THE USE OF NON-SHRINKING MORTAR FOR ANCHORING BOLTS IN CONCRETE MEMBERS

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The Use of Non-Shrinking Mortar for Anchoring Bolts in Concrete Members

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PROBLEM

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The Bridge Division of the Michigan State Highway Department has been encountering trouble in properly placeing anchor bolts in concrete. It was found that these bolts, which were placed in the fresh concrete when it was first poured, were not always in the correct location when it came time to attach the end plate and supporting beam assembly. This often necessitated the removal of the bolt and relocating in the correct position. Since this duplication of effort was costly and laborious, a better method of placing anchor bolts was sought. It was believed that if the bolts could be placed after the concrete has hardened, instead of in the fresh state, that this trouble could be eliminated.

In general the proposed method of placing the bolts after the concrete has hardened is as follows. The proper location in the hardened concrete is determined and a hole is drilled, the bolt is placed and mortar or grout is used to hold the bolt in the hole. The question immediately arises as to what type of mortar to use to give an adequate bond between the bolt and the grout and the grout and the concrete. Since ordinary cement-sand mortar shrinks considerably during curing, it was feared that it would not develope adequate bonding strength.

It was felt that if a mortar or grout which would not show appreciable shrinking could be utilized, bonding strength would be developed which would be as great as the tensile strength of the bolt. Some investigation disclosed several brand products on the market which were or could be made into non-shrink grouts or mortars. It was decided to test four of these products to determine which would be best suited for the purpose of anchoring bolts in hardened concrete.

The first of these products is Sauereisen Iron Cement No. 35 made by the Sauereisen Cement Company of Pittsburgh, Pennsylvania. This is a ready mixed mortar requiring only the addition of water before it is used. The company states that this is a chemically formulated iron compound in a powder form. It is claimed that the compound expands slightly on curing. It hardens by chemical set or metalizing action. Suggested use for the product is for anchoring bolts, setting heavy machinery, filling cracks in castings, waterproofing concrete and brick and as a cement floor hardener. It is claimed that the product has good resistance to the action of water, oils and heat, but is not resistive to acids.

The second of these products is called X-Pando Pointing Mortar. It is made by the X-Pando Corporation of Long Island City, New York. This is also a prepared mortar requiring only the addition of water before using. It was used to anchor railings and stanchions at the Roosevelt Memorial, Hyde Park, New York and is recommended for pointing brick, stone, concrete, terra cotta tile and all types of masonry joints. Suggested use for this mortar is also as a brush or wash coat on stucco, concrete and stone and for patching cracks in concrete floors. The company claims that the mortar expands after setting. This slight expansion forces the mortar into the pores of the material with which it is to bond. It can be applied at zero temperatures. This product is intended as a pointing mortar which means that it is intended for use in applications ½ inch to 1 inch thick. In mortaring around anchor bolts it will be used in applications within these limits.

The third product to be tested is Embeco Non-Shrink Grout made by the Master Builders Company of Cleveland, Ohio. This is a prepared aggregate which is introduced in a sand-cement mortar. It is claimed that this added aggregate will cause the mortar to expand slightly on curing. This volumetric expansion forms a void filling stable ingredient that is strong, elastic and insoluble. The suggested use for this mortar is for floor repair, grouting around machinery, concrete reintergration, mortaring around anchor bolts and sealing concrete pipe joints. It is claimed that in a previously performed pull out test similar to that proposed here this mortar developed a bond strength of 678 per square inch.

The fourth mortar to be tested is called iron bond. Iron bond is mixed with normal Portland Cement. It consists of iron fillings along with an electrolyte which gives a strong mortar when mixed with cement.

DISCUSSION

DISCUSSION

In actual field construction the holes, in which the bolts would be placed for grouting, would be drilled into the hardened concrete. This would leave a roughned surface for the grout or mortar to penetrate thus providing a good bonding surface. It was desired to simulate this condition in the laboratory as nearly as possible. However, to make concrete specimens which would be large enough to drill without shattering would require excessive labor and materials. A substitute method was sought. After discussion and consideration it was decided to make standard 6 inch by 12 inch cylinders that would have a 2 inch core molded in the center. Although this core would have a smoother surface than a drilled hole it was felt that this surface would be satisfactory. If the bond attained in this test was great enough, then the bond under the field conditions would certainly be as great or greater. The first problem to be solved was how to obtain the 2 inch core in the cylinder. The method adopted in this test is to use a 2 inch cardboard mailing cylinder coated with paraffin which could be removed after the concrete hardens.

The 2 inch cardboard cylinders used are the same as are used for mailing purposes. It was necessary to paint them with a brush and hot liquid paraffin. However, it was discovered that this method deposited excessive paraffin on the cylinder and it was feared that this paraffin would be left on the concrete when the form was removed. This was proved so with the first 7 cylinders made as they required thorough cleaning on the inside surface of the core. After further experiments it was discovered that if the cylinders were heated over an open flame from a bunsen burner, that the paraffin penetrated the cardboard and excessive amounts were not left on the outside.

The bolts used were obtained from the bridge division of the Michigan State Highway Department. They were painted with a protective orange colored paint which had to be removed for the test. This was accomplished by the use of carbon trichloride, steel wool and considerable rubbing. The paint was removed because the bond between steel and mortar or grout was to be a factor in this experiment. It was felt the paints presence would effect this bond.

The first experimental cylinder was made and allowed to cure in the moist room for 7 days after which it was removed and the bolt placed in the core. Since this cylinder was merely to serve as a test for the method to be used, the bolt was mortared with a 1:3 cement sand mortar with enough water added for workability. One of the things noted about this cylinder was the shrinkage of the top surface of the mortar after it had been placed. This shrinkage was approximately 1/8 inch down from the top surface of the concrete in a very short time. At the time of the test it was also noted that a definite line of demarcation existed between the mortar core and the concrete cylinder indicating the shrinkage of the mortar.

Since the tensile strength required for pull out on this specimen was only of passing inportance, it was decided to pull the core when the mortar was 3 days old. At this time this specimen was capped with plaster of paris. A heavy steel plate was obtained. A hole $2\frac{1}{2}$ inches in diameter was made in the center. This plate was made from stock $\frac{5}{8}$ inches by 7 X 7 inches and was used for capping and later for testing. See Figure 1.

The first specimen was taken to the testing laboratory. It was placed in the universal testing machine with the concrete cylinder upper most resting on the heavy steel plate which was resting on the rigid frame of the machine. The extended bolt was centered in the steel plate and hung downward in the machine. A steel coupling was screwed on to the bolt and another bolt screwed into the opposite end of the coupling. This bolt extended downward where it was gripped by jaws which were attached to the movable head of the machine. As this movable head moves downward it exerts a pull on the bolt and core which is measurable in pounds on the machine. See Figures 1 and 2. The $2\frac{1}{2}$ inch hole in the heavy steel plate was larger than the core thus allowing the core to pull out when it failed in bond. The machine was started and the pull applied. The bolt with the core intact came out at 19,015 pounds, (see Figure 3) however, it was felt that a true bond failure was not obtained because the cylinder split up the side due to internal tension. The bond at failure was calculated to be $\frac{19,015}{73.2} = 264$ pounds per sq. in.

square inch. The tension in the cylinder causing the crack was $\frac{19,015}{7X2X12} = 796$# per square inch. This first test while it

FIGURE 1.

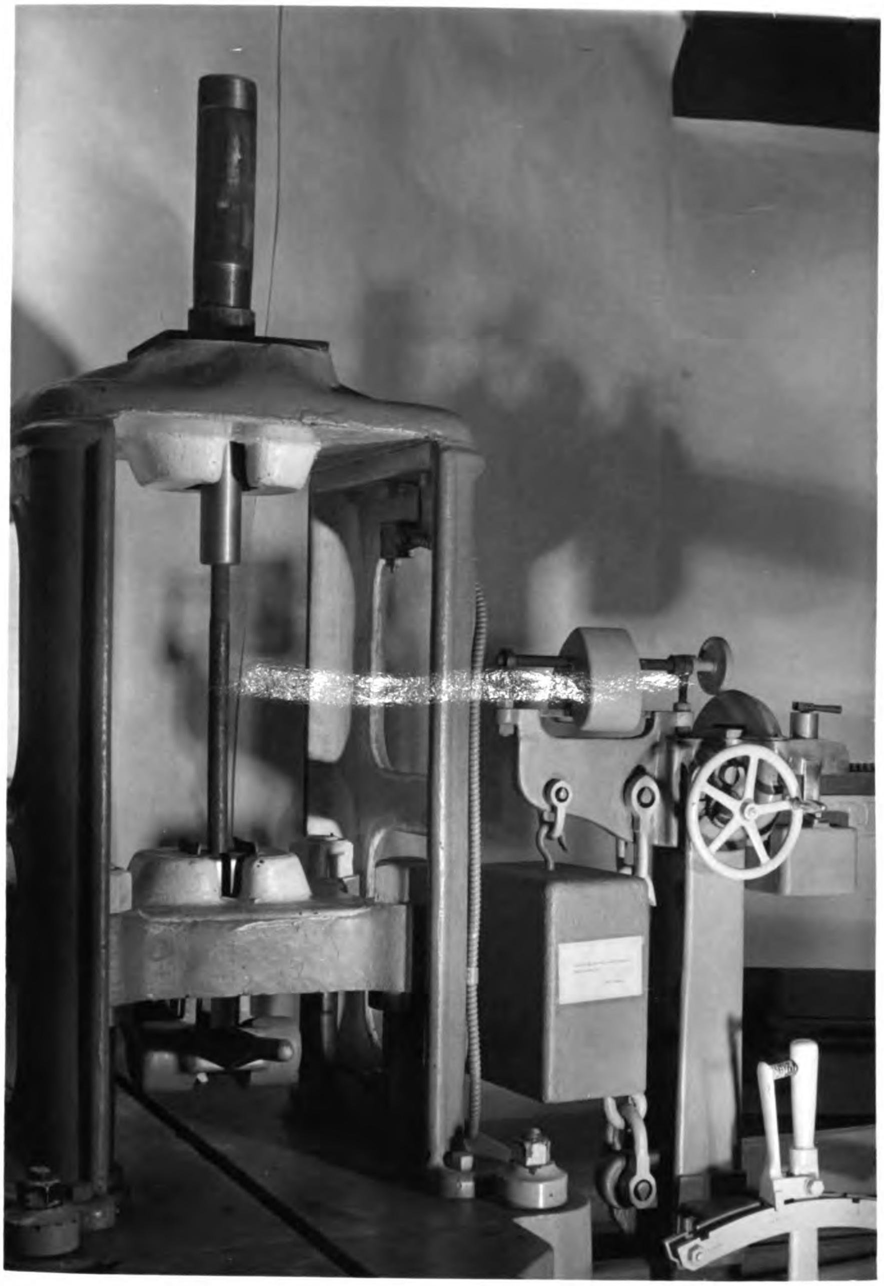

FIGURE 2.

FIGURE 3.

was successful in one respect demonstrated one fault with my procedure. The mass of concrete around the bolt was not large enough to withstand the internal tensile stresses evolved in the test.

A method of correcting this was sought. The method for testing the next trial cylinder was to utilize a standard steel 6 X 12 forming cylinder placed around the concrete specimen. Around this was placed three heavy steel bands which could be drawn together by means of three half inch by three inch machine bolts. It was hoped that this would give the concrete the strength required and allow the core to fail in bond.

Another cylinder was made with the bolt mortared with a 1:3 mortar and tested at 3 days. The cylinder was strengthened as mentioned above. This specimen failed at 25,350 pounds pull, indicating a greater unit bond strength than was attained in the previous test. However, upon removing the steel form and bands from the cylinder, it was discovered that the specimen was cracked up the side as before. It was decided that this method would not make the concrete cylinders strong enough to give a true measure of the bond failure. Since time was growing short a different, more rapid method of measuring the bonding strength was adopted.

It was decided to substitute for the 6 X 12 inch cored concrete cylinder a steel pipe section. The pipe must be large enough in diameter to allow the bolt to be introduced and mortared in place. It was found that the nearest immediately available size was $2\frac{1}{2}$ inch inside diameter black steel pipe. Several feet of this pipe was obtained and cut into sections 12 inches long. It was intended to use the pipe sections in the same manner as the hollow concrete cylinders had been used. The 12 inch long pipe was threaded on one end to allow a coupling band to be screwed on. See Figure 3. This coupling band was made by sawing a standard pipe coupling in half. The band was turned up on the pipe for about one inch. The sawed edge of the coupling was to serve as bearing area on the steel plate in the testing process.

While the mortars would not be used in this manner in the field it was believed that the relative results would be the same. That is, the mortar which would give the greatest bond strength in this test would give the greatest bond strength in the concrete. Since the bond strength would depend a great deal upon the expansive qualities of the mortar, this assumption was believed to be correct. The expansion of the mortars or non-shrink ability should be the same regardless of the surrounding material.

The first test specimen using this method was made up using a 1:3 cement sand mortar and tested at 4 days. The initial failure occured at 15,720 pounds. The bond strength at failure was $\frac{15,720 \text{ lbs.}}{94.5 \text{ sq. in.}} = 167$ pounds per square inch. The failure was between the core and the pipe. This unit bond stress was less than that obtained using the concrete cylinders, which was to be expected. Five hours before the pull out was made, phenol dye was placed on the top surface of the mortar. If the mortar had shrunk away from the steel casing the dye would run down into this space and could be measured when the core had been pulled. Upon pulling the core it was discovered that the dye had penetrated a distance of $\frac{7}{16}$ inches at its maximum penetration.

Everything considered, it was decided that this method was successful and the experiment proceded using steel pipe for the pull out test.

PULL OUT TEST

PULL OUT TEST

The specimens, three for each type of mortar were made six at a time. The first two types of mortars used were X-Pando and Sauereisen Iron Cement. The instructions for X-Pando stated that water should be added to the prepared mortar until it was of a workable consistancy. The dry mortar was a light gray in color and somewhat fluffy in texture. Water was added according to instructions until the mortar was of a workable consistancy but was not too liquid. It was found that five pounds of the dry material did not quite fill two cylinders so another six pounds of it was made up in another batch. This made enough mortar for the specimens desired.

Sauereisen Iron Cement was found to be a fine black powder which was quite dense. The instructions on the product stated that it should be mixed at a 2;1 ratio, 2 part cement to 1 part water. However, it was decided to make the consistancy of this material as nearly the same as the X-Pando as possible, so, considerably less water was used. It was found that this material was slightly harder to mix than X-Pando in that the powder did not combine with the water readily. Thirteen pounds of the dry material was mixed at this time with several pounds left for further tests.

With both mortars, the mortar was introduced to the steel cylinders in small increments with a steel trowel. It was rodded with a $\frac{3}{8}$inch steel rod, and vibrated by blows of the hand on the cylinder in an effort to get the material uniformly placed throughout the cylinder. These first six specimens were allowed to sit out in the air overnight and then were placed in the moist room where they would remain until the 6th day. They were removed from the moist closet 24 hours before testing and allowed to dry out.

The first cylinder tested was one made with Sauereisen Iron Cement. Upon applying a pull to the bolt it was found to break loose at 1,140 pounds pull and water came from the interior of the mortar. It was evident that either the mortar had not been used correctly or had not been cured properly. The other two cylinders were not tested and it was decided to make three more cylinders using this material but with different methods.

Better luck was had with the X-Pando specimens. With the first specimen tested it was found that the initial bond failure occured at 24,120 pounds. The bond failure occuring was between the core and the bolt. However, to pull the bolt out it was found that an increasingly greater pull was necessary. When the load had been increased to 36,800 pounds it was noted that the bolt, which was gripped by the jaws of the machine, (see Figure 1.) had been decreased in cross section at the threaded section. This indicated that the yield point of the steel had been reached and the load was removed from the specimen. In order to pull the bolt from the cylinder, the head of the bolt would have to crush through the full length of the cylinder.

The next six specimens made up were made using Embeco mortar and Iron Bond mortar. The cylinders were filled in the same manner as the previous ones had been. They were allowed to remain out in the air overnight and then were placed in the moist closet for curing. Upon testing these specimens it was found that the bond failure occured between the mortar core and the pipe casing.

In remaking the Sauereisen Iron Cement specimens it was found that there was not enough material left to fill three cylinders. Two were filled and the 3rd was only partially filled. Compression and tension specimens were not made due to this shortage. The mortar was mixed this time with 2 parts cement to 1 part water by weight as per instructions on the product. This made the mortar to be of a pouring consistancy. The specimens were placed in the moist closet after setting out overnight and were removed 24 hours before testing to dry out. Seven days after being made the specimens were tested and found to be almost entirely lacking in strength. The mortar was in a condition similar to the specimens previously made in that it was soft and watery.

COMPRESSION TESTS

COMPRESSION TESTS

The compression cubes were made according to the instructions in A.S.T.M. The material used for filling the cubes was obtained from the same batch which was used to fill the cylinders. The cubes were placed in the moist closet immediately after being made. The forms were removed 24 hours after placing in the moist room and the specimens were placed in the water tank where they remained until the 7th day for testing. Considerable difficulty was encountered in removing the Sauereisen specimens from the molds. In spite of thorough cleaning and oiling of the molds, the material stuck to the molds and some of the corners broke off of the cubes. Upon testing the Sauereisen pull out specimens it was decided not to test the compression cubes of this material. New specimens would be made and tested later in the experiment. The compression cubes made of Embeco mortar and Iron Bond mortar were made according to A.S.T.M. designation also and were cured in the same manner. Later in remaking the Sauereisen pull out specimens it was found that shortage of material eliminated making compression cubes of this product. For this reason no data is available on the compressive strength of this material.

TENSION TESTS

TENSION TESTS

The tension test briquets were made according to A.S.T.M. designation. The material for filling the molds was obtained from the same batch that was used to fill the cylinders. Difficulty was encountered in removing the Sauereisen specimens from the molds in that they tended to stick to the molds. The briquets were placed in the moist closet immediately upon being formed. The forms were removed at 24 hours and then the specimens were placed in a water tank until the 7th day when they were tested.

This test was not considered to be of importance since the proposed use of the mortars would not stress them in tension. However, it was believed that tension tests would give a little more information about the products.

Due to the lack of strength in the Sauereisen pull out specimens and the shortage of this material no data was obtained on the tension strength of this material.

DATA

With X-Pando, Embeco mortar and Iron Bond mortar, water was added until they were of a workable consistancy but were not too liquid. This procedure was followed with the first trial on Sauereisen Iron Cement but on the second trial water was added until the mortar was of a pouring consistancy. The proportions used in each case are listed below.

X-PANDO

11.0 lbs. X-Pando	2.508 lbs. water

SAUEREISEN IRON CEMENT

13.0 lbs. Iron Cement	4.240 lbs. water (1st trial)
7.078 lbs. Iron Cement	3.539 lbs. water (2nd trial)

EMBECO MORTAR

4.70 lbs. Normal Portland Cement

5.25 lbs. sand

5.00 lbs. Embeco

2.095 lbs. water

IRON BOND

15.0 lbs. Normal Portland Cement

0.797 lbs. Iron Bond

4.350 lbs. water

The manufacturers recommendation for mixing Embeco was 1 part cement (1 bag 94 lbs.) 1 part sand (1 cu. ft., assumed weight 105 lbs.) and 1 part Embeco (100 lbs.). These proportions were followed in this experiment.

Recommended proportions for Iron Bond Mortar were five pounds Iron Bond to 1 bag (94 lbs.) of cement. These were the proportions used for this material.

PULL CUT TEST DATA

Mortar	Lbs. Pull	Unit Stress psi
X-Pando	24,120	620
X-Pando	23,320	599
X-Pando	23,630	607
Embeco	23,120	245
Embeco	23,240	247
Embeco	22,360	237
Iron Bond	13,210	140
Iron Bond	15,640	166
Iron Bond	15,250	167

Mortar	Averages		Type of failure
	Pull-Lbs.	Stress-psi	
X-Pando	23,690	608	Bolt-core bond failure
Embeco	22,906	243	Core-pipe bond failure
Iron Bond	14,333	158	Core-pipe bond failure

The inside surface area of the pipe (core surface area) was calculated to be $\pi \times 2.5'' \times 12'' = 94.3$ sq. in. The surface area of the bolt in contact with the mortar was calculated to be $11.19'' \times \pi \times 1'' + 4 \times 1.5'' \times 0.625'' = 38.95$ sq. in.

The rate at which the movable head of testing machine moved downward was 0.105 inches per minute.

COMPRESSIVE TEST DATA

Mortar	Lbs. compression	Unit Stress psi	Average psi
X-Pando	10,950	2,740	
X-Pando	12,610	3,160	2,930
X-Pando	11,550	2,890	
Embeco	25,925	6,490	
Embeco	23,620	5,920	6,597
Embeco	29,500	7,380	
Iron Bond	36,990	9,250	
Iron Bond	36,190	9,040	9,120
Iron Bond	36,270	9,070	

The cross sectional area of the compression cubes was 4 square inches.

TENSION TEST DATA

Mortar	Lbs. Tension	Unit Stress psi	Average psi
X-Pando	398	398	
X-Pando	340	340	378
X-Pando	397	397	
Embeco	463	463	
Embeco	423	423	441
Embeco	438	438	
Iron Bond	540	540	
Iron Bond	550	550	552
Iron Bond	566	566	

The cross sectional area of the tension briquets was 1 square inch.

CONCLUSIONS

CONCLUSIONS

If a selection of a mortar for the purpose of anchoring bolts in concrete members is made upon the basis of these experiments alone then the choice would be limited down to either Embeco or X-Pando. The Iron Bond specimens while they were highest in compression and tension showed a low strength in the pull out test. The lack of success with the Sauereisen specimens does not necessarily indicate that this product could not be used but more information is needed as to how to use and cure it.

The average pull required to break the bond in the X-Pando was 23,690 pounds and in the Embeco was 22,905 pounds. Based on these strengths alone the figures show X-Pando to be slightly stronger. The differance in the type of failure should bear some consideration. The X-Pando specimens failed in bond between the bolt and the mortar. An increasingly greater pull was needed to pull the bolt out because the head of the bolt would have to crush through the depth of the mortar. It is conceivable that in this process the pull on the bolt would become great enough to break the bond between the core and the cylinder. If the same average unit bond stress is assumed to exist between the mortar core and the cylinder that existed between the bolt and the mortar, that is 608 psi, this should occure at 608 x 94.3 = 57,334 pounds. Of course, if a dowel had been used instead of a bolt the initial failure would be of greatest importance.

The bond failure in the Embeco specimens occured between the mortar core and the cylinder. One of the questions entering my mind when this occured was why had not the failure occured between the bolt and the core as in the case of the X-Pando? My explanation for it is this. The head of the bolt was acting in compression on a small area of the mortar at the same time the bond was being stressed. The compressive tests showed that the compressive strength of Embeco to be greater than twice that of the X-Pando. This greater compressive strength provided more assistance towards retaining the bolt in place in the mortar. Again, if a dowel had been used instead of a bolt, the results would have been different.

A more careful analysis of the stresses actually occuring in an anchor bolt in a bridge already constructed, would show the compressive strength to be a very important factor. Actually, it seems doubtful that an anchor bolt would be stressed on a bridge by a direct pull as it was in these tests. It would seem that the bolt would be stressed by a lateral movement of the members attached to the bolt. This would make the compressive strength an important factor as well as the bond strength in that the mortar on one side of the bolt would be in direct compression.

Two other factors to be considered are the ease of preparing the mortar and cost. As explained previously, X-Pando is a prepared mortar requiring only the addition of water whereas Embeco is an admixture which is added to a sand and cement mortar. Both are compartively easy to prepare, although the one ingredient in X-Pando provides great simplicity. The relative costs depend upon the cost and availability of Embeco, X-Pando, sand and Portland Cement.

It was intended to make tests of the mortar in respect to their volumetric expansion or non-shrinkability but time limitations prohibited this. Investigations of this type would no doubt give more information which could be used to properly evaluate the mortars for the purpose of anchoring bolts in concrete members.