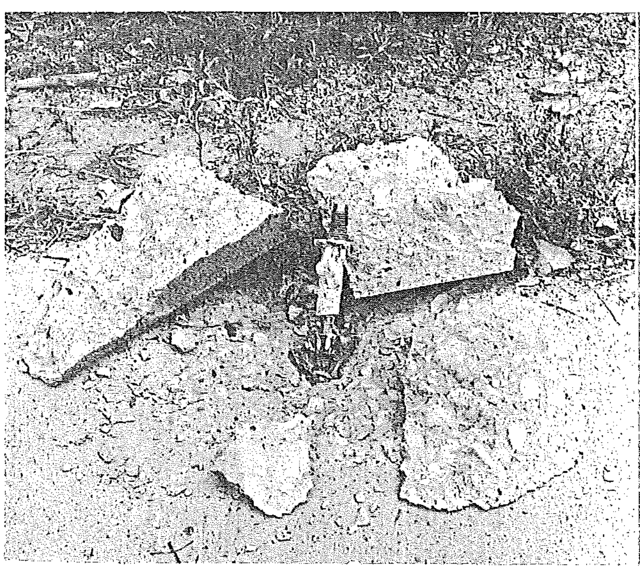
Figure 7. Expansion anchor broke large corner from slab even though 1-1/2 ft from transverse joint (left), but another (right) far from transverse joint developed full strength of the bolt without damage to the pavement.

7-in. Deep
5-1/2 in. From Edge

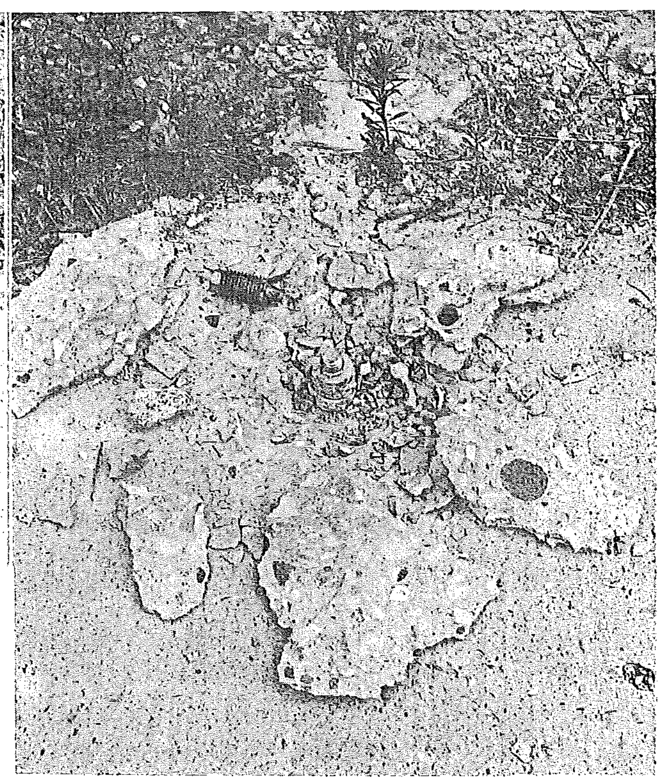


7-in. Deep
5-1/2 in. From Edge

Figure 8. After initial spalling, two anchors set in epoxy at similar depths and distances from the pavement edge, in one case developed strength of the bolt (left), and in another, failed by spalling to the pavement edge for the entire anchorage depth.



7-in. Deep
7 in. From Edge



7-in. Deep
7 in. From Edge

Figure 9. After initial surface spalling, anchors similarly installed failed in the expansion shield (left), and developed strength of the bolt (right).

of the two anchorages spaced 7-in. from the edge failed by spalling full depth (Fig. 9); one failure consisted of surface spall plus fracture of the expansion shield, while the other consisted of a surface spall and bolt fracture.

TABLE 2
FIELD TESTS OF BETHLEHEM 3/4-in. K-1 EXPANSION ANCHORS

| Test No. | Description | Distance From Edge, in. | Hole Depth, in. | Ultimate Load, kips | Load at Time of Surface Spall | Type of Failure* |
|---|---|---|---|---|---|---|
| 1 | K-1 | 3-1/2 | 7 | 19 | -- | Concrete fracture to pavement edge, full depth. |
| 2 | K-1 | 3-1/2 | 7 | 18 | -- | Concrete fracture to pavement edge, full depth. |
| 3 | K-1 | 5-1/2 | 7 | 25-1/2 | -- | Concrete fracture to pavement edge, full depth. |
| 4 | K-1 | 5-1/2 | 7 | 23-1/2 | -- | Concrete fracture to pavement edge, full depth. |
| 5 | K-1 | 6 | 7 | 28 | -- | Pavement cracked from edge to nearby joint, loosening insert. |
| 6 | K-1 | 6 | 7 | 33 | -- | Bolt broken, concrete intact. |
| 7 | K-1 | Far | 7 | 33 | -- | Bolt broken, concrete intact. |
| 8 | K-1 | Far | 7 | 32-1/2 | -- | Bolt broken, concrete intact. |
| 9 | K-1 + Epoxy | 5-1/2 | 7 | 32 | 25 | Surface spall 3-in. deep, full depth concrete fracture to pavement edge. |
| 10 | K-1 + Epoxy | 5-1/2 | 7 | 37-1/2 | 29 | Surface spall 1-1/2 in. deep, load then increased until bolt broke. |
| 11 | K-1 + Epoxy | 7 | 7 | 26-1/2 | -- | Surface spall 2-1/2 in. deep to pavement edge load then increased until bolt broke. |
| 12 | K-1 + Epoxy | 7 | 7 | 33-1/2 | -- | Surface spall 2-in. deep, load then increased until bolt broke. |

*In most cases, the inserts pulled out 1/2 to 3/4 in. before ultimate failure.

In general, the combination expansion anchor-plus-epoxy anchorages resulted in a surface spall caused by the epoxy at intermediate load, followed by a typical expansion anchor failure in which there was some slippage terminated by fracture of the bolt, the expansion shield, or the concrete, at the maximum load. Thus it seems that for a total hole depth of 7 in., the epoxy would serve mainly as a waterstop, since the expansion anchor is not actually resisting very much load until after the surface spall has occurred. A better anchorage would probably result if the epoxy were placed in the hole first and the expansion anchor set in the epoxy, instead of just filling the hole with epoxy after the expansion anchor has been set.

## Conclusions

The field tests showed that it is possible to develop the minimum ultimate strength of hard grade rebars, using epoxy grouts and 1-1/4 in. diam holes in a 9-in. pavement slab. The amount of surface spalling is considerable, and penetrates to depths of 3 to 4 in. for anchorages of 7- and 8-in. depth in concrete having compressive strengths of 5,000 to 6,000 psi. Series 1 and 2 anchorages had average nominal shear bond stresses at the epoxy-concrete interface of 950 and 1,300 psi, respectively. This indicated the effect of insufficient cleaning of bond surfaces in Series 1. By comparison, the laboratory tests previously reported gave average stress values up to 1,800 psi at failure, when large spall-type failures were not possible.

Although the edge distance experiment with epoxy anchorages was not extensive, the limited results indicate that such anchorages can be set with edge distance equal to depth, without serious reduction in capacity. Since testing was limited to 3/4-in. bars in 1-1/4 in. diam holes 7-in. deep or less, in concrete with compressive strength above 5.000 psi, no positive statement can be made concerning edge distance requirements in general. The amount and location of steel reinforcement in a slab would certainly affect the mode of failure to some extent. In cases where the anticipated loading will be vertically upward, it would seem prudent to maintain edge distances at least equal to depth, for anchorages similar in size to the ones tested.

Three-quarter inch Bethlehem K-1 expansion anchors set 7-in. deep may fail by spalling out to the pavement edge, when set less than 6 in. from the edge of slabs having compressive strengths of 5,000 to 6,000 psi. Corners may also be broken off if such anchors are set near an edge, less than 2 ft from a transverse joint or corner. These distances would undoubtedly be larger in weaker concrete.

Epoxy grouts used to fill holes above expansion anchors that were set 7-in. deep, added nothing to the ultimate strength of the anchorage, since the expansion anchors were not brought into play until after the epoxy-concrete portion of the anchorage had failed. This would not necessarily be the case in deeper anchorages, since the epoxy-concrete system would soon develop the strength of the bolt if depth were increased significantly. Also, the epoxy may serve a valuable function as a water-stop in the shallower anchorages, since any water trapped in the system could do considerable damage upon freezing, or introduce corrosion problems.

## Recommendations

Based on the results of the field tests, it is recommended that the upper portion of Table 8 of Research Report No. R-579 be revised to read as follows:

| Bar Diam, in. | Steel Type (ASTM Designation) | Grouting Agent | Hole Dimensions, in. | |
|---|---|---|---|---|
| | | | ND | Depth |
| 3/4 | A 15 Hard Grade | Epoxy mortar or grout | 1-1/2 | 9 |
| 1 | A 15 Hard Grade | Epoxy mortar or grout | 1-3/4 | 14 |

This is an increase of 1/4-in. in hole diameter. Any installations made under the former recommendation should be adequate if the surfaces were cleaned as suggested in the previous report. The present recommendation should provide slightly more room for cleaning the holes, and some additional safety factor if the dust is not entirely removed from the bond surfaces. Again, it is emphasized that the important point of preparation is that the walls be clean and dry before grouting, regardless of the cleaning method used. Any dust, oil, or free water on the surfaces can reduce bond strength.

For concrete compressive strengths within the range of the field test values, Bethlehem Type K-1 expansion anchors of 3/4-in. size, set about 7-in. deep near the edge of a slab, should be provided with edge distances not less than the anchorage depth, and should be 2 ft or more from a corner. Although no larger expansion anchors were tested, it would seem reasonable to allow proportionately larger edge and corner distances for the larger anchors, by ratios varying with the ultimate bolt strength. Greater depth might also be required for the larger diameter anchors.

If epoxies are specified for use with expansion anchors, it should be realized that the epoxy will add nothing to the ultimate strength of a shallow anchorage, but may be valuable as a seal. Where combination anchorages are set, it is believed that setting the expansion anchor into the epoxy would be more beneficial than simply filling the hole above the expansion shield.