EVALUATION OF EXPANSION ANCHORS, SELF-DRILLING, TORQUE-TYPE, AND STUD-TYPE

MICHIGAN DEPARTMENT OF STATE HIGHWAYS AND TRANSPORTATION

TESTING AND RESEARCH DIVISION
RESEARCH LABORATORY SECTION

EVALUATION OF EXPANSION ANCHORS, SELF-DRILLING, TORQUE-TYPE, AND STUD-TYPE

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Over the past several years, various types of concrete expansion anchors have been evaluated, as requested through the Department's New Materials Committee or the Construction Division. These anchors fall into two general categories: those which are self-drilling; and those which require a pre-drilled hole in the concrete. These latter we shall call 'non-drilling' to differentiate them from the 'self-drilling' which form their own hole. The types of non-drilling anchors discussed are flush, stud, and torque types.

It has been established from past testing programs that the ultimate pull-out load that an expansion anchor sustains usually occurs after considerable slippage has taken place. Since the primary application of expansion anchors in highway construction is for use as lane ties, it is imperative that any given anchor be able to sustain maximum loads with minimum slippage. Many anchors require some pull-out slippage to develop resistance, but slippage of a lane tie allows the joint to open.

Non-drilling anchors require holes of close tolerance to ensure proper pull-out resistance. Oversize holes can reduce capacity while undersize holes prohibit proper insertion. Torque-type anchors must have adequate torque applied to reach their proper pull-out resistance; however, over-torque may ruin the anchor, break the bolt, or fracture the concrete. Placement of the anchor in green concrete or too near an edge or corner may fracture the concrete due to large lateral pressures exerted when the anchor is expanded. Also, up until this year, it has been very difficult to perform meaningful inspection to determine whether anchors have been properly installed. Since each District now has anchor testing equipment, detrimental factors of contractor installed anchors can now be checked in the field.

The anchors in this report were tested against a slippage criterion rather than ultimate load. Variables for the tests were location of the anchors in relation to the slab surface, size of the expansion anchors, and amount of torque applied to torque-type anchors prior to pull-out. The tests were conducted to determine the load capacity at 1/32 in. slippage.

TEST SAMPLES

Previously reported tests evaluated the capacities of 5/8, 3/4, and 7/8-in. self-drilling anchors, and non-drilling flush and torque-type anchors set in the pavement edge and surface. The results of these tests can be seen in the Appendix, which also shows how definitions of failure have varied through the years. This report presents further evaluations of the self-drilling types and non-drilling flush, stud, and torque-type concrete anchors.

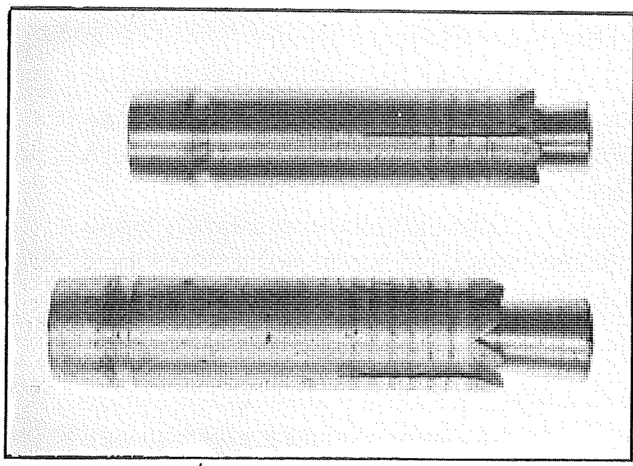


Figure 1. 3/4 and 7/8-in. Rawl anchors.

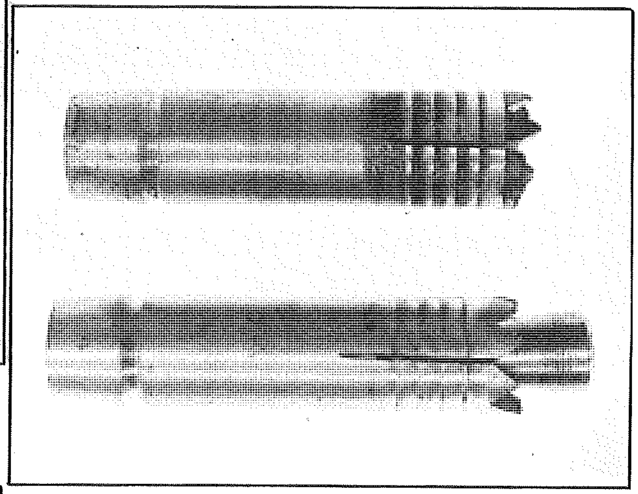


Figure 2. 3/4-in. Arro anchor. Note worn teeth on Arro anchor (top) after failure to penetrate concrete.

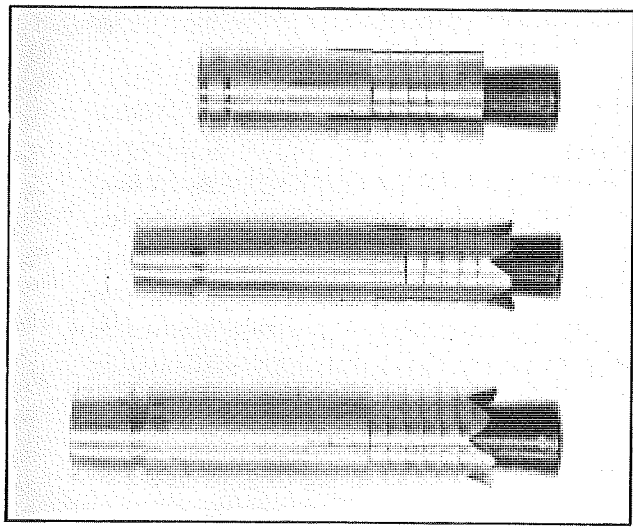


Figure 3. Phillips anchors tested, from top to bottom, 3/4-in. non-drilling flush-type, 3/4-in. self-drilling, and 7/8-in. self-drilling.

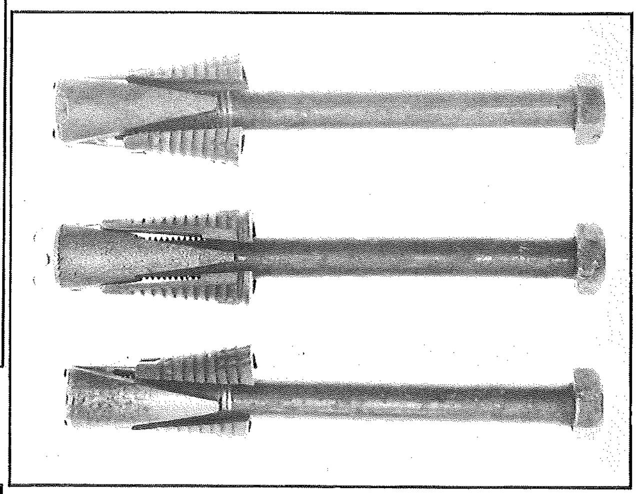


Figure 4. Frazer and Jones torque-type anchors (top to bottom) D3, D2, and D13.

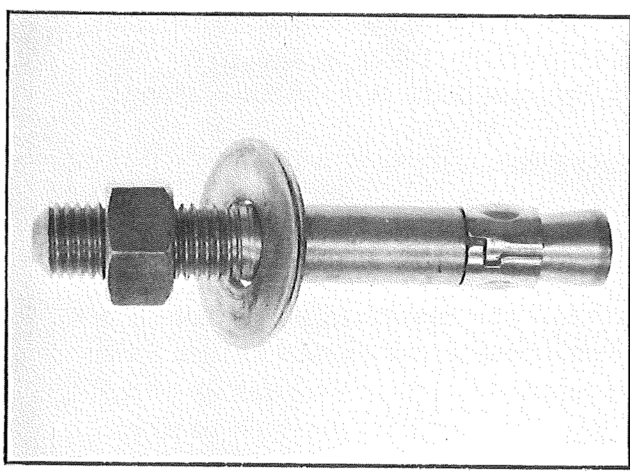


Figure 5. 3/4 x 5-1/2-in. Rawl-Stud anchor.

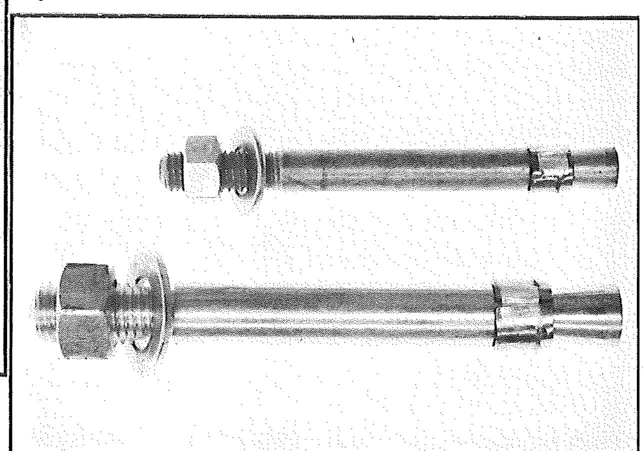


Figure 6. Hilti Kwik-Bolt concrete anchors 1/2 x 5-1/2-in. and 3/4 x 7-in.

Self-Drilling

The self-drilling anchors tested were 3/4 and 7/8-in. Rawl (Fig. 1), supplied by the Rawlplug Co. of Detroit, Michigan; and 3/4-in. Arro (Fig. 2) self-drilling anchors supplied by Power Actuated Tool Co. of Chicago, Illinois. For comparison purposes, 3/4 and 7/8-in. Phillips Red Head self-drilling anchors were also tested (Fig. 3). Previous Phillips self-drilling anchor evaluation and results are listed in the Appendix.

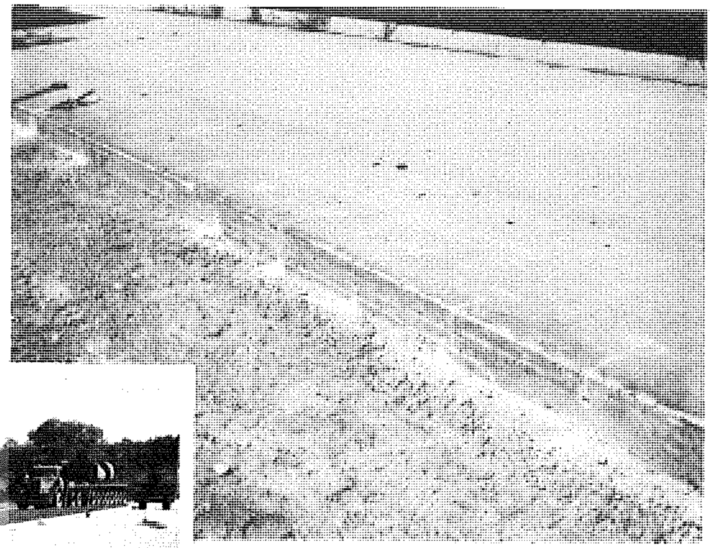
Non-Drilling Torque-Type

The torque-type anchors evaluated are the Frazer and Jones D2, D3, and D13 shield-type expansion anchors. They were supplied by the Frazer and Jones Co. of Syracuse, New York. The Frazer and Jones D13 was previously evaluated in MDSHT Research Report R-987 and pull-out results are listed in the Appendix. The Frazer and Jones D13 requires a hole drilled 1-1/4 in. in diameter and the D2, and D3 require 1-3/8-in. diameter holes. The D2, D3, and D13 shields differ slightly in length and shield surface design. The D2 is approximately 1/2 in. longer than the D3 and D13 (Fig. 4). The Frazer and Jones anchors are similar in design to the previously tested Bethlehem K-1, except for the bail used to hold the wedges in place while the expanding plug is pulled outward when the bolt is torqued. Frazer and Jones anchors have a sheet metal bail mechanically fastened to a pair of wedges, while Bethlehem uses a bail integrally cast with the wedges. Frazer and Jones anchors are supplied as a shield, the bolt portion of the assembly is a separate item. The Frazer and Jones D2, D3, and D13 anchors were evaluated in 3/4-in. diameter sizes. Since the minimum diameter for lane ties is now specified at 5/8 in., anchors of this size were not evaluated because the threaded 5/8 in. bolt has a root diameter smaller than 5/8 in. Pull-out results on the previously evaluated Frazer and Jones D13 and Bethlehem K-1 are listed in the Appendix.

Non-Drilling Stud-Type

The Rawl-Stud concrete anchor is a high tensile steel masonry fastener manufactured by the Rawlplug Co. of New Rochelle, New York. The fastener features a dual interlocking expansion wedge assembly. It requires a pre-drilled hole the same diameter as the stud. When the stud is driven into the pre-drilled hole, the wedges ride against the stud shoulder. Then as the tension developed by the tightened nut pulls up on the stud, the wedges are forced out by the conical wedging action of the contoured base. The wedges grip the wall of the hole, developing an anchor locking force which increases with additional tensile loading on the stud. The Rawl-Stud comes in sizes from 1/4 by 1-3/4 to 1-1/4 by 12 in. This evaluation used the 3/4 by 5-1/2 in. Rawl-Stud (Fig. 5) which requires a minimum 3-in. deep hole and a minimum torque of 65 lb-ft.

Figure 7. Installation site. Note randomly drilled holes for different size and type anchors.



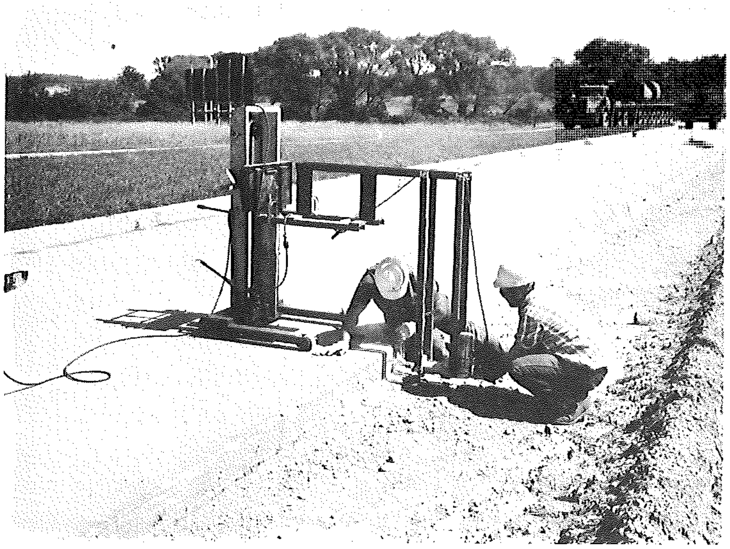
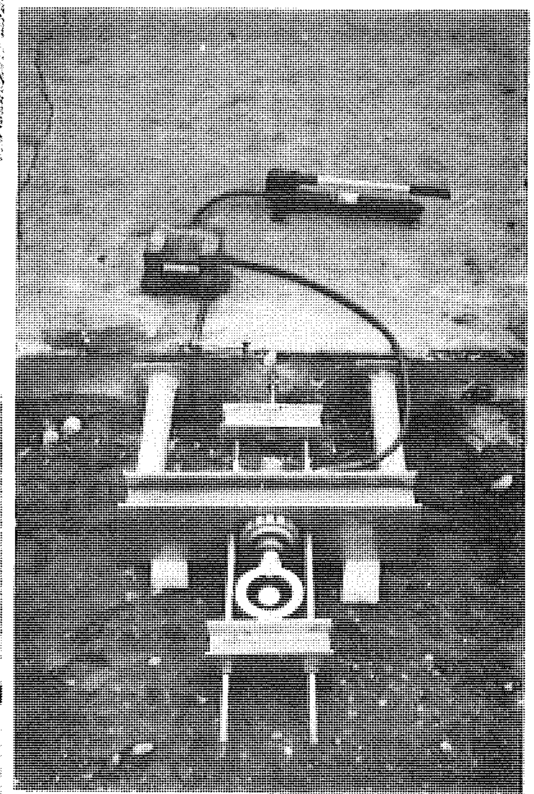


Figure 8. Fixture used to hold roto-hammer in correct alignment while drilling holes.

Figure 9. 20,000 lb capacity test frame used to apply load to the anchors.



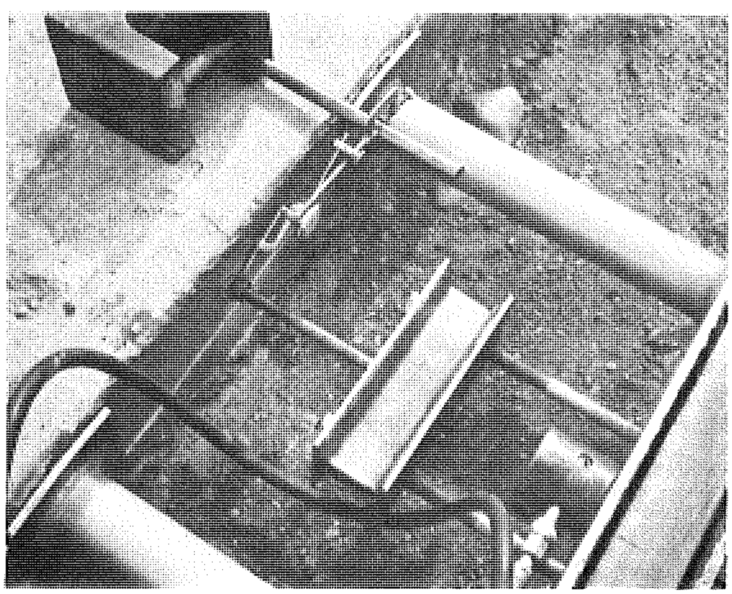


Figure 10. Indicator arrangement used to measure anchor extrusion.

The Hilti Kwik-Bolt concrete expansion anchor is a stud-type anchor manufactured by Hilti Fastening Systems of Columbus, Ohio. The Kwik-Bolt is designed to be installed in a hole drilled with a carbide drill bit of the same nominal diameter as the anchor. The bottom of the hole is not required to set the anchor, therefore, it can be said that the Kwik-Bolt works in a 'bottomless hole.' As the anchor is driven into the hole, the independent spring steel wedges are pretensioned against the side of the hole and prevent the anchor from turning while setting. The dimensions of the Kwik-Bolt used in this evaluation are 1/2 by 5-1/2 and 3/4 by 7 in. (Fig. 6).

Non-Drilling Flush-Type

Phillips 3/4-in. non-drilling flush-type concrete expansion anchors, shown in Figure 3, were also evaluated as requested by the Department's Construction Division. Previous evaluations have been conducted on 3/4-in. Phillips non-drilling flush-type anchors with pull-out results shown in the Appendix. Phillips 3/4-in. non-drilling flush-type anchors require a 1-in. diameter hole pre-drilled 3-3/16 in. deep with a conventional carbide masonry drill. The anchor is then inserted and set flush with a few hammer blows, using a setting tool usually supplied with the anchors.

INSTALLATION AND TESTING

The anchors were installed in the edge of an unused ramp at the Grass Lake truck weighing station located on westbound I 94 east of Jackson. The slab is 9 in. thick and was built in 1962. Concrete cores taken from the vicinity of the area used for the experiment show an average core compressive strength of 5,500 psi.

The location of the self-drilling, and the non-drilling flush-type and torque-type concrete expansion anchors were predetermined using random number tables. The anchors were placed approximately 18 in. apart. Stud-type anchors were set arbitrarily along the edge or surface of the concrete (Fig. 7).

Tentatively, six samples of each self-drilling, and non-drilling flush-type concrete expansion anchors were to be installed in the pavement edge 4-1/2 in. from the top of the slab. In addition, three samples of each self-drilling anchor, except Phillips anchors, were to be installed in the pavement edge 6 in. from the top of the slab. The self-drilling anchors were drilled into the concrete with an electric roto-hammer. Holes for the non-drilling flush-type Phillips anchors were drilled with a 1-in. drill bit powered by an electric roto-hammer. The fixture used to hold the roto-hammer in correct alignment while drilling anchors and holes can be seen in Figure 8. Before final installation, all holes were blown clean with compressed air. The self-drilling and flush-type anchors were set by the driver and hammer method, and to obtain uniformity the anchors were driven to refusal.

Six samples of each Frazer and Jones concrete expansion anchors were installed in the slab edge at 90 lb-ft and six at 120 lb-ft torque, 4-1/2 in. from the top of the slab. In addition, six more samples of each type of anchor were installed 6 in. from the top of the slab at 120 lb-ft torque. Holes for the Frazer and Jones anchors were made with an air hammer utilizing carbide insert star bits and Timken star bits. The holes were blown clean with compressed air before anchor installation.

Torque values recommended by the manufacturer were 110 to 130 lb-ft for application in rock. Since MDSHT Standard Specifications call for a 100 lb-ft torque on torque-type concrete expansion anchors, values of 90 and 120 lb-ft, were applied to determine the effect of torque on load capacity, and the reaction of the concrete to the expansive forces caused by installation. The torque applied to the Frazer and Jones anchors was measured with a 150 lb-ft capacity torque wrench.

Six samples of the Rawl-Stud 3/4 by 5-1/2 in. concrete anchor were installed on the surface of the pavement. It has already been established that stud-type anchors are not suitable for lane tie application because of their lack of resistance to slippage. They may be suitable for non-critical application such as fastening decorative type railings. The Rawl-Stud 3/4-in. anchors were installed in pre-drilled holes the same diameter as the stud and torqued to the manufacturer's recommended minimum of 65 lb-ft with a 150 lb-ft capacity torque wrench. The pre-drilled holes were drilled with an electric roto-hammer and blown clean with compressed air.

Five samples of the Hilti Kwik-Bolt 1/2 by 5-1/2-in. concrete expansion anchors were set in the edge of the concrete; three at 2-1/2 in. from the top of the slab and two at mid-slab. The depth of the pre-drilled holes was 3-1/2 in. Nine of the 3/4 by 7-in. Kwik-Bolt anchors were installed on the surface of the concrete; three in 4-1/2-in. deep holes and six in 5-1/2-in. deep holes. All but two of the holes were drilled with a Hilti hammer-drill using a drill bit the same diameter as the anchors. All holes were blown clean with compressed air prior to anchor installation. Each anchor was set as per manufacturer's recommendations.

Testing

Load was applied to the anchors by a hydraulic ram and pump, acting through a 20,000-lb capacity aluminum frame (Fig. 9). The load was monitored by use of a calibrated dynamometer ring and dial indicator. Pull-out slippage was measured by a dial indicator, and load was recorded when slippage reached 1/32 in. Figure 10 shows the draw-bar and indicator arrangement used to test the self-drilling, and the non-drilling flush-type and stud-type anchors. Figure 11 shows the fixture used to grip the bolts inserted in the Frazer and Jones torque-type expansion anchors during testing.

Results

Table 1 shows results of the pull-out tests on Arro, Phillips, and Rawl self-drilling concrete expansion anchors.

The location of the 3/4 and 7/8-in. self-drilling anchors with respect to distance from the surface apparently does not affect the load capacity at 1/32 in. slippage. In most cases where the anchors were expanded without fracturing the concrete, they were able to withstand sufficient load to meet the allowable design load at 1/32 in. slippage. It should be noted that the concrete at this site seemed to be in good condition and is quite strong.

In previous testing, it has been found that 7/8-in. anchors are capable of developing loads high enough to spall the concrete before the specified pull-out is attained when the anchors are set close to the surface. Three out of the four 7/8-in. self-drilling Rawl anchors, installed 6 in. from the top of the 9-in. slab, fractured the concrete. Two of these fractured the concrete during installation, one during testing. The 3/4-in. Rawl self-drilling anchors performed well and attained sufficient load to meet the allowable design load at 1/32 in. slippage.

The Arro concrete expansion anchors were very difficult to install since they would not penetrate through the stone in the concrete (Fig. 2). After numerous attempts, only one 3/4-in. self-drilling Arro anchor was tested and it failed to meet the allowable design load. An Arro manufacturer's product bulletin states that Arro self-drilling anchors will fail to perform properly in materials such as concrete with hard aggregate, high density stone, brittle and/or soft brick.

Further analysis subjected each self-drilling anchor to a hardness evaluation. The anchors evaluated were the 3/4 and 7/8-in. Phillips and Rawl and the 3/4-in. Arro. Using the Rockwell Hardness "C" Scale, the Phillips and Rawl anchors had an average Rockwell C hardness of 60 and 59, respectively. The Arro anchor attained an average of 41. A cross-section of each anchor was cut and etched showing the depth of case hardening. The Arro anchor had considerably less depth of case hardening than the Phillips and Rawl anchors. This explains the problems encountered in drilling through hard aggregate with the Arro anchor.

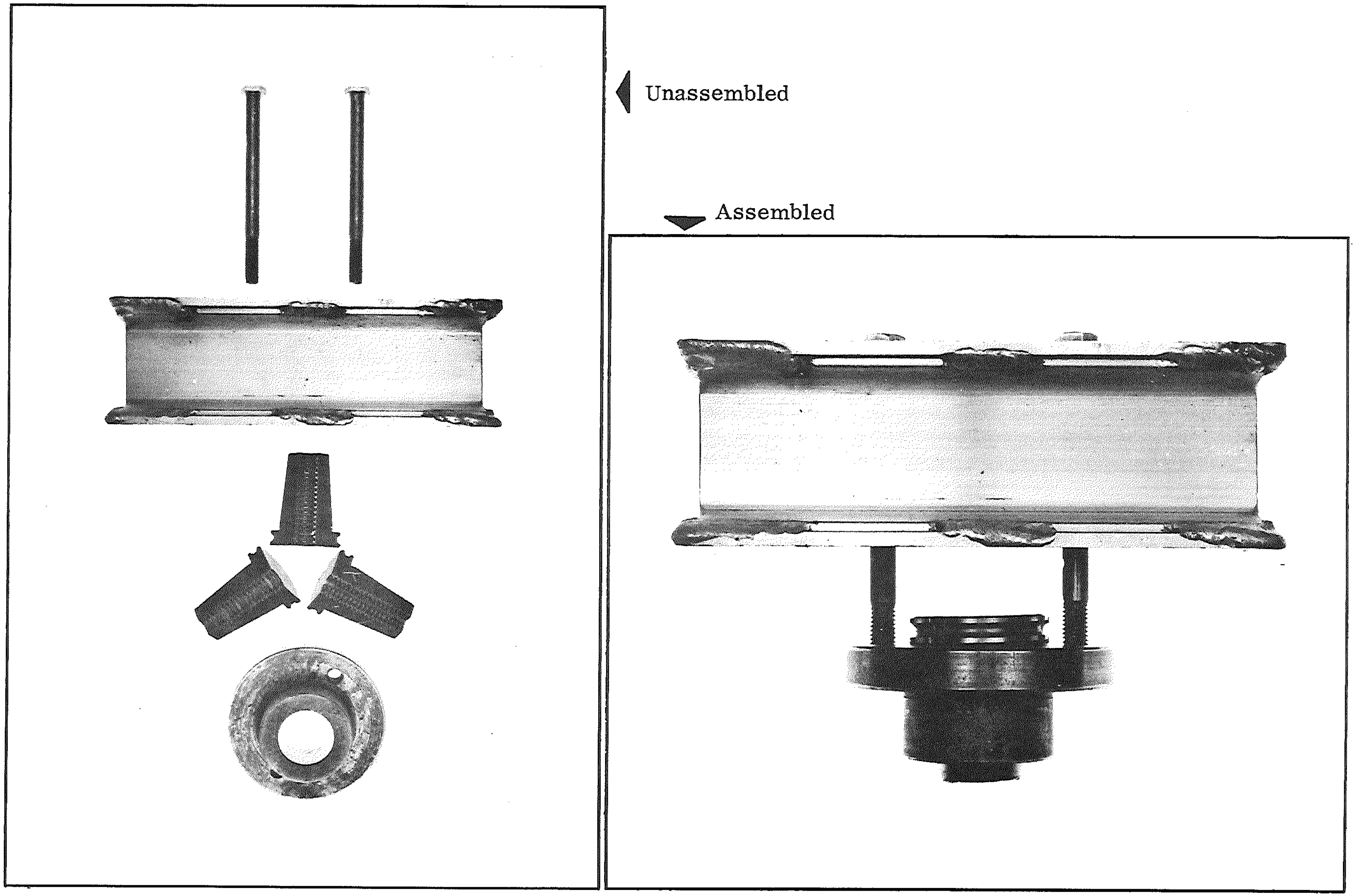


Figure 11. Fixture used to pull-out torque-type anchors.

TABLE 1
SELF-DRILLING ANCHOR PULL-OUT RESULTS

	Type of Anchor	Distance From Top of Slab, in.	Load at 1/32 in. Slippage, lb	Maximum Load Applied, lb	Maximum Slippage, in.
3/4-in. Bolt Diam.	Rawl	4-1/2	11,400	14,400	1/16
	Rawl	4-1/2	9,800	15,800	1/8
	Rawl	4-1/2	14,000	15,800	1/16
	Rawl	4-1/2	11,800	15,800	1/16
	Rawl	4-1/2	12,000	15,800	1/8
	Rawl	4-1/2	13,800	15,800	1/16
	Average		12,100	15,600	
	Rawl	3	13,400	15,800	1/16
	Rawl	6	13,400	14,400	1/8
	Rawl	6	6,600	8,600	1/4
	Average		11,100	12,900	
7/8-in. Bolt Diam.	Rawl	4-1/2	7,400	15,800	3/16
	Rawl	4-1/2	7,800	11,800	3/16
	Average		7,600	13,800	
	Rawl*	6	800	7,200	
	Rawl	6	Drilled anchor near transverse crack which probably caused concrete to fail when setting anchor.		
	Rawl	6	Concrete broke around anchor when trying to break off collar after anchor was set.		
	Rawl	6	10,600	15,800	1/16
3/4-in. Bolt Diam.	Phillips	4-1/2	9,200	15,800	3/8
	Phillips	4-1/2	5,200	15,800	5/8
	Phillips	4-1/2	6,300	15,800	1/16
	Phillips	4-1/2	5,800	15,800	1/16
	Phillips	2	8,000	14,900	3/8
	Phillips	4-1/2	11,400	15,800	1/8
	Average		7,700	15,700	
7/8-in. Bolt Diam.	Phillips	4-1/2	11,200	14,400	--
	Phillips	4-1/2	7,400	15,800	1/16
	Phillips	4-1/2	8,300	15,800	1/8
	Phillips	4-1/2	9,800	15,800	1/8
	Phillips	4-1/2	11,200	15,800	1/16
	Phillips	4-1/2	10,900	15,800	1/16
	Average		9,800	15,600	
3/4-in. Diam.	Arro	4-1/2	4,600	13,800	7/16
	Arro	6	Fractured concrete during installation.		
	Arro	6	Anchor failed to penetrate stone in concrete.		

Note: Numerous attempts to drill Arro self-drilling anchors into pavement edge failed due to deterioration of teeth on the anchor.

* Concrete fractured around anchor.

The average load at 1/32 in. slippage for the Phillips 3/4-in. self-drilling anchors was above the recommended allowable design load values established by previous evaluations (7,500 lb). The average load sustained by the 7/8-in. Phillips self-drilling anchor was below the recommended design load value of 12,000 lb previously established for this size anchor. Results of additional tests performed since the design values for 7/8-in. self-drilling type anchors were issued, have shown, in some cases, values less than those originally recommended. The reasons for this may be slight variation in anchor steel hardness, equipment used in drilling anchors, or strength of the concrete in which the anchors were installed. In any case, the variations that have occurred should be taken into account when establishing recommended design values. Therefore, rather than having a requirement which in some instances cannot be met, we recommend that the allowable design load values be used only as a guideline and not a requirement for expansion anchors used as lane ties. Since we now have the capability to evaluate individual field installations the problem of variability in the load sustaining capabilities caused by previously mentioned factors can be alleviated by adjusting the anchor spacing to meet the specified load per lin ft of joint.

TABLE 2
PHILLIPS NON-DRILLING FLUSH-TYPE
ANCHOR PULL-OUT RESULTS
(3/4-in. Bolt Diameter)

Sample No.	Distance From Top of Slab, in.	Load at 1/32 in. Slippage, lb	Maximum Load Applied, lb	Maximum Slippage, in.
1	4-1/2	3,400	8,000	5/16
2	4-1/2	10,900	11,400	--
3	4-1/2	12,000	13,200	1/8
4	4-1/2	15,800	15,800	--
5	4-1/2	9,800	15,400	3/16
6	4-1/2	13,400	15,800	1/16
Average		10,900	13,300	

Table 2 shows the pull-out results of the Phillips non-drilling flush-type anchors. As shown, the load sustained at 1/32 in. slippage is quite high. When installed properly, the Phillips 3/4-in. flush-type anchors should perform satisfactorily.

Pull-out results of the torque-type Frazer and Jones concrete expansion anchors are shown in Table 3. The location of the anchors with respect to slab surface shows that at a 6-in. depth, 40 percent of the Frazer and Jones anchors fractured the concrete before they could be torqued to 120 lb-ft (Fig. 12). None of the anchors drilled at mid-slab fractured the concrete while being torqued. Only three D13 anchors, drilled 6 in. from the surface, met the recommended design load of 10,000 lb at 1/32 in. slippage. The Frazer and Jones D2 anchors set at mid-slab with 120 lb-ft torque met the design load of 10,000 lb with 50 percent fracturing the concrete (Fig. 13).

The pull-out resistance of the Frazer and Jones anchors at 1/32 in. slippage vary little with the magnitude of the applied torque. The average load sustained at 1/32 in. slippage with 90 lb-ft torque was 7,300 lb; those anchors torqued to 120 lb-ft averaged 7,370 lb. An increase from 90 to 120 lb-ft results in an increase in load capacity of less than 1 percent. Failure to reach greater load capacities for higher torqued anchors may be attributable to the breaking of the bail-to-wedge connector which would prevent proper expansion of the anchor. Previous tests of this type of anchor showed wide variation in capacity when installation torque was increased. Since there was a high tendency for the Frazer and Jones anchors to break the concrete at the test site, which is very strong, installation in green concrete or weak concrete would result in considerably more breakage.

Results of the pull-out tests on Hilti Kwik-Bolt expansion anchors are shown in Table 4. The average load at 1/32 in. slippage for the 1/2 by 5-1/2-in. anchors set in the edge of the pavement was 5,000 lb. The 3/4 by 7-in. anchors were installed on top of the pavement in 4-1/2 and 5-1/2-in. holes. The load at 1/32 in. slippage averages 4,400 lb and 6,300 lb, respectively. Note that all the holes were drilled to depth with a Hilti hammer-drill, except samples 13 and 14 which were drilled with a Skil roto-hammer. The Skil roto-hammer tends to drill a less precise hole which may reduce the holding capacity of the anchor.

Pull-out results of the 3/4 by 5-1/2-in. Rawl stud-type concrete expansion anchors embedded 4-1/2 in. (Table 5) show an average load at 1/32 in. slippage of 3,950 lb. All the Rawl studs sustained a maximum load of 15,800 lb without any damage to the concrete.

TABLE 3
FRAZER AND JONES PULL-OUT TEST RESULTS

3/4-in. D2 Anchor

Sample No.	Distance From Top of Slab, in.	Concrete Hole Diam., in.	Concrete Hole Depth, in.	Torque, lb ft	Load at 1/32 in. Slippage, lb	Maximum Load Applied, lb	Maximum Slippage, in.	Remarks
1	4-1/2	1-3/8	4	90	5,700	15,800	5/16	
2	4-1/2	1-3/8	4	90	6,000	11,800	1/2	
3	4-1/2	1-3/8	4	90	7,400	14,900	3/4	Fractured concrete
4	5-1/2	1-3/8	4	90	3,200	8,600	3/8	Fractured concrete
5	4-1/2	1-3/8	4	90	10,600	15,800	3/16	
6	6-1/2	1-3/8	4	90	7,800	8,600	1/8	Fractured concrete
Average					6.800	12.600		
7	4-1/2	1-3/8	4	120	7,400	15,800	5/16	
8	4-1/2	1-3/8	4	120	2,800	7.200	1/4	Fractured concrete
9	5-1/2	1-3/8	4	120	7,800	15,800	3/16	
10	4-1/2	1-3/8	4	120	6,600	8,000	--	Fractured concrete
11	4-1/2	1-3/8	4	120	4,800	12,900	9/16	Fractured concrete
12	4-1/2	1-3/8	4	120	2,000	14,900	7/8	Fractured concrete
Average					5,200	12,400		
13	6	1-3/8	4	---	--	--	--	Fractured concrete at 100 lb ft torque
14	6	1-3/8	4	---	--	--	--	Fractured concrete at 70 lb ft torque
15	6	1-3/8	4	120	4,300	--	--	Fractured concrete
16	6	1-3/8	4	---	--	--	--	Fractured concrete at 30 lb ft torque
17	6	1-3/8	4	120	4,000	8,600	7/16	Fractured concrete
18	6	1-3/8	4	---	--	--	--	Fractured concrete at 80 lb ft torque
Average					4,200	8,600		

TABLE 3 (Cont.)
FRAZER AND JONES PULL-OUT TEST RESULTS

3/4-in. D3 Anchor

Sample No.	Distance From Top of Slab, in.	Concrete Hole Diam., in.	Concrete Hole Depth, in.	Torque, lb ft	Load at 1/32 in. Slippage, lb	Maximum Load Applied, lb	Maximum Slippage, in.	Remarks
1	4-1/2	1-3/8	4	90	9,200	14,400	1/8	Fractured concrete
2	4-1/2	1-3/8	4	90	6,600	12,900	5/16	Fractured concrete
3	4-1/2	1-3/8	4	90	7,400	11,400	3/16	Fractured concrete
4	4-1/2	1-3/8	4	90	8,300	12,400	1/4	Fractured concrete
5	4-1/2	1-3/8	4	90	8,900	15,800	3/8	
6	4-1/2	1-3/8	4	90	10,000	14,300	--	Spalled out large section of concrete
Average					8,400	13,500		
7	4-1/2	1-3/8	4	120	10,900	15,800	3/16	
8	4-1/2	1-3/8	4	120	10,300	14,000	1/4	Fractured concrete
9	4-1/2	1-3/8	4	120	5,700	15,800	5/16	
10	4-1/2	1-3/8	4	120	12,000	13,200	--	Spalled out large section of concrete
11	4-1/2	1-3/8	4	120	10,300	15,800	3/16	
12	4-1/2	1-3/8	4	120	11,200	15,200	5/16	Fractured concrete
Average					10,100	15,000		
13	6	1-3/8	4	120	10,000	13,500	1/4	Fractured concrete
14	6	1-3/8	4	---	--	--	--	Fractured concrete at 100 lb ft torque
15	6	1-3/8	4	---	--	--	--	Fractured concrete at 50 lb ft torque
16	6	1-3/8	4	120	9,800	15,400	--	Fractured concrete
17	6	1-3/8	4	120	--	--	--	Fractured concrete on initial loading
Average					9,900	14,450		

TABLE 3 (Cont.)
FRAZER AND JONES PULL-OUT TEST RESULTS

	Sample No.	Distance From Top of Slab, in.	Concrete Hole Diam., in.	Concrete Hole Depth, in.	Torque, lb ft	Load at 1/32 in. Slippage, lb	Maximum Load Applied, lb	Maximum Slippage, in.	Remarks
3/4-in. D13 Anchor	1	5-1/2	1-1/4	4	90	4,800	11,200	3/8	Fractured concrete
	2	4	1-1/4	4	90	7,200	14,900	1/2	Fractured concrete
	3	4	1-1/4	4	90	5,400	15,800	1/4	
	4	4	1-1/4	4	90	9,200	10,600	1/16	Fractured concrete
	5	4	1-1/4	4	90	6,800	11,800	5/16	Fractured concrete
	6	4	1-1/4	4	90	6,800	10,300	3/16	Fractured concrete
	Average					6,700	12,400		
	7	4	1-1/4	4	120	10,300	12,600	3/16	Fractured concrete
	8	4	1-1/4	4	120	10,600	13,800	3/8	Spalled out large section of concrete
	9	4	1-1/4	4	120	800	11,400	--	Fractured concrete
	10	4	1-1/4	4	120	8,300	15,800	5/16	
	11	4	1-1/4	4	120	4,000	14,300	9/16	Fractured concrete
	12	4	1-1/4	4	120	6,600	15,800	9/16	
	Average					6,800	14,000		
	13	6	1-1/4	4	120	10,000	15,800	3/16	
	14	6	1-1/4	4	120	7,400	11,400	1/4	Fractured concrete
	15	6	1-1/4	4	120	6,800	12,000	9/16	Fractured concrete
	16	6	1-1/4	4	120	10,900	15,800	1/8	
	17	6	1-1/4	4	120	10,000	12,000	3/16	Fractured concrete
	18	6	1-1/4	4	---	--	--	--	Fractured concrete at 60 lb ft torque
	Average					9,000	13,400		

Figure 12. Concrete fracture caused by Frazer and Jones torque-type anchor during testing. Similar cracks sometimes occurred during torque application before pull-out loads were applied.

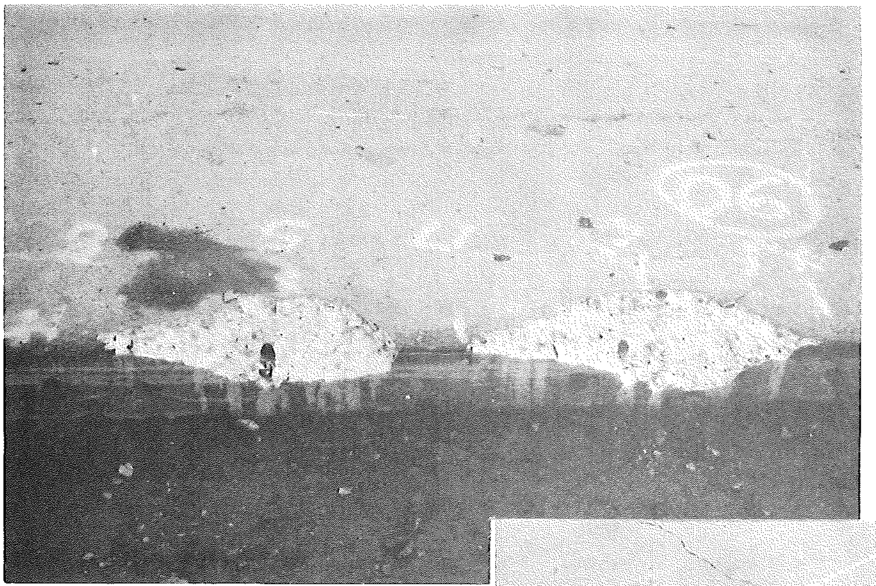


Figure 13. Type of concrete spalling obtained during testing of the Frazer and Jones torque-type anchors at mid-slab. Note that extensive spalling on right was increased by the transverse crack in the pavement.

TABLE 4
HILTI KWIK-BOLT CONCRETE EXPANSION ANCHOR PULL-OUT RESULTS

Sample No.	Dimensions of Anchor, in.	Concrete Hole Depth, in.	Number of Turns to Set Anchor	Load at 1/32 in. Slippage, lb	Maximum Load Applied, lb	Maximum Slippage, in.	Remarks
1	1/2 x 5-1/2	3-1/2	2	3,800	10,600	5/8	Anchor set 2-1/2 in. from top of slab Spalled concrete
2	1/2 x 5-1/2	3-1/2	1-1/2	3,400	9,800	1/4	Anchor set 2-1/2 in. from top of slab Spalled concrete
3	1/2 x 5-1/2	3-1/2	2	4,600	9,400	3/4	Anchor set 2-1/2 in. from top of slab
4	1/2 x 5-1/2	3-1/2	2	7,400	10,000	1/2	Anchor set 4-1/2 in. from top of slab
5	1/2 x 5-1/2	3-1/2	2	5,800	10,000	1/2	Anchor set 4-1/2 in. from top of slab
Average				5,000	10,000		
6	3/4 x 7	4-1/2	2	4,800	18,600	--	Anchor set 4 in. from edge of slab
7	3/4 x 7	4-1/2	1-1/2	4,000	18,600	7/16	Anchor set 3-1/2 in. from edge of slab
8	3/4 x 7	4-1/2	1	4,300	18,600	3/8	Anchor set 4 in. from edge of slab
Average				4,400	18,600		
9	3/4 x 7	5-1/2	1-1/2	6,000	18,600	3/8	Anchor set 12 in. from edge of slab
10	3/4 x 7	5-1/2	1/2	7,700	18,600	3/8	Anchor set 12 in. from edge of slab
11	3/4 x 7	5-1/2	1-1/2	6,800	18,600	3/8	Anchor set 12 in. from edge of slab
12	3/4 x 7	5-1/2	4	7,800	14,400	7/8	Anchor set 12 in. from edge of slab Stripped threads on anchor
13	3/4 x 7	5-1/2	3	3,400	9,200	1	Anchor set 12 in. from edge of slab Hole drilled with Skil roto-hammer
14	3/4 x 7	5-1/2	4	6,300	18,600	3/8	Anchor set 12 in. from edge of slab Hole drilled with Skil roto-hammer
Average				6,300	16,300		

TABLE 5
RAWL 3/4 x 5-1/2 in. STUD-TYPE CONCRETE
EXPANSION ANCHOR PULL-OUT RESULTS

Sample No.	Distance From Edge of Slab, in.	Concrete Hole Diam., in.	Depth of Embedment, in.	Torque, lb ft	Load at 1/32 in. Slippage, lb	Maximum Load Applied, lb	Maximum Slippage, in.
1	12	3/4	4-1/2	65	5,400	15,800	--
2	12	3/4	4-1/2	65	2,800	15,800	5/8
3	12	3/4	4-1/2	65	3,400	15,800	3/8
4	4	3/4	4-1/2	65	3,200	15,800	5/16
5	4	3/4	4-1/2	65	5,700	15,800	1/4
6	4	3/4	4-1/2	65	3,200	15,800	3/8
Average					3,950	15,800	

DISCUSSION

Several problems exist in the specification and use of expansion anchors for lane ties.

1) Many anchors require some pull-out or slippage to develop resistance, but slippage of a lane tie allows the joint to open.

2) Some anchors generate large lateral pressures when expanded and may fracture the pavement if set in green concrete, or close to an edge, joint, or crack.

3) Torque-type anchors must have adequate torque applied before their pull-out resistance develops to the required level. However, overtorque may ruin the anchor, break the bolt, or spall the concrete.

4) Non-drilling anchors require drilled holes of precise diameter in order to develop proper pull-out resistance. Oversize holes can reduce capacity considerably, while undersize holes prevent insertion.

5) It is very difficult to perform meaningful inspection to determine whether anchors have been properly installed.

Most of the 3/4 and 7/8-in. self-drilling and non-drilling flush-type anchors evaluated in this program have demonstrated their ability to develop relatively high pull-out resistance at low slippage. However, the 3/4-in. Arro self-drilling anchors failed to meet the minimum requirements, were too soft to drill through typical Michigan aggregates, and should not be considered for use by the Department.

The 7/8-in. self-drilling anchors, although not meeting the previously recommended lane tie design load of 12,000 lb, sustained enough load with minimum slippage to work satisfactorily if set at mid-depth and if the spacing is adjusted to meet the applicable requirements.

Previous evaluations have shown that 7/8-in. self-drilling anchors set too close to an edge in weak or green concrete might cause concrete failure at time of installation. Therefore, it would seem reasonable to set such anchors at mid-depth, with tolerances of perhaps $\pm$ 1/2 to 3/4 in. for 9-in. pavement.

The self-drilling anchors are easier to inspect for proper installation since the hole is drilled by the anchor to a depth equal to the length of the anchor. The anchor is then driven over the plug until refusal. The finished installation properly done, has a predetermined appearance that is more easily recognized by casual observation.

The evaluation of the Phillips 3/4-in. non-drilling flush-type anchor shows that it performs well when properly installed. Like many other items, however, the extent to which this capability is exhibited on the job depends on quality control in the construction process. It is important that the proper size drill bits be used for making the holes and that the anchors are properly set. It is recommended that the Phillips 3/4-in. non-drilling flush-type anchor be included in the approved list of concrete expansion anchors (Table 6). They are then subject to field test to determine whether installation has been done properly.

TABLE 6
ANCHORS APPROVED FOR LANE TIES
OR OTHER APPLICATIONS

Self-Drilling	Non-Drilling	
	Flush-Type	Torque-Type
Phillips	Hilti HDI	Bethlehem K-1 Shields
Star	Phillips	Taper Bolt
Chicago		
Rawl		

For lane tie applications, Bethlehem K-1 Shields are to be torqued to 100 lb ft and used only at mid-slab in concrete which has developed the designed 28-day compressive strength. All other anchors to be installed as per manufacturer's recommendations.

The Frazer and Jones D2, D3, and D13 torque-type anchor test results show a high percentage of concrete failure during installation and testing even in the very high strength location used for these tests. Previous evaluation of the Frazer and Jones D13 anchors in MDSHT Research Report No. R-987 shows a noticeable drop in load sustaining capability when the torque was increased from 90 to 120 lb-ft (Appendix). This was also evident in the present evaluation of the Frazer and Jones D2 anchors. This is probably due to failure of the bail-to-wedge connection, not allowing proper expansion of the anchor. The average loads sustained by the Frazer and Jones anchors, with exception of the D3, are considerably less than the recommended 10,000-lb design load value. The average load at 1/32 in. slippage sustained by the D3 just meets the recommendation. The overall performance of these torque-type anchors suggests their unsuitability for application as lane ties. Furthermore, difficulty in installation of torque-type anchors is also a problem, since construction crews normally do not use torque wrenches. Improperly torquing the anchors, either overtorquing or undertorquing, is very difficult to detect during inspection and can greatly reduce the effectiveness of the lane tie. Overtorquing can shatter a new slab, and effective repair of such a spall is highly questionable. The probability of load capacity variation due to improperly torqued anchors at the time of installation, plus the above mentioned problems, suggest that the Frazer and Jones anchors not be used as lane ties.

The Rawl 3/4-in. stud-type concrete expansion anchor sustained an average load of 4,000 lb at 1/32 in. slippage, as shown in Table 5. As stated before, stud-type anchors of this type are not suitable for lane tie application due to their slippage under load. The Rawl stud-type anchor requires a minimum of 65 lb-ft torque to be applied for best results. This creates difficulty in field inspecting the anchors for proper torque. Experience has shown that improperly torqued anchors may reduce their holding capacity considerably at a given amount of slippage. The low load at initial slippage plus the difficulty of inspecting torque-type stud anchors, indicates that these anchors should not be used by the Department for any critical applications. They may be suitable for special applications on non-structural items, where subsequent slippage and loosening would not be a serious problem. It is obvious that there is considerable reserve capacity as the anchor expands further under steady pull. However, vibration of the loosened connection could be quite another matter.

A previous evaluation was made on Hilti Kwik-Bolts with results published in MDSHT Research Report R-640 (Appendix). Present test results are shown in Table 4.

Table 7 shows the results of the recent tests extracted from Table 4, for requested comparison with the advertised capacities from the manufacturer's sales literature. Manufacturer's capacities were taken from Hilti's Test Report No. 8783R.

TABLE 7
COMPARISON OF TEST RESULTS WITH MANUFACTURER'S ADVERTISING CAPACITIES, KWIK-BOLT ANCHORS

Stud Diam., in.	Hole Depth, in.	Mfr's Advertised Capacities		Test Results	
		Average Pull-Out, lb [1]	Concrete Compression, psi	Average Pull-Out, lb [1]	Concrete Compression, psi
1/2	3-1/2	13,200	6,000	10,000	5,500
3/4	4-1/2	15,650	6,000	18,600 [2]	5,500
3/4	5-1/2	20,050	6,000	17,550	5,500

1 Average ultimate load.
2 Ultimate load applied by test equipment in this experiment.

The Kwik-Bolt advertised capacities from recent literature are similar to those established in our field testing. Table 4 shows how depth of embedment of 3/4-in. anchors increases the holding capacity at 1/32 in. slippage. Note that with stud-type anchors, manufacturer's recommendations on a drill and hole size should be followed exactly since oversize holes can weaken the anchorage considerably. Sample 13 was drilled with a Skil roto-hammer which sometimes tends to drill-out a larger diameter hole than the manufacturer's hammer. This caused the anchor's load capacity to be low. Location of the anchor with respect to pavement edge caused the concrete to spall when set too near the surface. Since the stud-type anchors are not recommended for lane ties due to slippage, only the 1/2 by 5-1/2-in. anchors were tested in the edge of the pavement.

Based on the results of past (MDSHT Research Report R-640) and present field tests, it is recommended that stud-type expansion anchors of the types tested be set with depth-to-diameter ratios of 6 to 8. Edge distance should be at least equal to the depth of embedment, and corner distances of 1 and 1-1/2 ft should be maintained for the 1/2 and 3/4-in. diameter stud anchors set in concrete with compressive strength in range of the field test values. Weaker concrete would require greater clearance.

RECOMMENDATIONS

Based on the discussion and results of the tests, the following recommendations are made:

1) Do not approve Arro self-drilling or Frazer and Jones D2, D3, and D13 non-drilling torque-type concrete expansion anchors for use as lane ties.

2) Add to the approved anchor list Rawl 3/4 and 7/8-in. self-drilling, and Phillips 3/4-in. Red Head non-drilling flush-type concrete expansion anchors. These anchors are to be properly installed in the edge of a 9-in. concrete pavement as lane ties for an additional pavement lane, concrete base course, or concrete shoulder. Vertical position in the pavement edge should be maintained at mid-depth, with a tolerance of not more than $\pm$ 3/4 in.

3) Establish the list given in Tables 6 and 8 as the current approved list of expansion anchors for the Department.

4) Use previously established allowable design load values only as a guideline. For lane tie applications adjust the anchor spacing to meet applicable requirements under local job conditions.

5) For other than lane tie applications, use the appropriate safety factors as given at the bottom of Table 8.

TABLE 8
ANCHORS APPROVED FOR APPLICATIONS OTHER THAN LANE TIES AND GUARDRAIL END SHOES

Non-Drilling Stud-Type
Hilti Kwik-Bolt
Phillips
Rawl
Wej-It

Note - Stud-type anchors are not suitable for lane tie or guardrail end shoes. They may have considerable slippage before developing higher capacities. Appropriate safety factors (see below) are to be applied to manufacturer's recommended pull-out loads.

Applicable Safety Factors (from ITT Phillips Drill Co., Engineering Bulletin No. 101)

A. Non-critical Applications (safety factor = 1.5 to 2.0). Non-critical application example fastening decorative type railings, etc.

B. Dead, Static, Variable or Shock Load Applications (safety factor = 4). Dead or static loads are self-explanatory. Variable loads are those in which the direction of the load remains constant, with changes in magnitude over a period of time. Shock loads are one time or infrequent loads such as encountered when concrete type barriers on bridge decks are struck by a car.

C. Vibratory Load Applications (safety factor = 12). Vibratory loads are rapidly changing loads with reversals in the direction of the net load; such as wind load on signs, or inertial loads on bridge-mounted signs due to structural vibrations of the bridge caused by traffic.

APPENDIX

Page

Excerpts from our previous concrete expansion anchor evaluations are being included for information purposes.

It should be mentioned that the criteria against which the anchors are tested greatly influences whether or not an anchor is acceptable.

Most of the anchors evaluated in the past were checked for capacity at 1/32 in. slippage. This is a requirement when anchors are to be used as lane ties. Some of the anchors which are not suitable for use as lane ties may perform adequately when used for different applications. Therefore, anchors which were originally recommended as being unsuitable for lane ties may now appear on the approved list with restricted applications.

A summary of all the anchors tested and their sources are given below.

I.T.T. Phillips Drill Co., Michigan City, Indiana

Phillips Self-Drilling
Phillips Non-Drilling Flush-Type
Phillips Stud-Type

Hilti Fastening Systems, Inc., Columbus, Ohio

Hilti Self-Drilling
Hilti HDI Non-Drilling Flush-Type
Hilti Kwik-Bolt Stud-Type

Rawlplug Company, Inc., New Rochelle, New York

Rawl Self-Drilling
Rawl Stud-Type

Power Actuated Tool Co., Inc., Chicago, Illinois

Arro Silver King Self-Drilling

Star Expansion Industries Corp., Mountainville, New York

Star Self-Drilling

Chicago Expansion Bolt Co., Chicago, Illinois

Chicago Self-Drilling

Frazer and Jones Company, Syracuse, New York

F&J D2 Torque-Type
F&J D3 Torque-Type
F&J D13 Torque-Type
F&J-1 Torque-Type

Bethlehem Steel Company, Bethlehem, Pennsylvania

Bethlehem K-1 Torque-Type

U. S. Expansion Bolt Co., York, Pennsylvania

Taper Bolt Torque-Type

Wej-It Corporation, Broomfield, Colorado

Wej-It Stud-Type

Static Field Tests of Kwik-Bolt and Phillips Stud-Type Concrete Anchors (Research Report No. R-640)

General

The purpose of this report was to determine the static capacities of Kwik-Bolt stud-type anchors and compare them with similar stud-type anchors produced by Phillips Drill Co. The field tests show (Table 1A) that Kwik-Bolt and Phillips 1/2-in. stud-type anchors have approximately equal capacities. Tables 2A and 3A include tests for comparison with the stud-type anchor results.

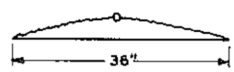
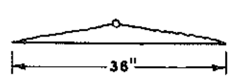
Recommendations

Based on the results of the field tests, it is recommended that stud-type expansion anchors of the types tested be set with depth-to-diameter ratios of 6 to 8. Edge distance should be at least equal to depth of embedment, and corner distances of 1, 1-1/2, and 2 ft should be maintained for the 1/2, 3/4, and 1-in. diameter stud anchors set in concrete with a compressive strength of approximately 5,000 psi. Until this or some similar study is completed, expansion anchors are not recommended for applications where the primary loading application is by impact, such as in anchorage of posts for bridge or guardrail.

TABLE 1A
SUMMARY OF TEST RESULTS

Test Number	Anchor Size and Type, in.	Distance From Edge, in.	Hole Depth, in.	Ultimate Load, kips	Remarks
1	1/2 by 5-1/2 Kwik-Bolt	3	2-1/4	9.5	Spalled to edge, spall 4-1/2 by 20 in., 2-1/4-in. deep at the bolt, 3-1/2-in. deep at the edge.
2	1/2 by 5-1/2 Kwik-Bolt	3	2-1/4	6.5	Cracked an area of concrete approximately 5-in. diam., bolt pulled out, sleeves remained in hole.
3	1/2 by 5-1/2 Kwik-Bolt	3	2-1/4	10.0	Surface spall 4 by 5 in., 2-1/4-in. deep at the bolt.
4	1/2 by 5-1/2 Kwik-Bolt	Far	2-1/4	8.5	Anchor pulled out, sleeves remained in hole, no spalling.
5	1/2 by 5-1/2 Kwik-Bolt	Far	2-1/4	9.5	Anchor pulled out, sleeves remained in hole, no spalling.
6	1/2 by 5-1/2 Kwik-Bolt	Far	2-1/4	8.5	Anchor pulled out, sleeves remained in hole, no spalling.
7	1/2 by 5-1/4 Phillips	Far	2-1/4	10.0	Anchor pulled out 1/4 in., surface spall 9 by 10 by 2-in. deep at the bolt.
8	1/2 by 5-1/4 Phillips	Far	2-1/4	9.5	Anchor pulled out 1 in., surface spall 4 by 7 by 1-in. deep at the bolt.
9	1/2 by 5-1/4 Phillips	Far	2-1/4	9.5	Anchor pulled out 3/4 in., surface spall 4-1/2 by 6 by 1-1/2-in. deep at the bolt.
10	1/2 by 5-1/2 Kwik-Bolt	Far	3-1/4	10.5	Anchor pulled out, sleeves remained in hole, no spalling.
11	1/2 by 5-1/2 Kwik-Bolt	Far	3-1/4	11.5	Anchor pulled out, sleeves remained in hole, no spalling.
12	1/2 by 5-1/2 Kwik-Bolt	Far	3-1/4	11.5	Anchor pulled out, sleeves remained in hole, no spalling.
13	1/2 by 5-1/4 Phillips	Far	3-1/4	11.5	Anchor pulled out 1 in., surface spall 9 by 9 by 1-1/2-in. deep at the bolt.
14	1/2 by 5-1/4 Phillips	Far	3-1/4	11.0	Anchor pulled out 3/4 in., surface spall 9 by 15 by 2-in. deep at the bolt.
15	1/2 by 5-1/4 Phillips	Far	3-1/4	12.5	Anchor pulled out 3/4 in., surface spall 7 by 11 by 2-in. deep at the bolt.
16	1/2 by 5-1/2 Kwik-Bolt	4-1/4	4-1/4	14.0	Anchor pulled out approximately 2 in. then it spalled to edge, spall 8-1/2 by 13 by 2-in. deep at bolt.
17	1/2 by 5-1/2 Kwik-Bolt	4-1/4	4-1/4	14.0	Anchor pulled out, sleeves remained in hole, no spalling.
18	1/2 by 5-1/2 Kwik-Bolt	4-1/4	4-1/4	11.5	Anchor pulled out, sleeves remained in hole, no spalling.
19	1/2 by 5-1/4 Phillips	4-1/4	4-1/4	11.5	Anchor pulled out, no spalling.
20*	1/2 by 5-1/4 Phillips	4-1/4	4-1/4	5.0	Anchor pulled out, no spalling. Not sufficiently expanded.
21	1/2 by 5-1/4 Phillips	4-1/4	4-1/4	11.5	Anchor pulled out approximately 2-1/2 in., surface spall 8-1/2-in. diam. approximately 1-1/2 in. deep at bolt.
22	1/2 by 5-1/2 Kwik-Bolt	Far	4-1/4	12.5	Anchor pulled out, sleeves remained in hole, no spalling.
23	1/2 by 5-1/2 Kwik-Bolt	Far	4-1/4	14.0	Anchor pulled out, sleeves remained in hole, no spalling.
24	1/2 by 5-1/2 Kwik-Bolt	Far	4-1/4	14.0	Anchor pulled out, sleeves remained in hole, no spalling.
25	1/2 by 5-1/4 Phillips	Far	4-1/4	10.0	Anchor pulled out 2 in., surface spall 6 by 9 by 1-1/2-in. deep at the bolt.

TABLE 1A (Cont.)
SUMMARY OF TEST RESULTS

Test Number	Anchor Size and Type, in.	Distance From Edge, in.	Hole Depth, in.	Ultimate Load, kips	Remarks
26	1/2 by 5-1/4 Phillips	Far	4-1/4	11.5	Anchor pulled out 2 in., surface spall 17 by 20 by 2-in. deep at the bolt.
27*	1/2 by 5-1/4 Phillips	Far	4-1/4	1.5	Stone in side of hole caused deformation of bolt, could not be properly set.
28	3/4 by 4-1/4 Kwik-Bolt	4-1/2	3-1/4	6.5	Anchor pulled out approximately 2 in., surface spall 7 by 8 in., approximately 1-in. deep at bolt.
29	3/4 by 4-1/4 Kwik-Bolt	4-1/2	3-1/4	7.5	Anchor pulled out approximately 1-1/2 in., surface spall 9 by 12 in., approximately 1-1/2-in. deep at bolt.
30	3/4 by 4-1/4 Kwik-Bolt	4-1/2	3-1/4	9.5	Spalled to edge after anchor pulled out 1 in., spall 8 by 20 by 2-in. deep at the edge.
31	3/4 by 4-1/4 Kwik-Bolt	Far	3-1/4	9.5	Anchor pulled out 3/4 in., surface spall 9 by 12 by 2-1/2-in. deep at the bolt.
32	3/4 by 4-1/4 Kwik-Bolt	Far	3-1/4	7.5	Anchor pulled out 1-1/2 in., surface spall 10 by 11 by 1-in. deep at the bolt.
33	3/4 by 4-1/4 Kwik-Bolt	Far	3-1/4	9.5	Anchor pulled out 2 in., surface spall 6-in. diam. 1-in. deep at the bolt.
34*	3/4 by 5-1/2 Kwik-Bolt	4-1/2	4-1/2	3.0	Anchor and sleeves pulled out, no spalling.
35	3/4 by 5-1/2 Kwik-Bolt	4-1/2	4-1/2	16.0	Anchor pulled out, sleeves remained in hole, no spalling.
36	3/4 by 5-1/2 Kwik-Bolt	4-1/2	4-1/2	11.5	Surface spall 3 by 4 by 1/2-in. deep, anchor pulled out, sleeves remained in hole.
37	3/4 by 5-1/2 Kwik-Bolt	Far	4-1/2	11.5	Anchor pulled out, sleeves remained in hole, no spalling.
38	3/4 by 5-1/2 Kwik-Bolt	Far	4-1/2	10.0	Anchor pulled out 3-1/2 in., small surface spall 5 by 5 by 1-in. deep at the bolt.
39	1 by 6 Kwik-Bolt	6	4-1/2	14.0	Cracked the slab to the edge, anchor pulled out. 
40	1 by 6 Kwik-Bolt	6	4-1/2	14.0	Spalled to edge, spall 9 by 27 by 3-1/2-in. deep at the edge, anchor pulled out.
41	1 by 6 Kwik-Bolt	6	4-1/2	12.5	Spalled to edge, spall 11 by 35 by 6-in. deep at the edge, anchor pulled out.
42	1 by 6 Kwik-Bolt	Far	4-1/2	17.5	Anchor pulled out 3/4 in., surface spall 16 by 18 by 3-1/2-in. deep at the bolt.
43	1 by 6 Kwik-Bolt	Far	4-1/2	17.0	Anchor pulled out 1 in., surface spall 18 by 30 by 3-1/2-in. deep at the bolt.
44	1 by 6 Kwik-Bolt	Far	4-1/2	15.0	Anchor pulled out, sleeves remained in hole, slight surface crack.
45	1 by 9 Kwik-Bolt	6	6	29.0	Anchor pulled out 1/2 in., surface spall 18 by 23 by 4-1/2-in. deep at the bolt, shallow at the edge.
46	1 by 9 Kwik-Bolt	6	6	22.5	Cracked the slab to the edge, anchor pulled out. 
47	1 by 9 Kwik-Bolt	6	6	20.0	Cracked the slab, anchor pulled out (near corner of slab).
48	1 by 9 Kwik-Bolt	Far	6	21.5	Anchor pulled out, sleeves remained in hole, no spalling.
49	1 by 9 Kwik-Bolt	Far	6	22.5	Anchor pulled out, sleeves remained in hole, no spalling.

* Denotes those anchors for which the low capacity could be expalined by observation.

TABLE 2A

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.

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

TABLE 3A

COMPARISON OF TEST RESULTS

WITH MANUFACTURER'S ADVERTISING CAPACITIES

Anchor Type	Stud Diameter, in.	Hole Depth, in.	Mfr's Advertised Capacities		Test Results	
			Average Pull-Out Strength, lb	Concrete Compression Strength, psi	Average Pull-Out Strength, lb	Concrete Compression Strength, psi
Kwik-Bolt	1/2	2-1/4	9,633	5,500	9,000	5,200 avg
Phillips	1/2	2-1/4	5,620	3,985 avg	9,500	5,200 avg
Kwik-Bolt	3/4	3-1/4	28,400	5,550	9,000	5,200 avg
Kwik-Bolt	1	4-1/2	32,933	5,500	16,500	5,200 avg

TABLE 4A
INSTALLATION DETAILS AND RESULTS
OF TORQUE AND PULL-OUT TESTING

Distance from top of slab, in.	Anchor Type	Bolt Diam., in.	Concrete Hole Diam., in.	Concrete Hole Depth, in.	Bolt Torque, lb-ft	Load at 1/32-in. Pull-Out			Average Load, lb
						Sample 1	Sample 2	Sample 3	
3	Flush	5/8	27/32	2-9/16	---	5,000	8,500		6,700
3	Self-Drilling	5/8	---	---	---	7,000	9,600	5,600	7,400
3	K-1 Shell	5/8	1-1/4	4	90	10,600	12,000	10,600	11,100
3	Flush	3/4	1	3-3/16	---	12,800	9,000	8,000	9,900
3	Self-Drilling	3/4	---	---	---	5,200	8,200	10,800	8,100
3	K-1 Shell	3/4	1-1/4	4	100	13,800	10,000	11,600	11,800
4-1/2	Flush	5/8	27/32	2-9/16	---	6,600	4,000	8,500	6,400
4-1/2	Self-Drilling	5/8	---	---	---	5,600	5,600	6,600	5,900
4-1/2	K-1 Shell	5/8	1-1/4	4	90	8,600	11,000	7,400	9,000
4-1/2	K-1 Shell	5/8	1-1/4	4	100	14,200	9,600	11,400	11,700
4-1/2	K-1 Shell	5/8	1-1/4	6	90	12,600	11,000	10,000	11,200
4-1/2	K-1 Shell	5/8	1-1/4	6	100	12,600	12,800	8,400	11,300
4-1/2	Flush	3/4	1	3-3/16	---	10,800	13,400	11,400	11,900
4-1/2	Self-Drilling	3/4	---	---	---	8,600	7,800	9,600	8,700
4-1/2	K-1 Shell	3/4	1-1/4	4	100	10,600	12,200	11,600	11,500
4-1/2	K-1 Shell	3/4	1-1/4	4	160	10,800	14,800	(2)	12,800
4-1/2	K-1 Shell	3/4	1-1/4	6	100	12,000	10,800	10,000	10,900
4-1/2	K-1 Shell	3/4	1-1/4	6	160	14,800	10,600	(3)	12,700
6	Flush	5/8	27/32	2-9/16	---	7,400	6,000	(1)	6,700
6	Self-Drilling	5/8	---	---	---	5,600	8,600	9,600	7,900
6	K-1 Shell	5/8	1-1/4	4	90	9,600	5,600	12,800	9,300
6	Flush	3/4	1	3-3/16	---	8,800	10,200	8,600	8,700
6	Self-Drilling	3/4	---	---	---	8,200	9,600	7,400	8,400
6	K-1 Shell	3/4	1-1/4	4	100	12,200	9,000	(4)	10,600

(1) Only two anchors of this type were set.
(2) Sample damaged; not tested.
(3) Concrete failed at 150 lb-ft torque during installation.
(4) Concrete failed at 85 lb-ft torque during installation.

Expansion Anchors for Use as Lane Ties
(Research Report No. R-807)

General

This report covers the results of a testing program conducted to evaluate the load capacity of K-1 expansion shells, self-drilling Red Heads, and flush or non-drilling type Red Head expansion anchors at 1/32 in. slippage. Table 4A shows the results of the pull-out tests for anchors installed 3, 4-1/2, and 6 in. from the top surface of the slab.

Recommendations

On the basis of these tests, design values indicated in Table 5A are recommended, provided that proper drill sizes are used and the same installation techniques are employed as in this experiment. The values given apply to expansion anchors used for lane ties in concrete pavements, concrete base course, and concrete shoulders.

TABLE 5A
RECOMMENDED DESIGN VALUES FOR EXPANSION ANCHORS

Anchor Type	Bolt Diam., in.	Concrete Hole Diam., in.	Concrete Hole Depth, in.	Bolt Torque, lb-ft	Allowable Design Load, lb
Flush	5/8	27/32	2-9/16	---	6,000
	3/4	1	3-3/16	---	8,000
Self-Drilling	5/8	---	----	---	6,000
	3/4	---	----	---	8,000
K-1 Shell	5/8	1-1/4	4	100	10,000
	3/4	1-1/4	4	100	10,000

TABLE 6A
DETAILS AND RESULTS OF PULL-OUT TESTING

Type of Anchor	Distance from Pavt. Surface, in.	Hole Diam, in.	Hole Depth, in.	Capacity at 1/32-in. Pull-out, lb	Type of Failure
Phillips 7/8	4-1/2	---	---	16,000	None
Phillips 7/8	4-1/2	---	---	16,000	None
Phillips 7/8	4-1/2	---	---	11,400	None
Phillips 7/8	4-1/2	---	---	16,000	None
Phillips 7/8	4-1/2	---	---	11,400	None
Phillips 7/8	4-1/2	---	---	10,200	None
				Avg 13,600	
Star 7/8	4-1/2	---	---	16,000	None
Star 7/8	4-1/2	---	---	16,000	None
Star 7/8	4-1/2	---	---	15,400	None
Star 7/8	4-1/2	---	---	8,600	None
Star 7/8	4-1/2	---	---	16,000	None
Star 7/8	4-1/2	---	---	15,800	None
				Avg 14,600	
Chicago 7/8	4-1/2	---	---	13,400	None
Chicago 7/8	4-1/2	---	---	13,000	None
Chicago 7/8	4-1/2	---	---	16,000	None
Chicago 7/8	4-1/2	---	---	12,400	None
Chicago 7/8	4-1/2	---	---	16,000	None
Chicago 7/8	4-1/2	---	---	16,000	None
				Avg 14,400	
Williams	4-1/2	1-5/8	4-1/2	11,600	None
Williams	4-1/2	1-5/8	4-1/2	6,800	None
Williams	4-1/2	1-5/8	4-1/2	15,600	Concrete
Williams	4-1/2	1-5/8	4-1/2	6,800	None
Williams	4-1/2	1-5/8	4-1/2	10,000	None
Williams	4-1/2	1-5/8	4-1/2	16,000	None
				Avg 11,200	
Phillips 7/8	3	---	---	13,000	None
Phillips 7/8	3	---	---	10,000	Concrete
Phillips 7/8	3	---	---	11,400	Concrete
Phillips 7/8	3	---	---	9,600	Concrete
Phillips 7/8	3	---	---	11,000	None
Phillips 7/8	3	---	---	12,000	Concrete
				Avg 11,200	
Star 7/8	3	---	---	12,200	None
Star 7/8	3	---	---	10,800	None
Star 7/8	3	---	---	7,400	None
Star 7/8	3	---	---	11,400	Concrete
Star 7/8	3	---	---	12,800	None
Star 7/8	3	---	---	11,600	None
				Avg 11,000	
Chicago 7/8	3	---	---	8,600	Concrete
Chicago 7/8	3	---	---	9,400	None
Chicago 7/8	3	---	---	6,800	Concrete
Chicago 7/8	3	---	---	10,800	None
Chicago 7/8	3	---	---	7,600	Concrete
Chicago 7/8	3	---	---	5,800	Concrete
				Avg 8,200	
Williams	3	1-5/8	4-1/2	3,400	None
Williams	3	1-5/8	4-1/2	15,000	Concrete
Williams	3	1-5/8	4-1/2	12,800	Concrete
Williams	3	1-5/8	4-1/2	12,000	None
Williams	3	1-5/8	4-1/2	10,200	None
Williams	3	1-5/8	4-1/2	5,200	None
				Avg 9,800	

Expansion Anchors for Lane Ties
(Research Report No. R-825)

General

This report covers an extension of the testing program previously carried out and reported in R-807 (March 1972). The anchors tested were 7/8-in. self-drilling Phillips, Star, and Chicago anchors; and Williams non-drilling sledge-drive anchors that can accommodate several different bolt sizes, and require 1-5/8-in. diameter holes in the concrete. Results of the pull-out tests are shown in Table 6A.

Recommendations

Based on the results and discussion listed, the following design values are recommended for the anchors tested.

1) Self-drilling, 7/8-in. Chicago, Phillips, and Star anchors; 12,000 lb.

2) Williams sledge-drive in 1-5/8-in. drilled holes 4-1/2-in. deep; 10,000 lb. (These were rejected later because of size of hole and materials used in the anchors.)

The values given apply to use of the anchors in the edge of 9-in. concrete pavement, as lane ties for an additional pavement lane, concrete base course, or concrete shoulders. Vertical position in the pavement edge should be maintained at mid-depth, with a tolerance of not more than $\pm$ 3/4 in.

Pull-Out Test Results of Hilti Fastening Systems
(Research Report No. R-867)

General

This report presents the results of testing conducted to evaluate the performance of self-drilling expansion anchors for use as lane ties, submitted by Hilti Fastening Systems. Hilti 5/8 and 3/4-in. self-drilling were tested and compared to 5/8 and 3/4-in. self-drilling Phillips anchors. Results of the pull-out tests are shown in Table 7A.

TABLE 7A
PULL-OUT TEST RESULTS

Anchor Type	Bolt Diam., in.	Load at 1/32-in. Pull-Out			Average Load, lb
		Sample 1	Sample 2	Sample 3	
Hilti	5/8	6,800	3,400	1,400	3,900
Phillips	5/8	5,400	6,800	6,200	6,100
Hilti	3/4	3,100	4,000	600	2,600
Phillips	3/4	6,600	5,400	7,400	6,500

Recommendations

Based on the results and observations made, it is recommended the Hilti anchors not be allowed for use by the Department.

Evaluations of "Wej-It," and "Taper-Bolt" Expansion Anchors (Research Report No. R-981)

General

The purpose of this evaluation was to determine the suitability of subject anchors for use as lane ties on highway projects. The anchors evaluated were 5/8, 3/4, and 7/8-in. diameter Wej-It; and 5/8, 3/4, and 1-in. diameter Taper-Bolts. Bethlehem K-1 shields were tested for comparison. Results of the pull-out tests are shown in Table 8A.

Recommendations

Based on the discussion and results of tests, the following recommendations are made:

1) Do not approve Taper-Bolts or Wej-It anchors for lane ties,

2) Consider the possibility of using 1-in. Taper-Bolts for attachment of guardrail end shoes to concrete parapet bridge rail on existing structures,

3) Due to large variation in load capacity of the Wej-It anchors, they are not recommended for sign mounting on structures, and stud-type anchors such as these are not recommended for end-shoe attachment to concrete parapet bridge rail.

TABLE 8A
RESULTS OF PULL-OUT TESTING

Anchor Type	Bolt Diameter, in.	Concrete Hole Diameter, in.	Nominal Bolt Torque, lb-ft	Load At 1/32-in. Pull-Out, lb						Average Load, lb
				Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	
WEJ-IT	5/8	5/8	---	5,400	6,200	7,700	3,400	6,000	7,400	6,000
	3/4	3/4	---	10,000	1,600	7,400	8,000	5,700	3,400	6,000
	7/8	7/8	---	3,200	5,200	10,000	12,300	[1]	4,300	7,000
Taper Bolt	5/8	5/8	100	6,800	4,300	4,800				5,300
	3/4	3/4	200	10,300[2]	10,600	12,000				11,000
	1	1	250	16,000[2]	16,000[2]	16,000[2]				16,000[3]
	5/8	5/8	[4]				6,300	16,000[2]	10,600[2]	
	3/4	3/4	250				10,600	[5]	10,000	10,300
	1	1	500				16,000[2]	16,000[2]	16,000[2]	16,000[3]
K-1	3/4	1-1/4	90	11,200	7,700	11,400				10,100
	3/4	1-1/4	120				15,500	8,800	9,200	11,200

[1] Stripped threads on bolt at two turns of nut.
[2] Load at less than 1/32-in. pull-out.
[3] 16,000 lb load not a maximum, but near calibrated capacity of the testing equipment.
[4] Varied torque, 125, 150, and 200 lb-ft. Average load not computed due to various torque values.
[5] Bolt failure while attempting to obtain seven turns of bolt, approximately 400 lb-ft torque.

Recommended Capacities for Expansion
Anchor Lane Ties, and Evaluation of
Frazer and Jones Concrete Expansion Anchors
(Research Report No. R-987)

General

This report presents the results of testing conducted to evaluate the performance of torque-type expansion anchors for use as lane ties. The anchors evaluated were 5/8 and 3/4-in. diameter Frazer and Jones D13 and FJ-1 torque-type expansion anchors. Results of pull-out tests for the 3/4 in. D13 are shown in Table 9A.

Recommendations

1) Based on the results of the tests, we recommend changes in use of anchors and of design values as given in Table 10A. This table includes recommended capacities and spacing for self-drilling anchors and Bethlehem K-1 anchors from previous evaluations, for ready reference. Note that the value for 3/4-in. self-drilling has been reduced from 8,000 to 7,500 lb.

2) Due to the present requirement for 5/8-in. minimum diameter for lane ties, it is recommended that the FJ-1 anchors not be approved for use, because the threaded 5/8-in. bolt has a root diameter considerably smaller than 5/8 in.

3) It is recommended that F&J D13 anchors not be approved, because of the probability of load capacity variation due to overtorque at the time of installation.

TABLE 9A
RESULTS OF TESTS ON
3/4-in. F&J D13 ANCHOR

Concrete Hole Depth, in.	Nominal Bolt Torque, lb-ft	Load at 1/32 in. Pull-Out, lb			Average Load, lb
		Sample 1	Sample 2	Sample 3	
4	90	12,000	8,000	6,800	8,900
4	120	6,000	5,700	6,600	6,200

TABLE 10A
RECOMMENDED USAGE AND DESIGN VALUES

New Concrete Widening

Anchor Type	Diameter, in.	Allowable Design Load, lb	Maximum Anchor Spacing, in.
Self-Drilling*	3/4	7,500	30
	7/8	12,000	48

Old Concrete Widening

Anchor Type	Diameter, in.	Torque, lb-ft	Allowable Design Load, lb	Maximum Anchor Spacing, in.
Self-Drilling*	3/4	---	7,500	30
	7/8	---	12,000	48
Bethlehem K-1 (Torque-Type)	3/4	100	10,000	40

* Acceptable self-drilling type anchors are: Phillips, Star, or Chicago.

Evaluation of 1/2 in. "Diamond" Self-Drilling Anchors
(Research Project 76 TI-376)

General

The purpose of this evaluation was to determine if the Diamond self-drilling anchors were comparable to Phillips self-drilling anchors. Evaluation was performed on 1/2-in. anchors only. Comparisons of four characteristics were made. These were: 1) average anchor hardness, 2) physical characteristics, 3) ease of installation, and 4) pull-out load. Results of pull-out tests are given in Table 11A.

Recommendations

On the basis of comparisons made, the Diamond anchors are not equal to the Phillips.

TABLE 11A
SUMMARY OF TEST RESULTS*

Sample No.	Diamond		Phillips	
	Load at 1/32-in. Extrusion, lb	Ultimate Load, lb	Load at 1/32-in. Extrusion, lb	Ultimate Load, lb
1	4,800	6,300	5,700	7,800
2	5,700	8,000	5,200	7,800
3	5,700	5,700	6,000	8,600
4	2,600	2,600	7,400	8,600
5	5,200	6,600	5,400	7,800
6	5,200	5,200	6,600	8,600
Avg	4,867	5,733	6,050	8,200

* 1/2-in. anchors only.

Expansion Anchor Evaluation
Hilti HDI Anchors
(Research Report No. R-1019)

General

This report covers experimental pull-out tests to evaluate the capacity of 3/4-in. Hilti HDI Expansion Anchors, at 1/32 in. maximum allowable slippage. Phillips 3/4-in. non-drilling flush-type anchors were included for comparison. Results of the pull-out tests are shown in Tables 12A and 13A.

Recommendations

1) Hilti HDI anchors that were evaluated, installed as per the manufacturer's recommendation, produced very good results; adequate for lane tie applications. They are recommended for consideration as lane tie anchors in widening full-strength concrete.

2) Phillips non-drilling anchors installed in the same manner as the Hilti anchors produced about 50 percent as much holding power. Since capacity is quite low, close spacing would be necessary to develop the required 3,000 lb-ft of joint, and there also would be special inspection problems. At this time, this anchor is not recommended.

3) Hilti anchors should not be used for widening concrete with less than 28 day strength.

4) Each type of anchor presents special problems with respect to installation and inspection. Non-drilling flush-type anchors have not been allowed to date. Construction staff will have to decide whether the Hilti system can be handled by inspectors and contractors to give a reasonably dependable anchorage system.

5) Recommended spacings and capacities for the various types of expansion anchors are shown in Table 14A.

TABLE 12A
HILTI HDI EXPANSION ANCHORS, 3/4-in.

Sample Number	Distance From Bottom of 9-in. Slab, in.	Approximate Load at Initial Slippage, lb	Slippage at 10,000 lb Load, in.	Load at 1/32-in. Slippage, lb	Maximum Load Applied, lb	Maximum Slippage, in.	Comments
1	4-1/2	1,000	0.014	More than 16,000[1]	16,000[1]	Less than 0.031	
2	2-1/2	4,500	---	7,500	7,500	---	Concrete spall to bottom of slab
3	2-1/2	--	---	--	--	---	Concrete fractured when anchor was set
4	4-1/2	Not determined	0.031	10,000	13,500	0.050[2]	
5	4-1/2	6,500	0.012	11,000	11,500	0.050[2]	
6	4-1/2	10,000	0.003	More than 15,000[1]	15,000[1]	0.025	
7	4-1/2	16,000	0.000	More than 16,000[1]	16,000[1]	0.002	
8	4-1/2	10,000	0.001	More than 16,000[1]	16,000[1]	0.014	
9	4-1/2	8,500	0.008	More than 16,000[1]	16,000[1]	0.025	
10	4-1/2	More than 16,000	0.000	More than 16,000[1]	16,000[1]	0.000	
11	4-1/2	16,000	0.000	More than 16,000[1]	16,000[1]	0.002	
12	4	10,000	0.005	More than 16,000[1]	16,000[1]	0.011	
13	3	--	---	--	--	---	Concrete fractured when anchor was set
14	3	--	---	--	--	---	Concrete fractured when anchor was set

[1] Test terminated, due to high load.
[2] Test terminated, due to slippage.

TABLE 13A
PHILLIPS "RED HEAD" NON-DRILLING EXPANSION ANCHORS (3/4-in.)

Sample Number	Load at Initial Slippage, lb	Load at 1/32-in. Slippage, lb	Maximum Applied Load, lb	Slippage at Maximum Load, in.
1	6,500	8,500	9,500	1/8
2	4,000	4,500	7,000	1/2
3	6,000	6,000	6,000	1/8
4	4,000	6,500	7,000	1/8
5	6,000	9,000	10,000	1/8
6	5,500	7,500	8,000	1/8
7	7,000	7,500	7,500	1/8
8	5,000	7,500	7,500	1/8
9	6,500	8,500	13,000	3/8
10	5,500	7,000	9,500	1/8

TABLE 14A
RECOMMENDED USAGE AND DESIGN VALUES

New Concrete Widening

Anchor Type	Diameter, in.	Allowable Design Load, lb	Maximum Anchor Spacing, in.
Self-Drilling[1]	3/4	7,500	30
	7/8	12,000	48

Old Concrete Widening

Anchor Type	Diameter, in.	Torque, lb-ft	Allowable Design Load, lb	Maximum Anchor Spacing, in.
Self-Drilling[1]	3/4	---	7,500	30
	7/8	---	12,000	48
Bethlehem K-1 (torque type)	3/4	100	10,000	40
Hilti HDI[2]	3/4	---	10,000	40

[1] Acceptable self-drilling type anchors are: Phillips, Star, or Chicago.

[2] If accepted by the Department, with appropriate requirements for installation and inspection.