TRC9704

Effects of Horizontal and Vertical Forces on Anchor Bolts

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EFFECTS OF HORIZONTAL AND VERTICAL FORCES ON ANCHOR BOLTS
TRC 9704

Phase 1 and 2: Effects of Vertical and Horizontal Forces on Anchor Bolt Performance

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INTRODUCTION

A very important component of a bridge is the anchoring system that is designed to connect steel beams to bridge pier caps. Anchor bolts that are embedded into the pier caps are used to make this connection. At present, the only guidance for anchor bolt placement is AASHTO's Standard Specification for Highway Bridges. Section 10.29.6 indicates that anchor bolts should be embedded in a pier cap a distance of at least ten times the diameter of the bolt. There is also no information that indicates levels of strength that can be expected when loads are applied. The purpose of this research is to look at tensile pullout capacity and shear resistance of the anchor bolts embedded in reinforced concrete. When completed, the research should indicate strengths that can be expected from the bolts in relation to depth of embedment and method of placement. It should also be able to provide guidelines for future placement of anchor bolts into bridge systems, enabling engineers to predict how such systems will perform when subjected to unexpected forces.

The research is divided into two phases. Phase 1 looks at vertical pullout strengths of anchor bolts embedded at predetermined depths of 10, 15, and 20 inches. Phase 2 examines the median embedment length, 15 inches, with horizontal forces applied. Both of the phases will test bolts that have been installed by the cast-in-place and drilled and grouted methods. A single bolt diameter, 1 ½ ", will be tested during both phases. The reinforced blocks of concrete in which the anchor bolts will be embedded are designed to be scaled down versions of actual pier caps, built using Arkansas Highway and Transportation Department (AHTD) plans.

PIER CAP CONSTRUCTION

Pier cap construction was based on actual plans obtained from the Arkansas Highway and Transportation Department (AHTD). Emphasis throughout the project was to use materials and installation methods common in Arkansas. Therefore, based on the plans, scaled down models were constructed for the project. The actual dimensions of the caps were 20' x 30" x 36". Guidance was received from an experienced contractor to ensure that correct installation procedures were followed from erection of the steel cages through installation of the anchor bolts.

PROPERTIES OF THE STEEL

A reinforcing cage was placed inside each of the pier caps. Since the caps were scaled down versions from actual Arkansas Highway and Transportation Department plans, the spacing of the rebar was placed according to those specifications. Six pieces of #6 rebar spaced approximately five inches apart were placed lengthwise along the top of the cap. Twenty-seven stirrups were then inserted along this rebar placed approximately 9 inches apart, center to center. In addition, two additional #4 bars and two additional #6 bars were tied lengthwise along the middle and bottom on each side of the cage, inside the stirrups (see Figure 1).

FIGURE 1 Reinforcing cage

PROPERTIES OF THE CONCRETE

The caps were cast using commercial ready-mixed concrete described as a 3500-psi summer mix. Each cap required nearly 6.5 cubic yards of concrete. The following material quantities were used in the mix:

MATERIAL	BATCHED QUANTITIES
CEMENT	2605 LB
FLYASH	453 LB
SAND	10190 LB
ROCK	11590 LB
WATER REDUCER	58 OZ
WATER	123 GL

The concrete had an average water/cement ratio of 0.56. Slump, air, unit weight, and temperature tests were performed on all concrete used in the pier caps. Cylinders were also cast for strength testing.

Field-testing results were as follows:

PIER CAP #	EMBEDMENT LENGTH (IN)	SLUMP (IN)	AIR %	UNIT WEIGHT (LB/FT^3)	28 DAY COMP. STRENGTH	28 DAY GROUT STRENGTH
1	15	4.25	2.3	148.6	4921 PSI	5813 PSI
2	10	2.75	3.2	148.0	5082 PSI	7688 PSI
3	15	1.50	3.7	150.3	5359 PSI	n/a
4	10	2.00	2.8	150.1	4969 PSI	n/a
5	20	4.50	2.0	153.2	5698 PSI	n/a
6	20	4.00	1.8	153.2	5749 PSI	-

Master Builders' Set Grout was approved for use in grouting the anchors for the drilled and grouted portion of the testing. This product conforms to the requirements of ASTM C 1107. It is a packaged dry hydraulic-cement based non-shrink grout. A mix proportion of 1:1 water to grout was used. This made a mixture that was free flowing and compared to observed field conditions.

ANCHOR BOLTS

Properties

The anchor bolts used during testing were composed of a single diameter swedge bolt, 1½", and a single grade of steel, Grade 36. Physical tests performed by the manufacturer on the bolts indicated average yield strengths of 47 ksi and tensile strengths of 70 ksi.

Placement

Cast-in-place construction indicates that the bolts were installed prior to placement of the concrete. They were held in place using 2 x 4 wood strips attached securely to the top of the forms. Holes were drilled into the center of the 2 x 4's to allow the bolts to slide through to the correct depth of embedment. The bolts were positioned into the caps so that any outward coning around the bolt due to pullout would not affect the surrounding bolts (see Figure 2).

FIGURE 2 Cast in Place Bolts

FIGURE 3 Drilled and Grouted

The drilled and grouted bolts were placed in the caps with spacing the same as that used for the cast-in-place bolts (see Figure 3). Before concrete placement, PVC piping was inserted along the top of the form at each location that a bolt was to be installed. This technique was used to make certain that when drilling the holes for bolt installment, there would be no interference with the reinforcing steel. After the concrete was allowed to harden, the PVC pipe was removed and three-inch diameter holes were drilled to depths that were 2 inches deeper than the actual embedment length of the bolts. Drilling was completed using a 60-pound rock drill and 3-inch carbide-tip bit. The bolts were then grouted into the cap and testing was conducted after 28 days.

TESTING

Vertical

Pullout tests were performed to determine the load-deflection behavior of the anchor bolts while being loaded in tension. A total of eighteen bolts were installed into the caps by the cast-in-place method and eighteen by the drill and grout method. For each of these two installment methods, six bolts were set at each of the three embedment depths of 10, 15, and 20 inches. Testing of the bolts involved direct vertical pullout of each bolt. The loading configuration shown (see Figure 4) was used for all testing and conforms to the requirements of ASTM E 488.

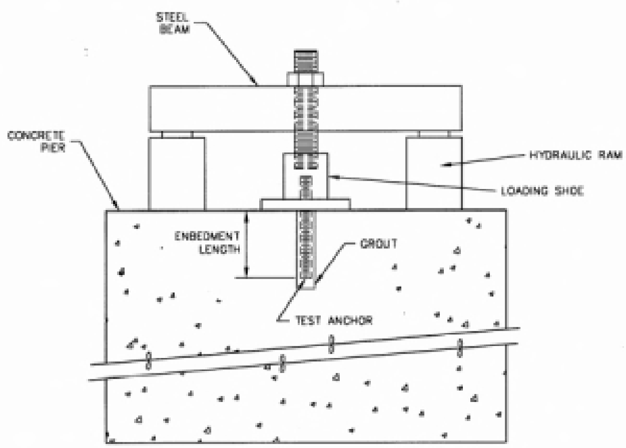


FIGURE 4 Schematic Drawing of Vertical Loading System

Two hydraulic rams were placed on either side of the anchor bolt. A steel beam was then lowered onto the rams. Beam measurement was 30" x 8" x 8". A hole was cut through the center of the beam to allow for the threaded rod to enter and attach to the loading shoe beneath it. The anchor bolt was also attached to the loading shoe. The hydraulic rams were operated by hand pumping, which raised the threaded rod and applied load to the bolt. Anchor displacement was then measured directly using a dial gage (see Figure 5). Loading on each of the 10 and 15 inch drilled and grouted embedded bolts was applied until a displacement of at least ½" was reached. It was then decided to continue to apply loading on subsequent bolts until a peak loading value was achieved.

FIGURE 5 Vertical Loading System

Horizontal

Horizontal forces applied to anchor bolts in a typical Arkansas bridge are actually bending forces as they are applied to the anchor bolts. As shown in the detail (See Figure 6), the sole plate rests on the elastomeric pad, which raises the point at which the shear forces are transferred by the sole plate to the bolt.

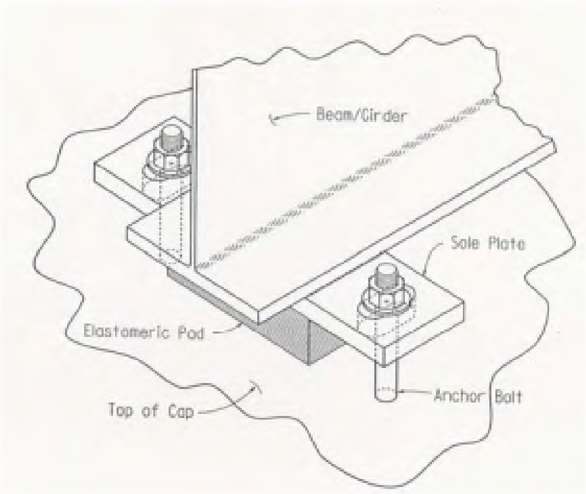


FIGURE 6 Bridge Detail

Therefore, the method used to apply load to the bolt (See Figure 7) was designed to apply the load above the surface of the concrete. The instrumentation applied the load perpendicular to the structure directly on the anchor. Displacement was measured in the direction of the applied load. Results gathered during this phase of the research included load applied, horizontal displacement of the anchor, depth to fixity and the mode of failure. Depth to fixity was determined through the use of contact switches. The contacts were placed every 0.5 inch along the length of the anchor and connected to an LED display (See Figures 8 and 9).

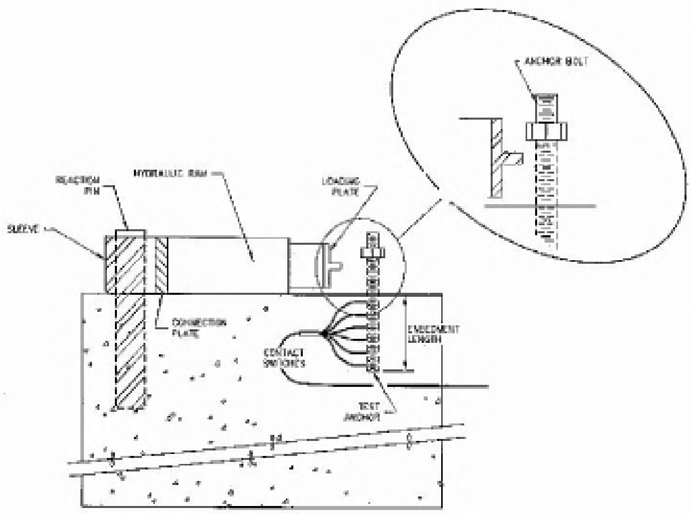


FIGURE 7 Schematic Drawing of Horizontal Loading System

FIGURE 8 Contact Switch Placement

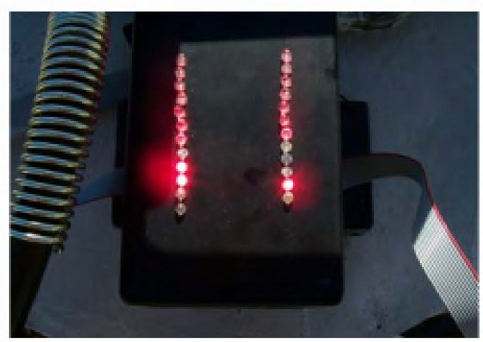
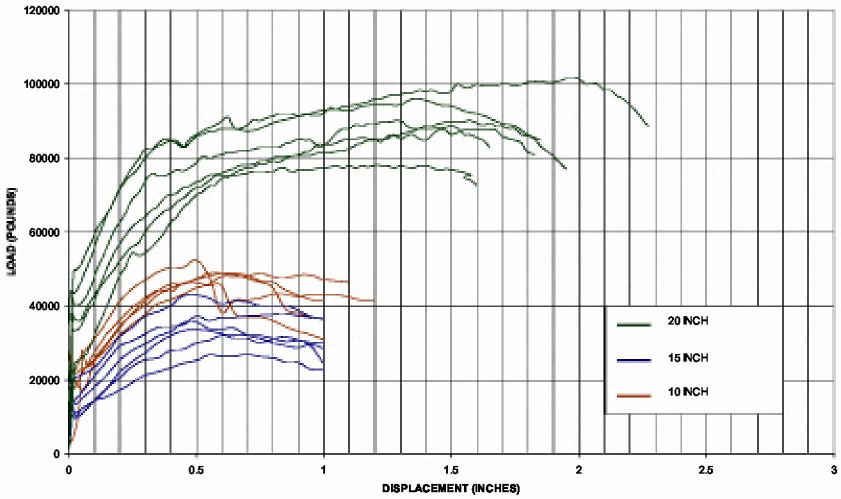


FIGURE 9 LED Display

During installation of the bolts into the caps, the contacts were placed facing the side of the bolt that the load would be applied. As contact was lost between the bolt and contact switch, the light on the LED display corresponding to the switch would turn off.

TESTING RESULTS

Vertical



Graph 1 Vertical Pullout of Cast-in-Place Bolts

Results of the vertical testing for the cast-in-place bolts reached a maximum load level of slightly over 100,000 pounds on the twenty inch bolts (See Graph 1). Noticeable on the graph is that the loading levels of the 10-inch bolts exceeded that of the 15-inch bolts. This was most likely due to the fact that a fair amount of vibration was used during placement of the concrete. Difficulties were experienced in maintaining the anchors in a vertical position during the concrete placement and vibration was used to eliminate this problem.

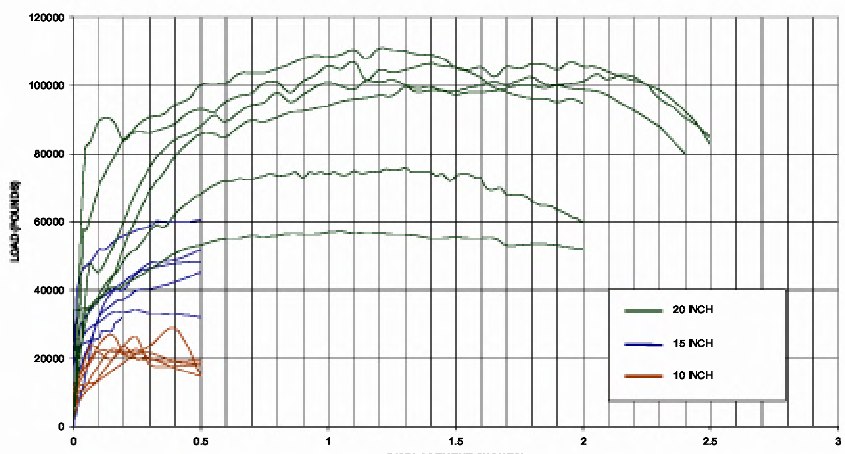
A predominant amount of the failures of the cast-in-place bolts occurred with a coning effect of the concrete around the bolt. A large thin layer of concrete would break away and directly

FIGURE 11 Pullout w/ Coning Effect

below this a smaller amount of coning would occur (See Figure 11). The remaining bolts pulled out smoothly with no coning effect at all (See Figure 12). Loading ranged from a high of 90,000 pounds for the 20-inch embedded bolts, 25,000 pounds for the 15-inch embedded bolts, and 45,000 for the 10-inch bolts.

FIGURE 11 Pullout w/ Coning Effect

In general, the pullout results of the drilled and grouted bolts all followed a similar pattern as that of the cast-in-place bolts and as expected, different load carrying maximums were achieved for each of the embedment lengths (See Graph 2). The 10 and 15-inch bolts had bond release between the grout and concrete (See Figure 13).



Graph 2 Vertical Pullout of Drilled and Grouted Bolts

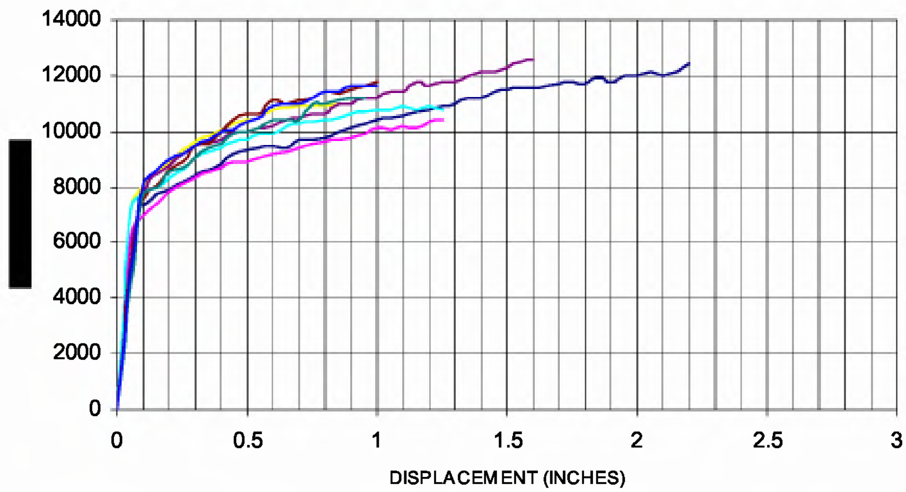
PVC piping was installed to depths of 7-8 inches to indicate where drilling could take place and avoid any steel reinforcement. While testing the 10 and 15-inch embedded bolts, there was indication that the smoothness of the concrete inside the grouting hole, caused by the PVC used to create the hole for the grout, might be having an effect on the strength of the bond between the concrete and the grout. Because of this, the PVC was place to a minimum of only 2-3 inches for the remaining 20-inch bolts with drilling being employed to remove the rest of the concrete to the required depth. Drilling left a much rougher surface for the grout to adhere to during the application of the load.

Drilled and Grouted bolts had peak loads ranging from a low of 21,000 pounds to a high of 110,000 pounds. Peak strengths for the 10 and 15-inch bolts ranged from 30,000 to 60,000 pounds. It must be noted that the 10 and 15 inch bolts were only pulled to ½" displacements. This means that peak loading values may not have been reached as demonstrated by the rising load values on the graph. Loads ranged from 57,000 pounds to 110,000 pounds for the 20-inch bolts. Bolt 2, which carried the least load, had grout pullout. All remaining bolts pulled out of the grout with less than an inch of coning. Bolt 4, which carried the highest level of loading, had water totally filling the drilled hole prior to grouting. The remaining holes had only 2-3 inches of water before the grouting. All water was removed from the holes immediately prior to grouting.

FIGURE 13 Bond Release of Concrete of Grout

Horizontal

Results of the horizontal testing for the cast-in-place bolts reached peak load values of 12,000 pounds at displacement distances of up to 2 inches (See Graph 3). The results clearly indicate that up to loading of 8,000 pounds the bolts were resisting the applied shear forces with little movement. Beyond this loading, bending of the bolts occurred. The remaining displacement measured after yielding of the bolt was the actual measurement of the amount of bend in the bolt and not horizontal movement



Graph 3 Horizontal Pullout of Cast-in-Place Bolts

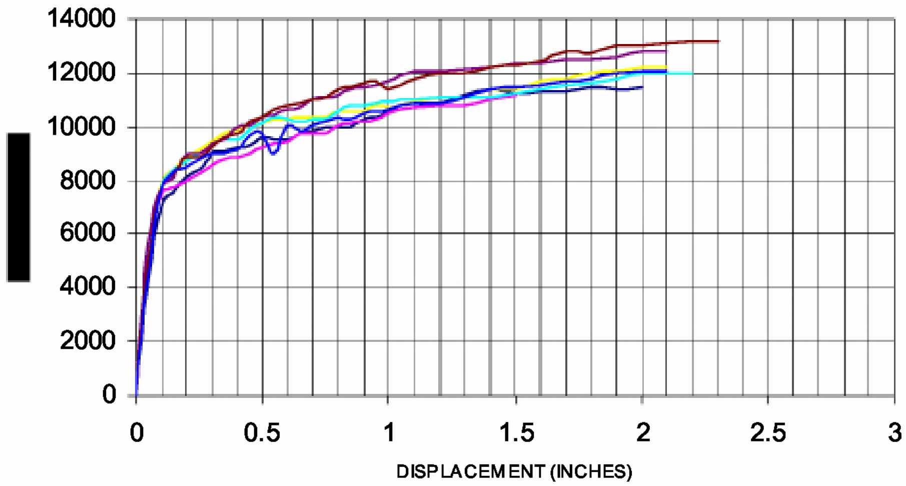
of the bolt in the concrete. Although there was some minor concrete spalling, this was very small (See Figure 15 and 16).

Figure 15 Initial Bolt Resistance

Figure 16 Secondary Bolt Bending

This would indicate that the ultimate strengths of the materials was not achieved but does not necessarily mean that failure had not occurred. Location of the bolt within the pier cap and the reinforcing steel kept the concrete from yielding to the applied forces; therefore, loading was discontinued after displacements greater than 1 to 2 inches.

The drilled and grouted bolts for this second phase of testing performed very similarly to the cast-in-place bolts. The bolts all resisted the applied force with minimal displacement until yielding of the bolt occurred (See Graph 4).



Conclusions

ASTM E 488 describes failure criteria to determine the strength of anchors in concrete. In section twelve of the specification it is described how to determine the maximum test load and the corresponding displacement for each of the test specimens at failure. Failure can occur by one or more of the following modes; shear cone node, failure of the structural member, pullout of the anchor, failure of the bond between the bolt and the concrete, the yielding or fracture of any component of the anchoring device. The anchoring device includes the entire system that anchors members together including the anchor, the pier cap, or the bond between the two.

All of the failures were seen in this experiment except failure of the structural member. Phase One, vertical pullout, had shear cone node, pullout of the anchor and bond failure indicating that the ultimate strength of the bolt had not been reached. Failure in Phase Two involved bending of the bolt and some fracturing of concrete around the bolt.

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