EFFECT OF SUPERPLASTICIZERS ON CONCRETE-STEEL BOND STRENGTH

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A Report on Research Sponsored by
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Abstract

Effect of Superplasticizers on Concrete-Steel Bond Strength

The effects of superplasticizers on concrete-steel bond strength are studied. Key variables are degree of consolidation, concrete slump, both with and without a superplasticizer, concrete temperature, and bar position. #8 deformed reinforcing bars were used with a 2 in. cover and a 10 in. bonded length. Concrete slumps ranged from 1-3/4 in. to 9 in. Three specimen depths were used. All specimens were modified cantilever beam specimens.

Based on the experimental results, high slump superplasticized concrete provides a lower bond strength than low slump concrete of the same strength. Superplasticized concrete provides a higher bond strength than high slump regular concrete with the same slump and water-cement ratio. Vibration of high slump concrete increases the bond strength compared to high slump concrete without vibration. Bond strength decreases as the amount of concrete below a bar increases, but the greatest effect appears to occur with top-cast (i.e. upper surface) bars.

INTRODUCTION

One of the major advances in concrete technology in the last twenty years has been the development of high-range water-reducers. The admixtures, also known as superplasticizers, are used to make high slump, very workable normal strength concrete as well as low slump, low water-cement ratio, high strength concrete. While superplasticizers have a number of important advantages, there is some concern with the high slump mixtures, since previous work has shown that bond strength tends to decrease with increasing slump for concrete without superplasticizers, especially for top-cast bars (3-7, 9).

This report presents the results of a study of the effects of high-range water-reducers on the bond strength between horizontal deformed reinforcing bars and concrete. The key variables are the degree of consolidation, concrete slump, both with and without a superplasticizer, concrete temperature, and bar position.

EXPERIMENTAL INVESTIGATION

To study the effects of high-range water-reducers on bond strength, test specimens, placement procedures, and test procedures were selected to reflect field conditions as closely as possible.

Test Specimens

Four specimen types and five different test bar positions were used for each set of specimens (Fig. 1): Two shallow specimens, 9x11x24 in., one with a bottom-cast bar (2 in. of concrete below the bar) and the other with a top-cast bar (8 in. of concrete below the bar); one medium specimen, 9x18x24 in., with a top-cast bar (15 in. of concrete below the bar); and one deep specimen, 9x39x24 in., with both a bottom-cast bar (2 in. of concrete below the bar), and a top-cast bar (36 in. of concrete below the bar). Eight sets of specimens were tested, each with different concrete properties, for a total of 32 test specimens and 40 bars.

Steel in addition to the test bar was kept to a minimum. Two #5 bars parallel to the test bar were provided to prevent the specimen from failing in flexure during pullout (Fig. 2), and a single transverse #5 bar was used to support the test bar. One or two small lifting brackets were added to help move the specimens.

The test bars were 40 in. long, with two 4-1/2 in. long, 1 in. diameter polyvinyl chloride (PVC) pipes as bond breakers to limit the bonded length of the test bar and to prevent a cone type pullout failure on the front surface of the specimen (Fig. 3). A 10 in. long, 1 in. diameter steel conduit was used to provide access to the test bar for unloaded end slip measurements. Based on previous work at the University of Kansas (3-5), a 2 in. concrete cover and a 10 in. embedment length was used to insure that a splitting failure occurred when the bars pulled out.

Material Properties

Concrete: Non-air entrained concrete was supplied by a local ready mix plant. Type I portland cement and 3/4 in. nominal maximum size coarse aggregate were used. A design water-cement ratio of 0.55 was used for all placements. Concrete slump was varied using both water content and high-range water-reducers. Superplasticizer was added directly into the ready mix truck immediately before placing until the desired slump was reached. Mix designs, aggregate properties, and concrete properties are summarized in Table 1.

Steel: ASTM A 615, Grade 60 #8 reinforcing bars were used for all tests. Deformation dimensions, bearing areas, and steel strengths are presented in Table 2.

High-Range Water-Reducer: The high-range water-reducer was PSI Super supplied by Gifford-Hill and Company, Inc. PSI Super is anionic naphthalene base material and meets or exceeds the requirements of ASTM C 494 (2) for Types F and G admixtures (8). High-range water-reducer dosages are given in Table 1.

Placement Procedure

Construction and placement procedures were selected to be as consistent as possible between individual specimens and concrete types. The formwork was constructed from 3/4 inch BB Plyform and standard 2x4's. Forms were coated with brushing lacquer to prevent water from being absorbed into the plywood. All joints and cracks were caulked to prevent water leakage.

Test bar preparation consisted of soaking in acetone for 45 seconds, wiping with a clean paper towel in one direction, discarding the paper towel, and wiping again with another towel. This was repeated until the bar was free of oil and grit. The bar was then installed using a silicon sealer to provide a non-binding connection to the bond breakers and conduit, as shown in Fig. 3. After placing the test bar in the form, it was again cleaned with acetone.

The test specimens were placed in three groups. Each group consisted of two or three sets of specimens.

The first set of specimens in Group 1 was fabricated using low slump concrete as it arrived from the ready mix plant. After placing the first set, high-range water-reducer was added to the concrete to increase the slump. One set of vibrated and one set of non-vibrated specimens were made with the superplasticized concrete. These specimens were placed at a concrete temperature of 84°F, which caused the superplasticizer to rapidly lose effectiveness and the concrete in the upper layers of the deep specimens to have a reduced slump.

Group 2 was made using a high slump regular (i.e. non-superplasticized) concrete. One set of vibrated and one set of non-vibrated specimens were made.

The first set in Group 3 used a medium slump concrete as it arrived from the ready mix plant. The high-range water-reducer was then added, and one set of vibrated and one set of non-vibrated specimens were placed.

The concrete was placed in the forms using shovels. For the vibrated specimens, the shallow, medium, and deep specimens were placed in one, two, and three lifts, respectively. The non-vibrated specimens were placed in a single lift.

The vibrated specimens were consolidated using a 1-1/2 in. electric internal vibrator. The specimens were vibrated at six points, with the vibrator inserted rapidly and withdrawn slowly. The concrete was vibrated until paste was seen coming to the surface. There was no attempt to consolidate the non-vibrated specimens.

After all of the specimens of a concrete type were consolidated, the specimens were screeded using a metal-edged screed. Immediately after screeding, the surface was finished using a magnesium hand float. Bleed tests were started upon completion of finishing.

A modification of the special bleed tests developed in earlier work at the University of Kansas (3-5) was used. The tests were performed on the surface of the shallow and deep specimens, away from the bonded length of the test bar. The tests used 5-1/2 inch square paper towels (from the same lot). The towels were placed on the surface of the concrete and covered with a glass plate to prevent evaporation. When fully saturated, the towels were replaced. The time on the surface was recorded for each specimen. The wet towels were weighed and then dried and weighed again to determine the amount of bleedwater. This test provides data on the amount of bleed water reaching the specimen surface as a function of time after finishing (Fig. 4). The tests were not solely a measure of bleed, since the towels drew water from the specimen surface. Bleed data was taken for approximately 90 minutes for Group 1 and 120 minutes for Groups 2 and 3.

The specimens were then covered with polyethylene and kept moist. The forms were stripped when the concrete strength reached about 3500 psi.

Standard 6x12 in. compression cylinders were made for each type of concrete, four for measuring the strength gain, and four for determining the concrete strength at the time of testing.

Test Procedure

The bond tests were made at concrete strengths between 4000 and 4800 psi. The specimens were tested using the pullout apparatus shown in Fig. 5, which is a modification of the equipment used by Donahey and Darwin (3-5). The test places the concrete around the test bar in tension, as it would be under actual conditions, and not in compression as in some earlier tests (4).

The specimens from a group were tested within a 10 hour period, at ages ranging from 5 days to 22 days. The bars were loaded at approximately 6 kips per minute. Load, loaded end slip, and unloaded end slip were recorded during the tests (Fig. 6 and 7).

Results and Observations

Plastic Concrete: Bleeding was rapid at first, but slowed as time passed (Fig. 4, Table 3). With only one exception, the shallow specimens exhibited more bleeding than the companion deep specimens. This difference between specimens is likely due to the method of placement. The shallow specimens, along with the initial lifts in the medium and deep specimens, were placed first, followed by the second and third lifts in the deeper specimens. Since the first concrete discharged from a ready mix truck is usually more fluid than the rest of the batch, this greater fluidity may account for the difference in surface bleed. These results also suggest that the bleed from the lower lifts in the deeper specimens had little effect on the bleed at the upper surface.

Overall, low bleed (15.4 to 21.6 g in 90 minutes) was obtained for the specimens in Group 1 (84°F, low slump regular and superplasticized concrete). Medium bleed (21.8 to 38.3 g) was obtained for the deep specimens in Groups 2 (78°F, high slump regular concrete) and 3 (53°F, medium slump regular and superplasticized concrete), as well as the shallow medium slump specimen in Group 3. High bleed (40.1 to 70.6 g) was obtained for the shallow high slump specimens in Groups 2 and 3, with Group 3 showing the highest amount of bleed. The greater bleed in Group 3 was probably caused by the lower concrete temperature which resulted in a slower rate of setting.

The vibrated specimens bled less than the non-vibrated specimens, with the exception of the Group 1 specimens (84°F, superplasticized concrete), which showed little difference. The greater bleed in the non-vibrated specimens may have been due to greater settlement which occurred subsequent to finishing.

In all cases, the rate of bleed was enhanced due to the coarseness of the fine aggregate (fineness modulus = 3.17).

Five specimens showed visual signs of settlement (top of the concrete surface settling below the top of the form):

1. Deep specimen 2D: 78°F, high slump regular, vibrated
2. Deep specimen 2H: 78°F, high slump regular, non-vibrated
3. Deep specimen 3H: 53°F, superplasticized, vibrated

4. Medium specimen 3K: 53°F, superplasticized, non-vibrated
5. Deep specimen 3L: 53°F, superplasticized, non-vibrated

Parallel settlement cracks developed over some of the test and dumm bars. Small cracks developed over the test bars only in:

1. Medium specimen 2G: 78°F, high slump regular, vibrated
2. Medium specimen 2C: 78°F, high slump regular, non-vibrated
3. Deep specimen 3D: 53°F, medium slump regular, vibrated
4. Shallow specimen 3E: 53°F, superplasticized, vibrated
5. Shallow specimen 3I: 53°F, superplasticized, non-vibrated
6. Medium specimen 3G: 53°F, superplasticized, vibrated

Noticeable cracks developed over both test and dummy bars in:

1. Deep specimen 2H: 78°F, high slump regular, vibrated
2. Deep specimen 2D: 78°F, high slump regular, non-vibrated
3. Deep specimen 3H: 53°F, superplasticized, vibrated
4. Medium specimen 3K: 53°F, superplasticized, non-vibrated
5. Deep specimen 3L: 53°F, superplasticized, non-vibrated

The cracks in the last specimen were particularly clear.

The non-vibrated specimens had many small surface voids, especiall under the reinforcement. The vibrated specimens had smooth sides wit very few voids.

Hardened Concrete: During pullout, a splitting type bond failur occurred in all cases. The top surface crack ran parallel to and abov the test bar over the bonded section of the bar and fanned out over th rear PVC bond breaker. Two different cracking patterns were observed o the front surface of the specimens (Fig. 8): a triple crack, one runnin straight down from the top to the test bar, and then two others a approximately 120 degrees to the first, generally occurred in th specimens with lower bond strengths. A double crack, one passing dow from the top surface to the test bar, then continuing on under the test bar to the top of the bearing pad of the testing machine, accompanied by a crack perpendicular to the first running across the face of the specime at the top of the bearing pad, occurred in the higher bond strength specimens.

The ultimate bond forces are listed along with test variables in

Table 4.

The compressive strength of the superplasticized concrete was 8% to 12% (360 psi to 460 psi) higher than the strength of the companion regular concrete (Table 4).

EVALUATION OF EXPERIMENTAL RESULTS

The test results are used to examine the effects of high-range water-reducers upon concrete-steel bond strength. The results are also used to examine the influence of the degree of consolidation, concrete slump, both with and without a superplasticizer, concrete temperature, and bar position.

The bond forces are converted to a bond force per unit length (kip/in.). These values are normalized to a concrete strength of 4000 psi using the assumption that, within the tested concrete range (4000 psi - 4800 psi), bond strength is proportional to the square root of the compressive strength. Therefore, the values are multiplied by $(4000/f'_c)^{1/2}$. The normalized values are summarized in Table 4 and Fig. 9.

Comparing bond strengths on a normalized basis is necessary, because in practice, job concrete strength is based on the concrete used, not on the non-superplasticized base concrete. Therefore, there would be no "increase" in bond strength due to the higher strength obtained with a high-range water-reducer.

Effect of High-Range Water-Reducer

The effects of the high-range water-reducer on bond strength are presented in Fig. 10-13.

For the higher temperature (84°F) concrete (Group 1), the actual bond strengths are nearly the same for the low slump base concrete and the vibrated superplasticized concrete (Fig. 10). The bond strengths are comparable at least in part because of the increased compressive strength of the superplasticized concrete. However, the bond strength of the non-vibrated superplasticized concrete is an average of 14% lower when compared to the base concrete, in spite of the higher concrete strength.

For the same mixes (Group 1), the normalized bond strength of th vibrated superplasticized specimens decreases an average of 6% whe compared to the low slump base concrete (Fig. 11). The normalized bon strength of the non-vibrated superplasticized concrete decreases a average of 19% compared to the base concrete. The top-cast bar bon strengths for the non-vibrated superplasticized concrete may not be full representative of non-consolidated concrete. The concrete in thes specimens was at a much lower slump when finished than when placed, due t the loss in effectiveness of the high-range water-reducer, requiring mor effort to finish the top surface. Therefore, the concrete around the top cast bars was probably well consolidated. The bottom-cast bars, whic were not influenced by the extra finishing, should be more representativ of non-vibrated concrete.

In the lower temperature (53°F) specimens (Group 3), both the actua and normalized bond strengths decrease from the medium slump base concret to the higher slump superplasticized concrete (Fig. 12 and 13). For th vibrated superplasticized specimens, the actual and normalized bon strengths drop an average of 12% and 15%, respectively. For the non vibrated superplasticized specimens, the actual and normalized bon strengths decrease an average 27% and 30%, respectively. These values ma be a better gage of the general trends than the higher temperatur specimens because there was no extra consolidation around the top bar (the concrete remained at a high slump during finishing).

Effect of Slump

The bond strengths of bottom-cast bars in regular concrete are no affected by concrete slump (Fig. 9). This observation agrees with earlie work (6,7,9).

However, the bond strengths of bottom-cast bars in th superplasticized concrete are significantly lower than those of bottom cast bars in the corresponding base concrete (Fig. 11 and 13), with a average decrease of 9% in Group 1 and 16% in Group 3 for the vibrate specimens.

In most cases, an increase in slump decreases the bond strengths o top-cast bars (Fig. 9 and 14). However, the decrease in normalized bon strength with increasing slump is less when a high range water reducer is added than when the water content is increased in order to increase the slump (Fig. 9).

Effect of Bar Position

Concrete Below Bar: As the amount of concrete below the test bar increases, the normalized bond strength decreases (Fig. 15). The decrease appears to be the least for the low slump regular concrete (Group 1), approximately 16% as the depth below the test bar increases from 2 to 36 in. The greatest decrease, 40%, occurs for the high slump regular concrete (Group 2).

Casting Position: The effect of casting position is seen when comparing top-cast to bottom-cast bars. The ratio of normalized top-cast strength to the average bond strength of the two bottom-cast bars, or "bond efficiency ratio" (6), is plotted as a function of the concrete below the bar (Fig. 16 and 17).

For the higher temperature regular concrete specimens (low slump in Group 1 and high slump in Group 2), there is a 10 to 40% decrease in the normalized bond strength between a bottom-cast bar and the top-cast bar with the least amount of concrete below the bar. The main portion of the decrease appears to be due to an upper surface effect. A smaller additional decrease in bond strength is associated with an increase in concrete depth below the top-cast bars.

In the higher temperature superplasticized specimens (Group 1), another factor strongly effects the casting position results. Although the concrete initially had a 9 in. slump, the slump had dropped to under 6 in. by the end of placement (all other 9 in. slump specimens remained at a 9 in. slump through finishing). This decrease in slump required more effort for finishing, which improved the relative consolidation around the top bars, especially the non-vibrated specimens (Fig. 16). This extra consolidation may account for the strength increases between bottom-cast and top-cast bars of 5% in some vibrated to 35% in some non-vibrated specimens.

The effect of casting position is seen more clearly for the lower temperature specimens (Group 3), with decreases of 15 to 60% (Fig. 17 There is some scatter in the 3-3/4 in. slump specimens, which may because the lower slump concrete was more difficult to finish, resulti in greater consolidation around the top-cast bars. Again, the effect casting position appears to be dominated by the upper surface effect, a the superplasticized specimens show only a slight decrease in normaliz bond strength as concrete below the bar increases from 15 to 36 in.

ACI "Top Bars" Verses Other Top-Cast Bars: The ACI Building Code (defines a "top bar" as "horizontal reinforcement so placed that more th 12 in. of concrete is cast in the member below the reinforcement". practice, a great deal of reinforcement falls under this definiti without being <u>top-cast</u> reinforcement.

In the current research, the differences in bond strength between t bars with 8 in. of concrete below the bar, non "top bars", and bars wi 15 in. of concrete below the bar, ACI "top bars", are relatively small with the exception of the non-vibrated superplasticized mix placed at 53 (Group 3) (Fig. 18 and 19). There is a greater reduction in bond strengt for the bars with 36 in. of concrete below them. But even here, sizeabl drops are obtained only for the high slump, <u>non-vibrated</u> specimens. Th shows that the choice of 12 in. of concrete below the bar for the 30 reduction in bond strength (handled with a 40% increase in developme length in ACI 318) for a "top bar" is arbitrary. There seems to be gradual decrease in bond strength with no sharp drop off point.

Comparing these results (Fig. 16-19) to research at the University o Texas (6) indicates that much of the drop-off in bond strength is an uppe surface effect. In the Texas tests, non top-cast bars generally showed gradual and relatively low decrease in bond strength with an increase i concrete below the bars from 2 to 39 in. In the current study, top-cas bars with only 8 in. of concrete below the bar show a sharp decrease i bond strength compared to bottom-cast bars with 2 in. of concrete belo the bar. In this light, it makes more sense to apply the "top-bar" facto to top-cast bars, regardless of the amount of concrete below the bar. I is questionable if such a large penalty is necessary for non top-cast bar with more than 12 in. of concrete below the bar. It may still b necessary to impose a large penalty for non top-cast bars with more tha

36 in. of concrete below the bar, particularly if high slump concrete is used.

Effect of Vibration on High Slump Specimens

The results clearly show the importance of vibration on bond strength in specimens made with high slump concrete. As shown in Fig. 20, the bond strengths in the vibrated specimens exceed the bond strengths in the non-vibrated specimens in all but two cases. The observations agree with the results obtained by Donahey and Darwin (3-5).

For the high slump, regular concrete, the bond strengths are an average of 14% lower for the non-vibrated specimens than for the vibrated specimens. For the bottom-cast bars, there is an average decrease of only 6% for the non-vibrated specimens, largely due to the consolidating effect of the concrete above the bar. The top-cast bars average a 23% decrease when not vibrated.

The superplasticized concrete, with just two exceptions, has a lower bond strength with non-vibrated specimens (Fig. 20). The trend is not apparent in two sets of the higher temperature top-cast specimens (Group 1). This, as mentioned earlier, is probably the result of the greater relative consolidation applied to some of the top-cast bars, especially the non-vibrated specimens.

The bottom-cast bars, which are away from the top surface, provide a good indication of the importance of vibration, with the non-vibrated specimens exhibiting a 25% decrease in bond strength compared to the vibrated specimens.

The non-vibrated lower temperature superplasticized specimens (Group 3) exhibit a uniform decrease in bond strength compared to the vibrated specimens, with the values dropping from 8% for the bottom-cast bars to 41% for the top-cast bars in the deep specimens.

Effect of Temperature and Bleed

Generally, the more rapidly the concrete sets up, the less deletereous are the effects of high slump and concrete below the bar. The bond strengths of the lower temperature superplasticized specimens (Group

3) are noticeably less than the bond strengths of the higher temperatu superplasticized specimens (Group 1) (Fig. 21). This is true regardle of whether the specimen was vibrated or not. The lower temperature caus the high-range water-reducer to keep the specimen at a higher slump for longer time and to delay set. This allows the lower temperature specime to bleed more (Table 3 and Fig. 22) and settle more, causing mo settlement cracking. The increased bleed and settlement decreases bo strength.

The higher slump concretes bled more than the lower slu specimens. For the lower temperature specimens, the superplasticiz specimens bled much more than the 3-3/4 in. slump regular specimens (Gro 3), with the vibrated specimens bleeding an average of 63% more and t non-vibrated specimens an average of 112% more (Fig. 23).

For the higher temperature regular concrete, the high slump specime (Group 2) bled an average of 87% more (both vibrated and non-vibrate than the low slump specimens (Group 1) (Fig. 24). The high slump regul concrete was cast on a different date and at a somewhat lower temperatu than the low slump regular concrete. The higher temperatu superplasticized concrete (Group 1) bled nearly the same as the low slu regular concrete. This was probably due to the rapid slump loss of t superplasticized concrete.

Bleed for the vibrated regular concrete only showed a line relationship between bleed and concrete slump (Fig. 25). This tre compares favorably with the results obtained from previous work at t University of Kansas on similar concrete (3-5).

Some comments on the relative effects of bleeding and settlement a desirable. The decrease in bond strength with an increase in depth c concrete beneath a bar is generally tied to both bleed and settlement The bleed tests (Table 3) in this investigation, however, indicate tha the shallow specimens bled more than the deep specimens. In spite c this, the top-cast bars in the deep specimens had lower bond strength than the top-cast bars in the shallow specimens. This suggests tha settlement, not measured, but expected to be higher in the deep specimens has a greater effect on bond strength than bleed.

Recommendations

The following recommendations reflect the findings of this study.

1. Superplasticized concrete is recommended when using a high slump mix.
2. All superplasticized concrete should be vibrated, especially when the concrete is placed in deep forms such as wall forms or column forms.
3. Care should be taken when using superplasticized concrete in cool weather (less than 55°F) to control possible excessive settlement and bleeding.
4. The current ACI "top-bar" requirements (1) should be applied to <u>top-cast</u> bars.

SUMMARY AND CONCLUSIONS

Summary

The purpose of this investigation was to study the effects of superplasticized concrete on the bond strength of horizontal deformed reinforcing bars. The key variables were the degree of consolidation, concrete slump, both with and without a superplasticizer, concrete temperature, and bar position. A total of 40 pullout tests were performed on 32 test specimens using #8 deformed bars. The results were evaluated to determine the effects of the major variables.

Conclusions

The following conclusions are based on the tests and analyses described in this report:

1. Vibrated, high slump concrete made with a high-range water-reducer has a lower bond strength than a low slump concrete of equal strength.
2. Vibrated, high slump, superplasticized concrete and its low slump, non-superplasticized base concrete appear to have approximately the same bond strength due to the increased concrete strength obtained with the addition of the high-range water-reducer.
3. A decrease in bond strength occurs when high slump concrete (superplasticized or not) is not vibrated.
4. Increased concrete slump has a negative effect on bond strength of

top-cast bars.

5. When using high-range water-reducers, the longer the concrete remai plastic (obtained with lower concrete temperatures in this study) t lower the bond strength.
6. A sharp drop-off in bond strength between bottom-cast bars and to cast bars strongly suggests an upper surface effect, even f relatively low amounts of concrete below the bar. The current A (1) "top bar" requirements appear to be unconservative for top-ca bars with less than 12 in. of concrete below the bar and are possib over-conservative for non top-cast bars with more than 12 in. concrete below the bar when low slump concrete is used.
7. The bond strength of top-cast bars decreases as the amount concrete below a bar increases.

Future Study

Based on this study, several other aspects concerning the use high-range water-reducers should be studied in order to fully understan the effect of these materials on concrete-steel bond strength:

1. The effects on bond strength of high-range water-reducers used t produce high strength, low slump concrete.
2. The effects on the bond strength of non top-cast bars (i.e. bars wit concrete above and below, such as in concrete walls).
3. The effects on bond strength when using higher cement factor concret mixes, different aggregate graduations or entrained air in order t reduce bleed.
4. The effects on the bond strength of smaller bars that do not cause splitting failure.

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REFERENCES

1. ACI Committee 318, "Building Code Requirements for Reinforced Concrete (ACI 318-83)," American Concrete Institute, Detroit, Michigan, 1983, 111 pp.
2. ASTM C 494, "Standard Specifications for Chemical Admixtures for Concrete," Annual Book of ASTM Standards, Part 14, American Society for Testing and Materials, Philadelphia, Pennsylvania, 1982, pp. 319-332.
3. Donahey, Rex C. and Darwin, David, "Effects of Construction Procedures on Bond in Bridge Decks," Structural Engineering and Engineering Materials SM Report No. 7, University of Kansas Center for Research, Inc., Lawrence, Kansas, January 1983, 125 pp.
4. Donahey, Rex C. and Darwin, David, "Effects of Innovative Construction Procedures on Bridge Decks: Part I, Effects of Construction Procedures on Bond in Bridge Decks," Structural Engineering and Engineering Materials SL Report 83-1, University of Kansas Center for Research, Inc., Lawrence, Kansas, June 1983, 28 pp.
5. Donahey, Rex C. and Darwin, David, "Bond of Top-Cast Bars in Bridge Decks," accepted for publication in the Journal of the American Concrete Institute.
6. Luke, J.J., Hamad, B.S., Jirsa, J.O. and Breen, J.E., "The Influence of Casting Position on Development and Splice Length on Reinforcing Bars," Research Report No. 242-1, Center for Transportation Research, Bureau of Engineering Research, The University of Texas at Austin, June 1981, 153 pp.
7. Menzel, Carl A., "Effect of Settlement of Concrete on Results of Pullout Tests," Research Department Bulletin 41, Research and Development Laboratories of the Portland Cement Association, November 1952, 49 pp.
8. "PSI Super, Superplasticizing High-Range Water-Reducer," Gifford-Hill and Company, Inc., Chemical Division, Charlotte, North Carolina, 1983, 2 pp.
9. Zekany, A.J., Neumann, S., Jirsa, J.O. and Breen, J.E., "The Influence of Shear on Lapped Splices in Reinforced Concrete," Research Report No. 242-2, Center for Transportation Research, Bureau of Engineering Research, The University of Texas at Austin, July 1981, 88 pp.

Table 1 Concrete Mix Designs and Properties
(Cubic Yard Batch Weights)

				Aggregate				Base or Regular Concrete			Superplasticized Concrete			
Mix Design	w/c Ratio	Cement #	Water #	Fine+ #	Coarse* #	Temp °F	Age at Test Days	Slump in.	Air %	Strength psi	SP-HRWR oz.	Slump in.	Air %	Strength psi
1	0.55	500	275	1555	1579	84	5	1-3/4	2-3/4	4280	96	6 - 9	n	4760
2	0.55	545	300	1453	1579	78	22	9	1	4000	--	--	--	--
3	0.55	510	280	1534	1579	53	11	3-3/4	1-1/2	4470	72	9	1-1/2	4830

+ Kansas River Sand - Lawrence Sand Company, Lawrence, KS
Bulk Specific Gravity = 2.62, Absorption = 0.5%
Fineness Modulus = 3.0 to 3.17

* Crushed Limestone - Hamms Quarry, Perry, KS
Bulk Specific Gravity = 2.52, Absorption = 3.5%
Maximum Size = 3/4 inch

Design Air Content = 2%

Slump and Air Values are as Measured

n Not measured

Table 2 Average Test Bar Data

Bar Size	#8
Deformation Spacing, in.	0.545
Deformation Height, in.	0.057
Deformation Angle, deg.	50
Deformation Gap, in.	0.313
Nominal Weight, lb/ft	2.650
Deformation Bearing Area, sq. in./in. length	0.239
Yield Strength, ksi	63.47
Tensile Strength, ksi	104.6

Deformation Pattern--Sheffield

Table 3 Specimen Bleed

Specimen No.	Specimen Description Slump-Type of Conc**-Size	Consolidation	Total Bleed grams	
			90 minutes	120 mi
1B	1-3/4"-R-Shallow	Vib	19.7	*
1D	1-3/4"-R-Deep	Vib	20.3	*
1F	9"-SP @ 84°F-Shallow	Vib	21.6	*
1H	9"-SP @ 84°F-Deep	Vib	18.4	*
1J	9"-SP @ 84°F-Shallow	Non Vib	17.8	*
1L	9"-SP @ 84°F-Deep	Non Vib	15.4	*
2B	9"-R-Shallow	Non Vib	46.9	51.0
2D	9"-R-Deep	Non Vib	31.0	34.5
2F	9"-R-Shallow	Vib	40.1	42.6
2H	9"-R-Deep	Vib	29.7	31.4
3B	3-3/4"-R-Shallow	Vib	27.1	29.8
3D	3-3/4"-R-Deep	Vib	21.8	24.2
3F	9"-SP @ 53°F-Shallow	Vib	46.1	51.1
3H	9"-SP @ 53°F-Deep	Vib	33.7	36.6
3J	9"-SP @ 53°F-Shallow	Non Vib	70.6	74.1
3L	9"-SP @ 53°F-Deep	Non Vib	38.3	40.4

* Data not taken full 2 hours.

** R = Regular
SP = Superplasticized

Table 4 Test Specimen Variables and Bond Strength

Bar Size	#8
Embedment Length	10 in.
Cover	2 in.

Specimen No.	Specimen Size*	Bar Position+	Concrete Below Bar in.	Concrete Strength psi	Slump in.	Consol. **	Bond Strength k/in	Norm. Bond Strength k/in	Conc. Mix Design No. ++
1A	S	B	2	4280	1-3/4	V	4.46	4.31	1 - R
1B	S	T	8				4.26	4.12	
1C	M	T	15				3.52	3.40	
1D	D	B	2				4.74	4.58	
1D	D	T	36				3.76	3.64	
1E	S	B	2	4760	9	V	4.44	4.07	1 - SP
1F	S	T	8		9		4.65	4.26	
1G	M	T	15		9		4.03	3.70	
1H	D	B	2		8		4.41	4.04	
1H	D	T	36		6		2.97	2.72	
1I	S	B	2	4760	9	N	3.12	2.86	1 - SP
1J	S	T	8		9		3.78	3.47	
1K	M	T	15		8		4.44	4.07	
1L	D	B	2		8		3.48	3.19	
1L	D	T	36		6		2.98	2.73	
2A	S	B	2	4000	9	N	4.31	4.31	2 - R
2B	S	T	8				2.99	2.99	
2C	M	T	15				2.68	2.68	
2D	D	B	2				4.45	4.45	
2D	D	T	36				1.56	1.56	
2E	S	B	2	4000	9	V	4.57	4.57	2 - R
2F	S	T	8				3.33	3.33	
2G	M	T	15				3.24	3.24	
2H	D	B	2				4.71	4.71	
2H	D	T	36				2.76	2.76	
3A	S	B	2	4470	3-3/4	V	4.09	3.87	3 - R
3B	S	T	8				2.81	2.66	
3C	M	T	15				3.98	3.77	
3D	D	B	2				4.60	4.35	
3D	D	T	36				2.35	2.22	
3E	S	B	2	4830	9	V	3.81	3.47	3 - SP
3F	S	T	8				3.22	2.93	
3G	M	T	15				2.57	2.34	
3H	D	B	2				3.76	3.42	
3H	D	T	36				2.33	2.12	
3I	S	B	2	4830	9	N	3.51	3.19	3 - SP
3J	S	T	8				2.82	2.57	
3K	M	T	15				1.84	1.67	
3L	D	B	2				3.47	3.16	
3L	D	T	36				1.38	1.26	

* S = Shallow Specimen, M = Medium Specimen, D = Deep Specimen
\+ B = Bottom-Cast, T = Top-Cast
** V = Vibrated, N = Non-Vibrated
++ R = Regular, SP = Superplasticized

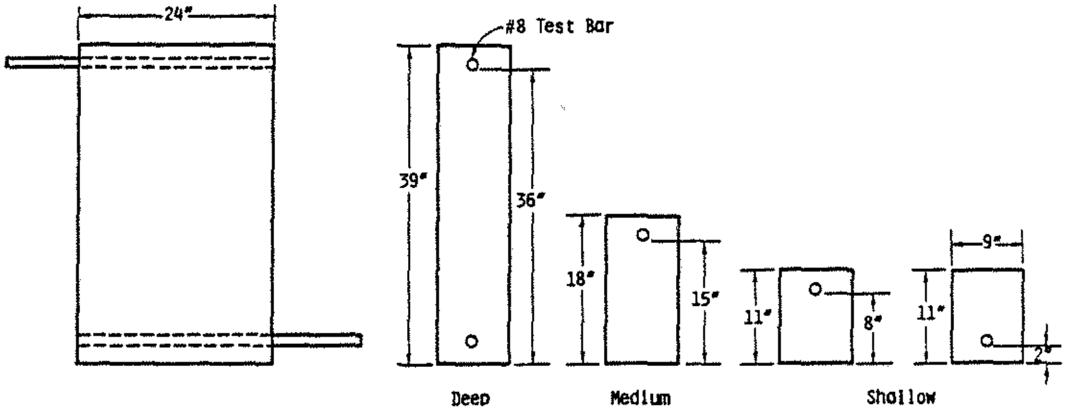

Fig. 1 Test Specimens

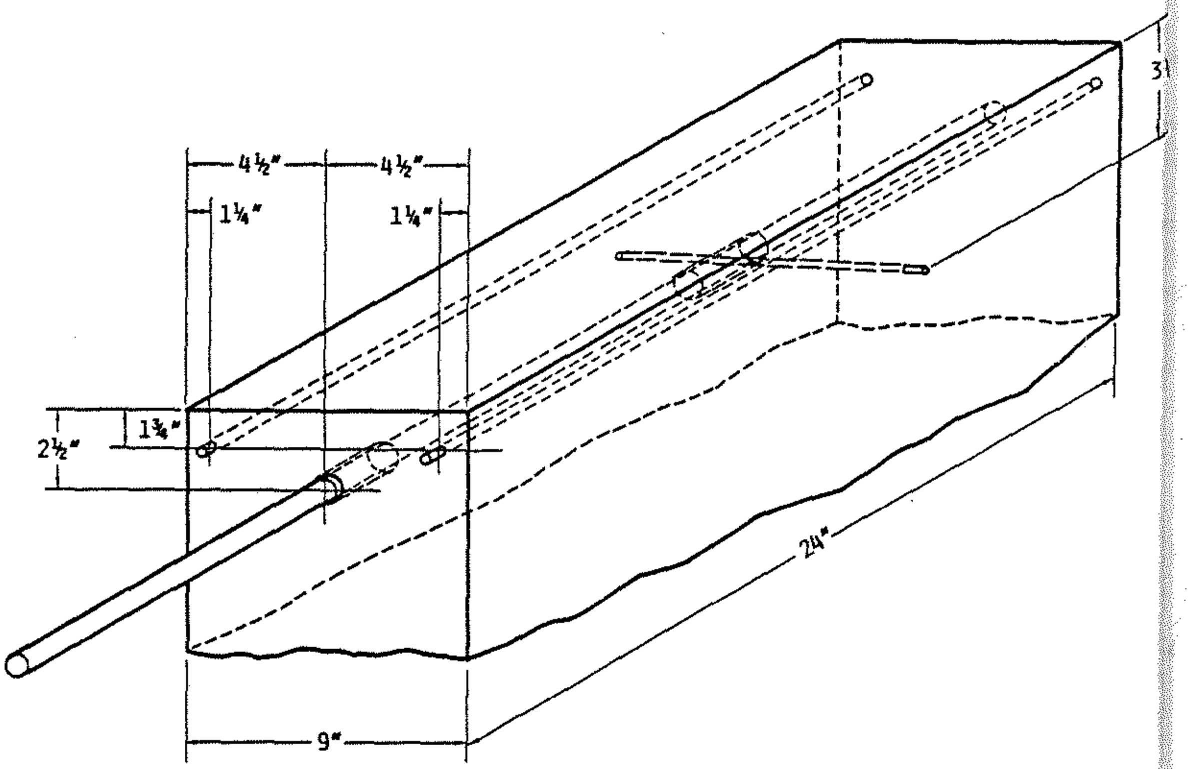

Fig. 2 Test Specimen Details

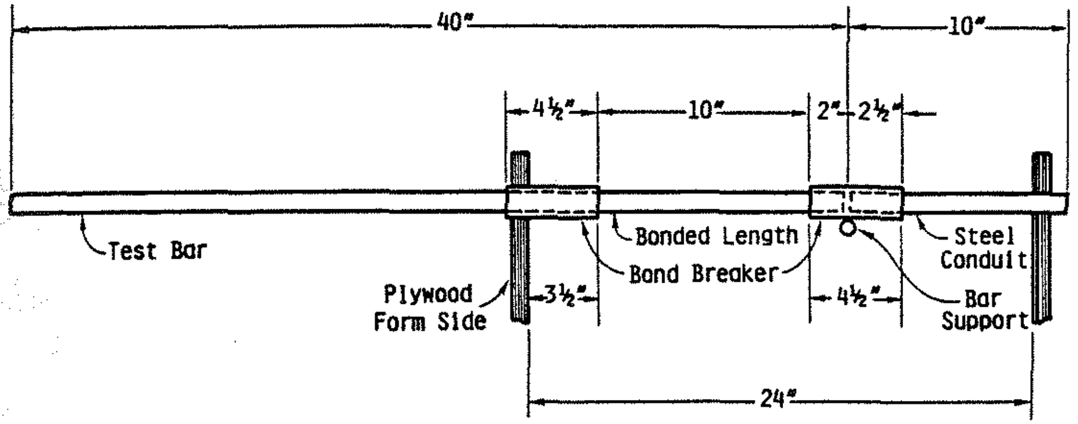

Fig. 3 Test Bar Installation

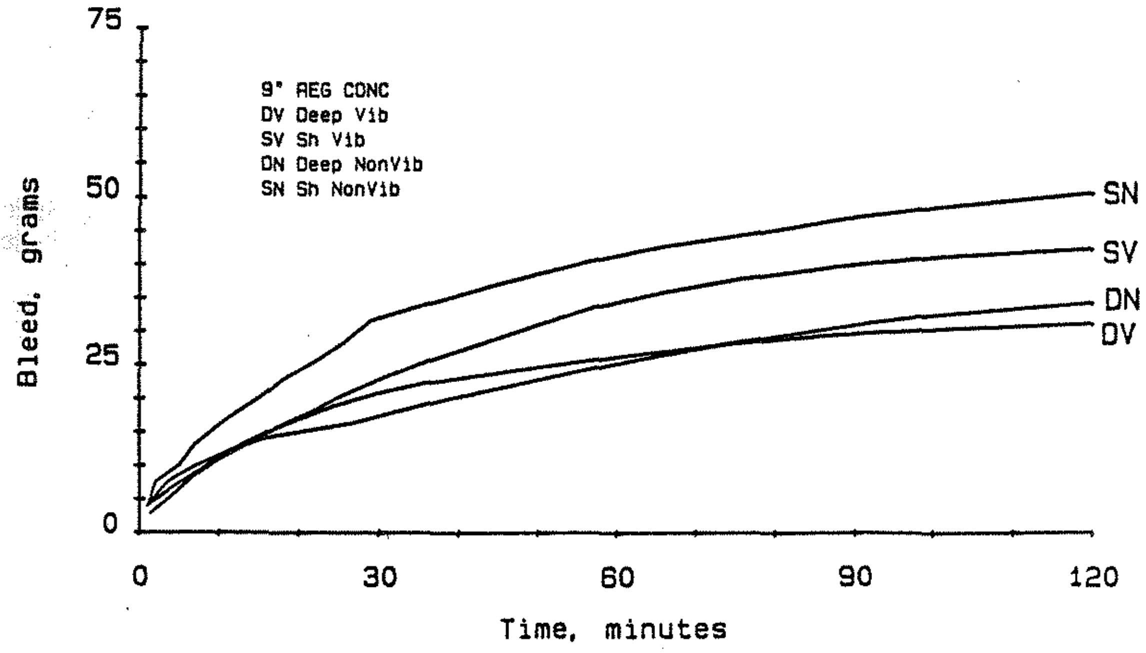

Fig. 4 Typical Bleed Test Curves

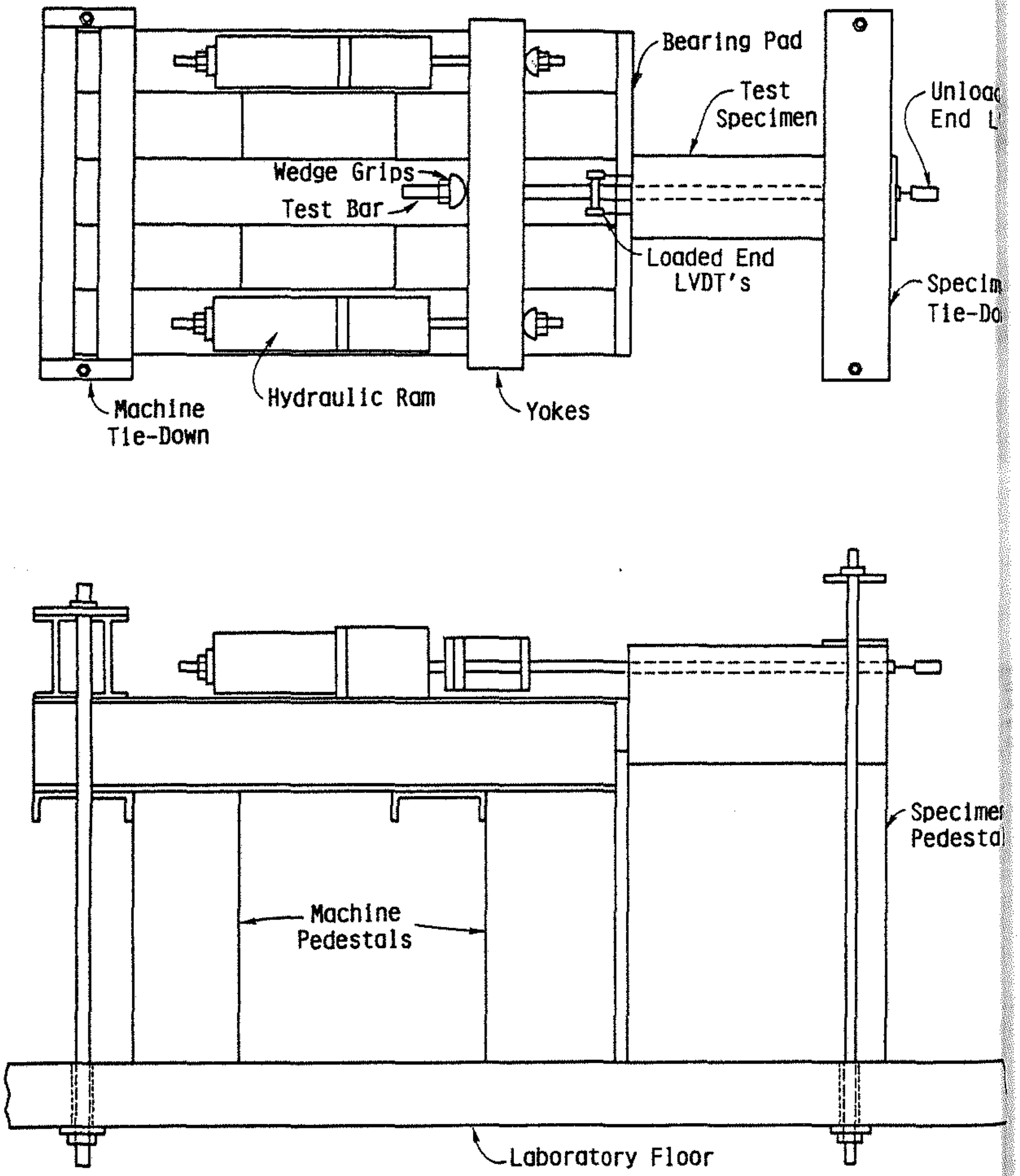

Fig. 5 Schematic of Bond Test

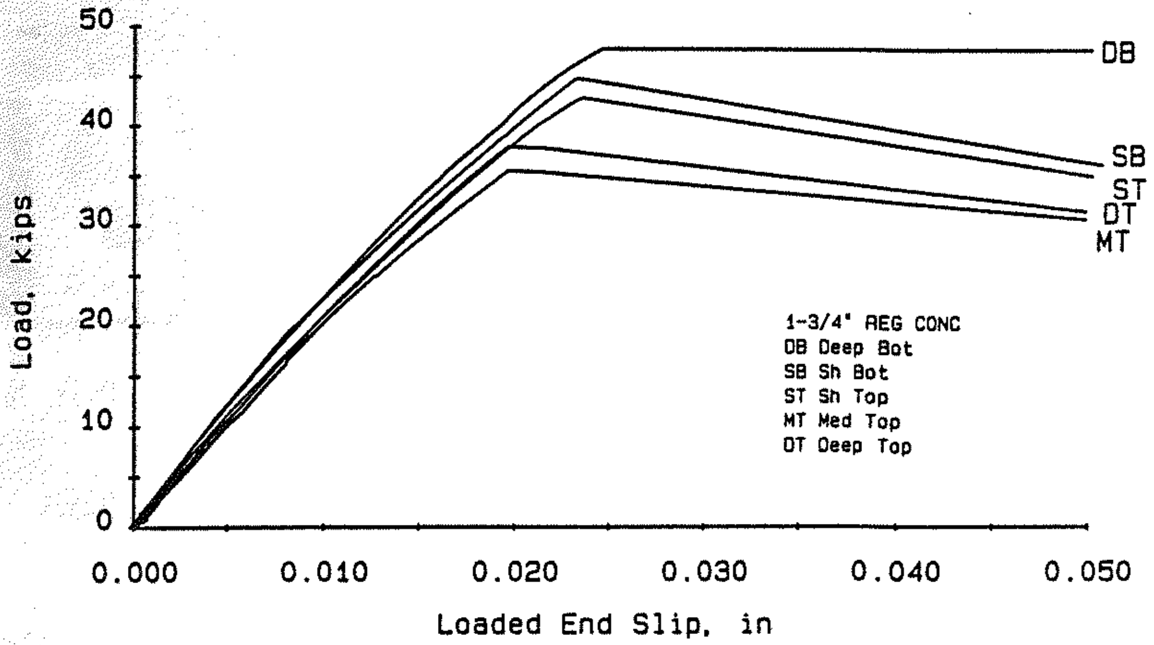

Fig. 6 Typical Load versus Loaded End Slip Curves

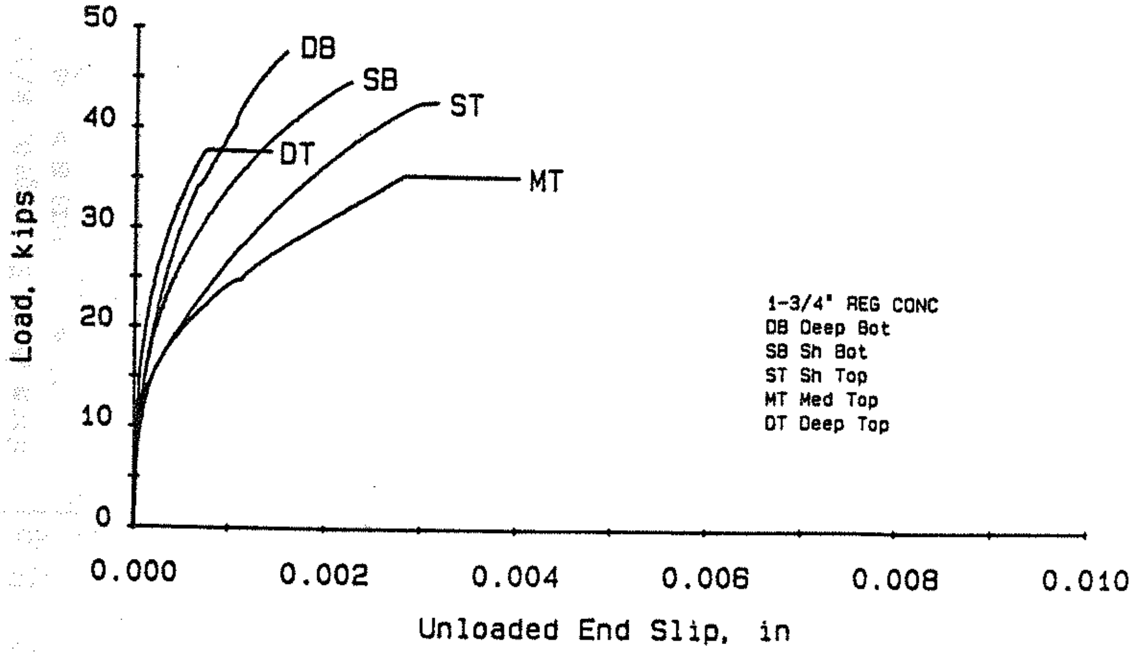

Fig. 7 Typical Load versus Unloaded End Slip Curves

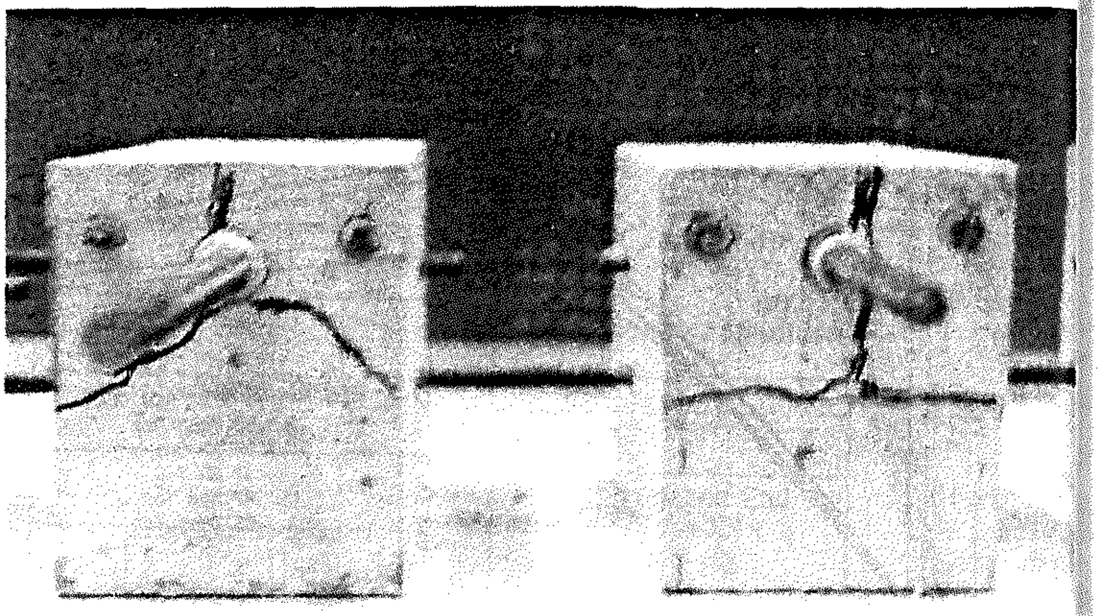

Fig. 8 Test Specimens After Pullout

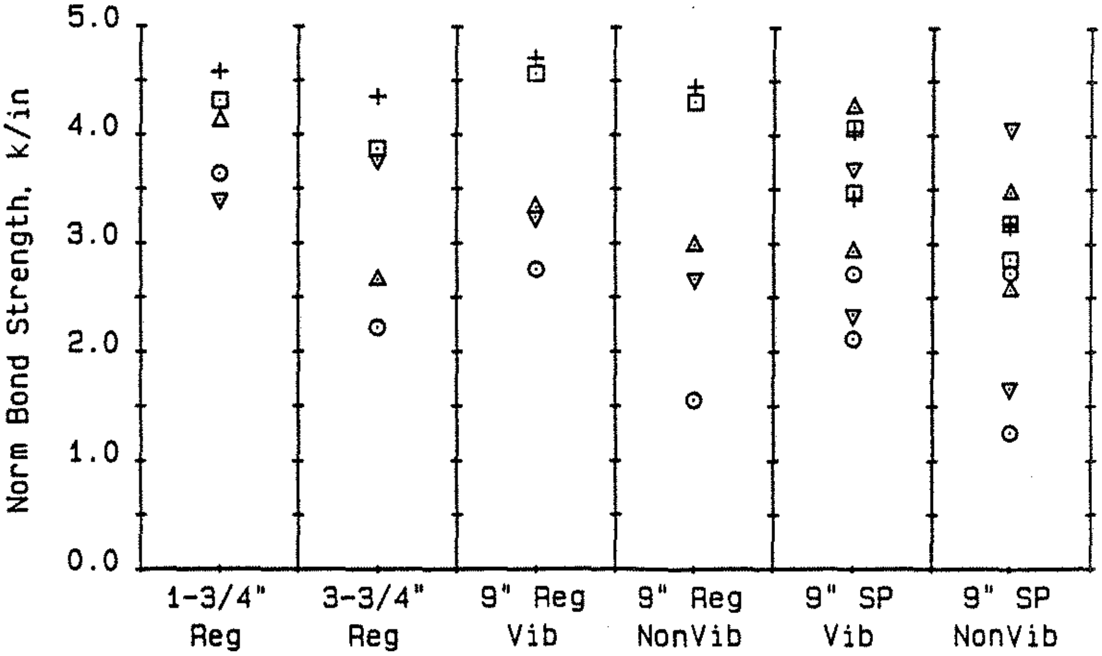

Fig. 9 Comparison of Normalized Bond Strengths for Different Types Concrete

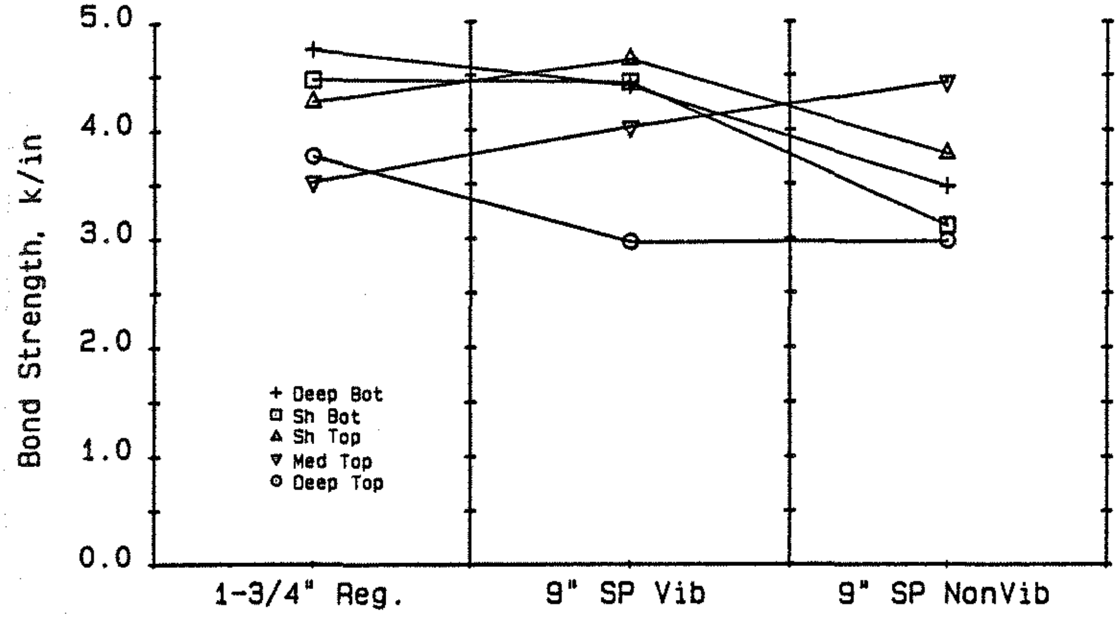

Fig. 10 Comparison of Bond Strengths for 84°F Base and Superplasticized Concretes

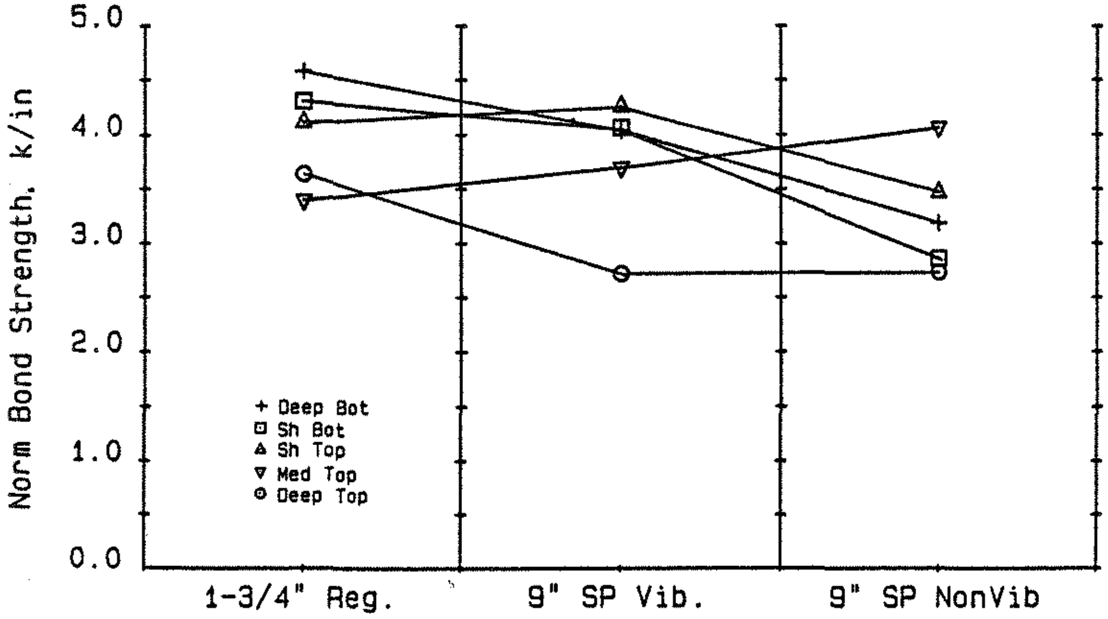

Fig. 11 Comparison of Normalized Bond Strengths for 84°F Base and Superplasticized Concretes

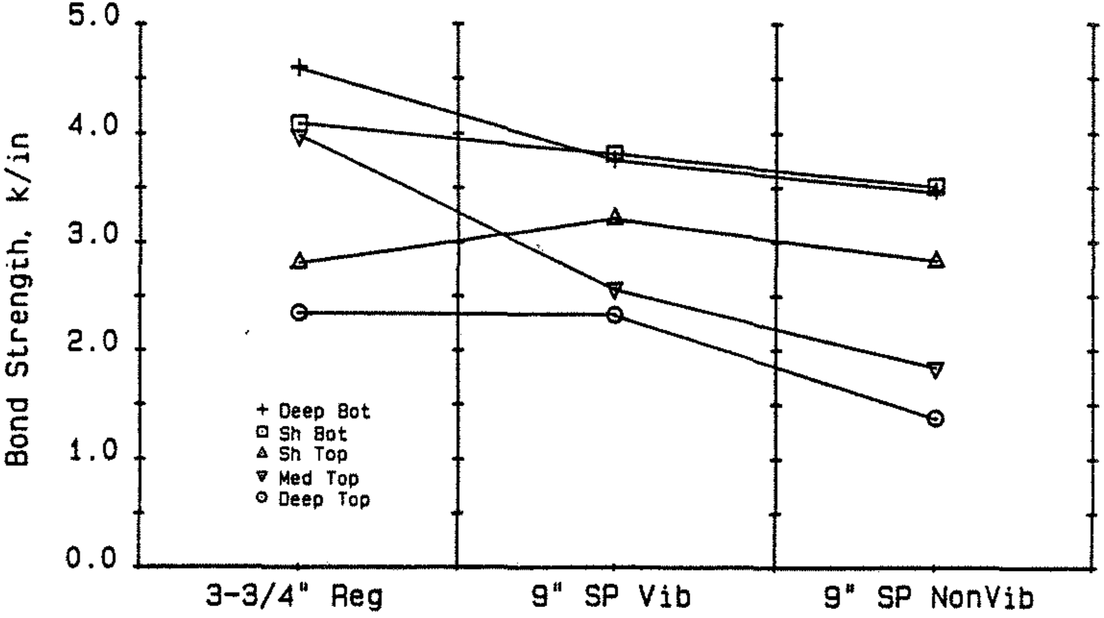

Fig. 12 Comparison of Bond Strengths for 53^{o}F Base and Superplasticiz
Concretes

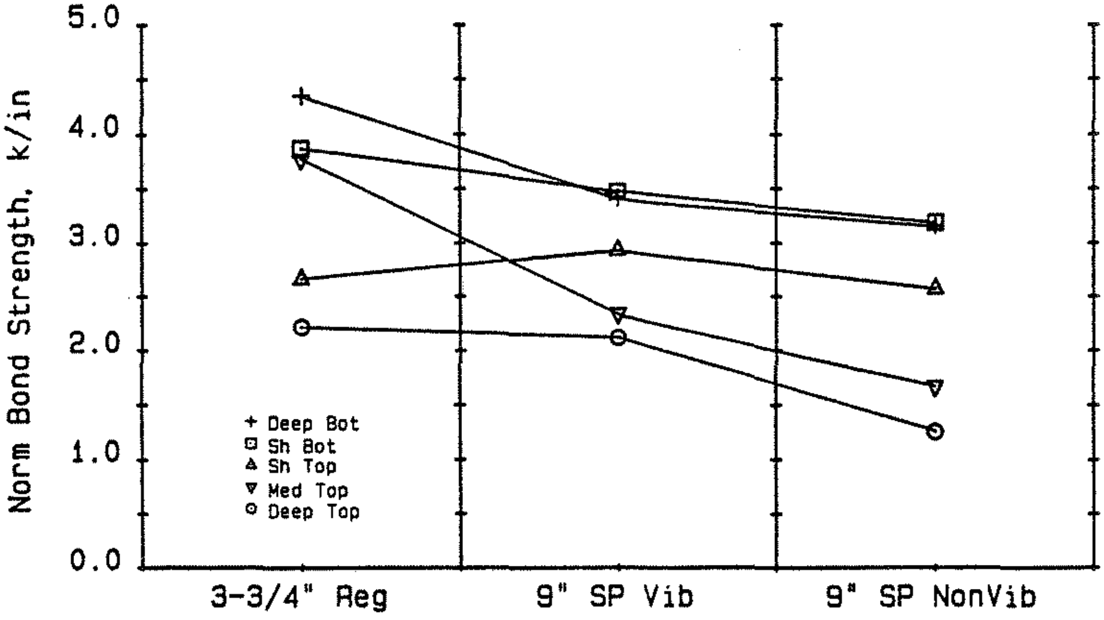

Fig. 13 Comparison of Normalized Bond Strengths for 53^{o}F Base and Superplasticized Concretes

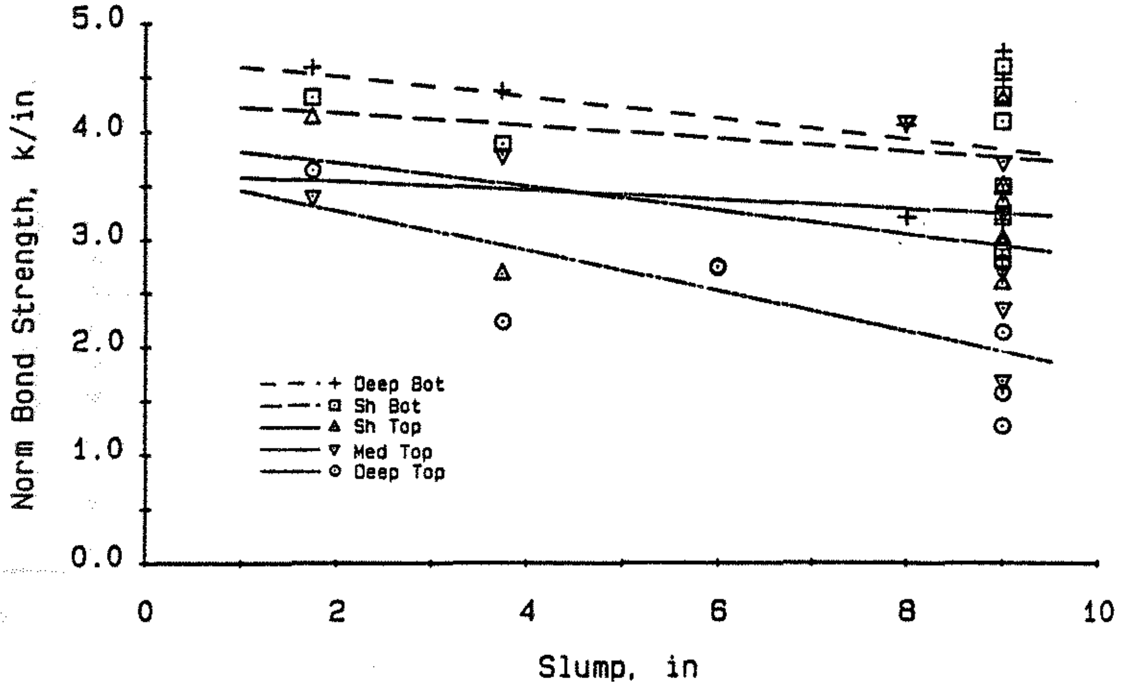

Fig. 14 Normalized Bond Strength versus Slump

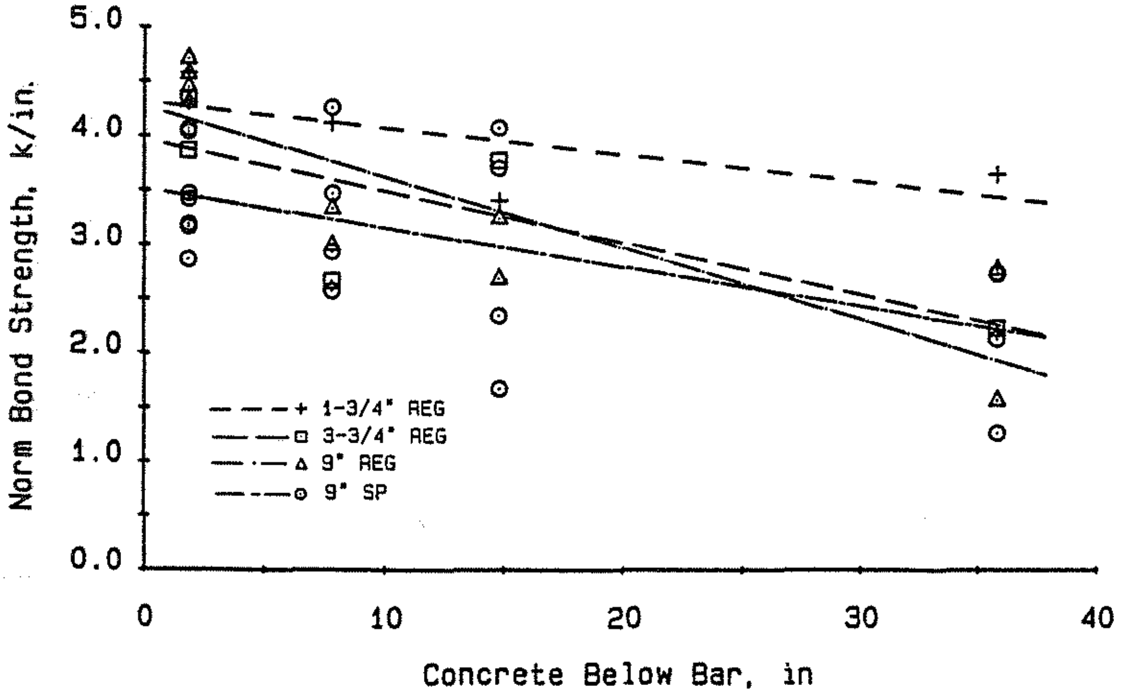

Fig. 15 Normalized Bond Strength versus Concrete Below Bar

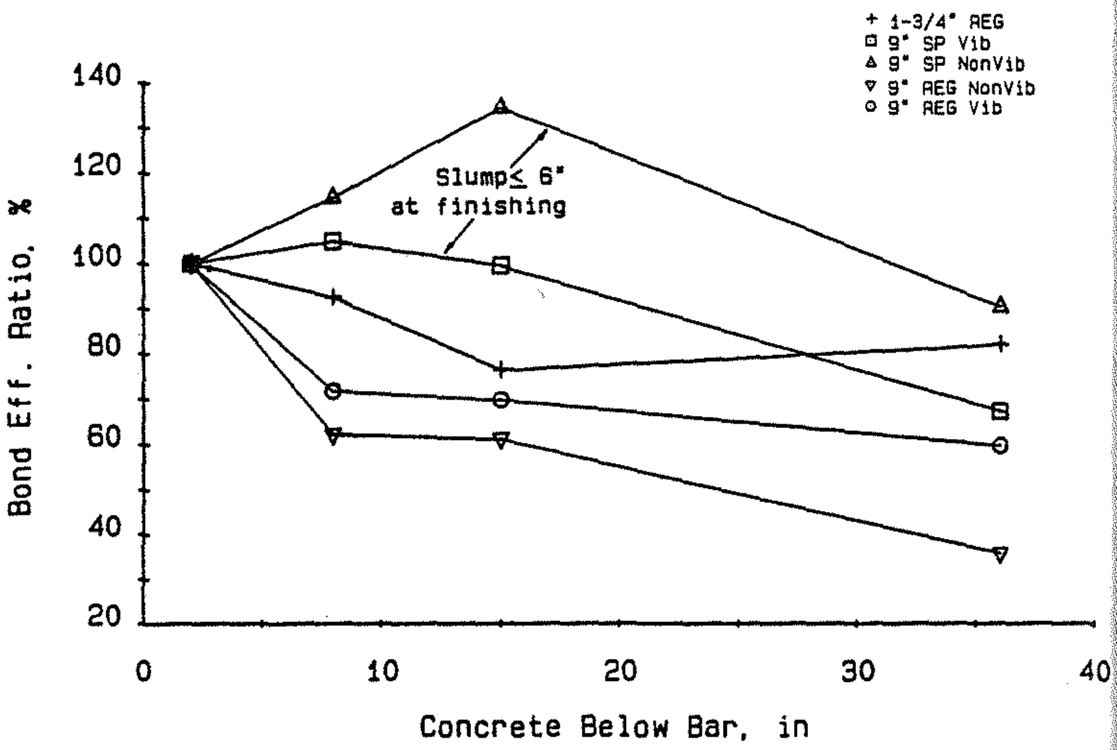

Fig. 16 Bond Efficiency Ratio versus Concrete Below Bar for Higher Temperature Concretes (78° - 84°F)

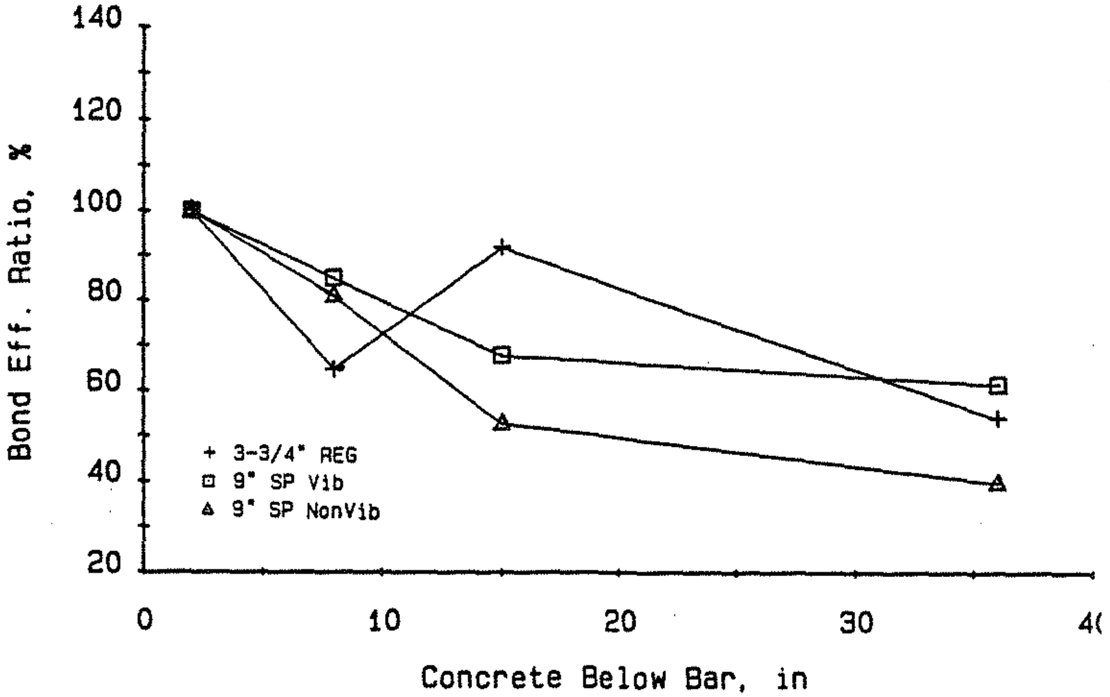

Fig. 17 Bond Efficiency Ratio versus Concrete Below Bar for Lower Temperature Concrete (53°F)

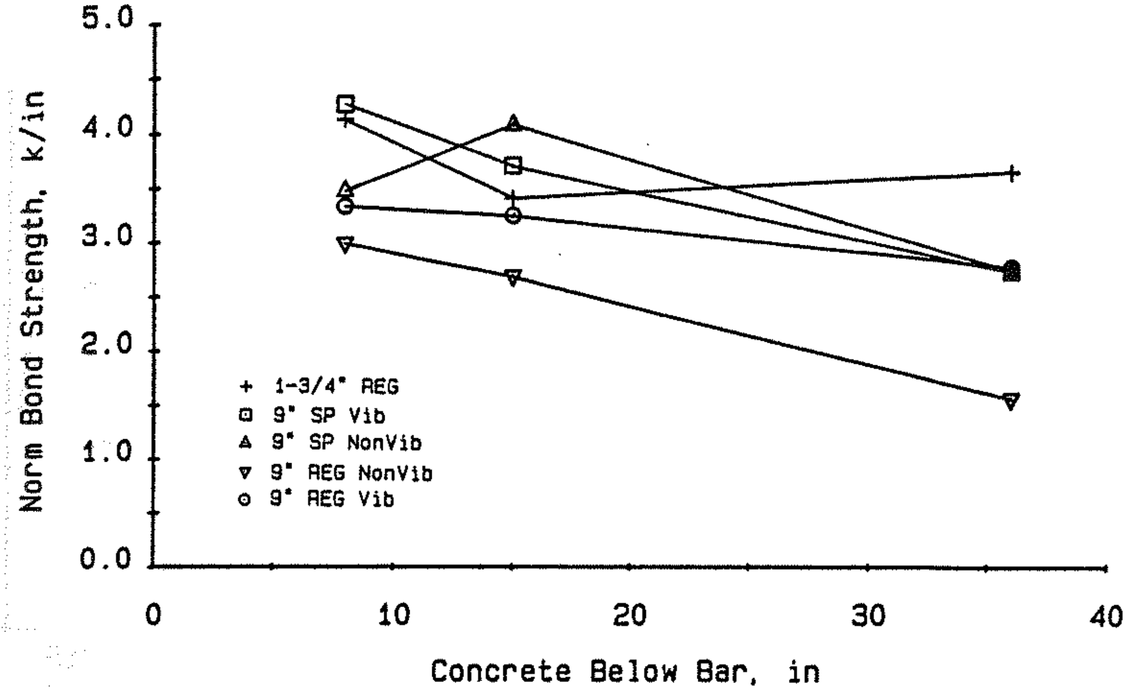

Fig. 18 Normalized Bond Strengths of Top-Cast Bars versus Concrete Below Bar for Higher Temperature Concretes (78° - 84°F)

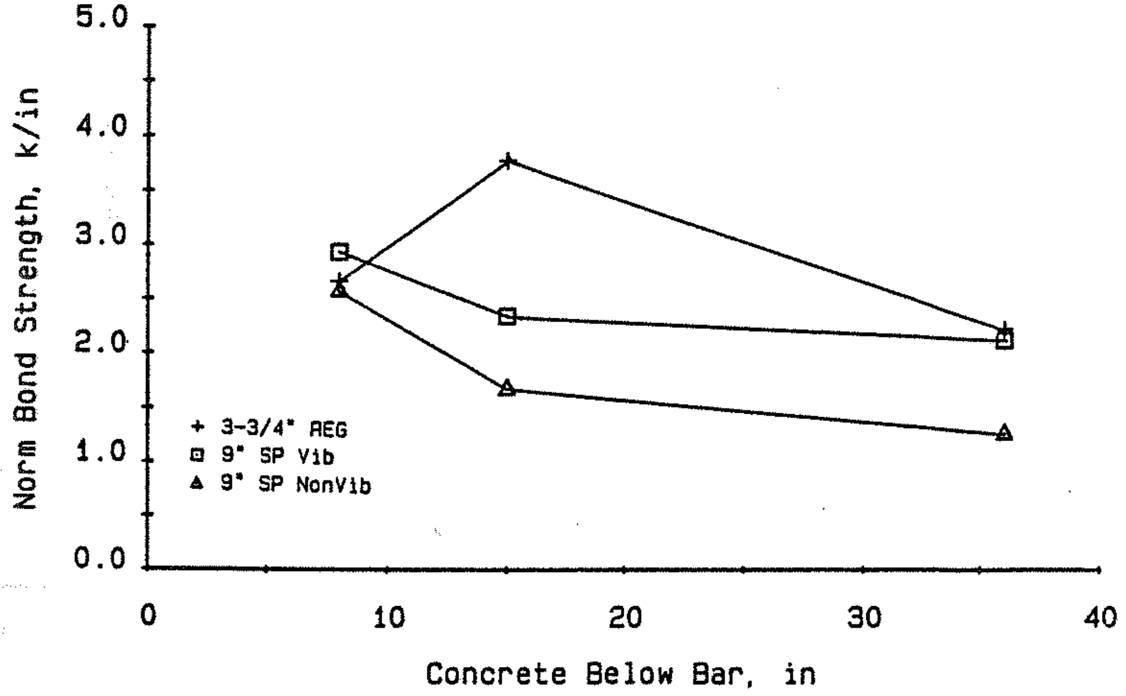

Fig. 19 Normalized Bond Strengths of Top-Cast Bars versus Concrete Below Bars for Lower Temperature Concrete (53°F)

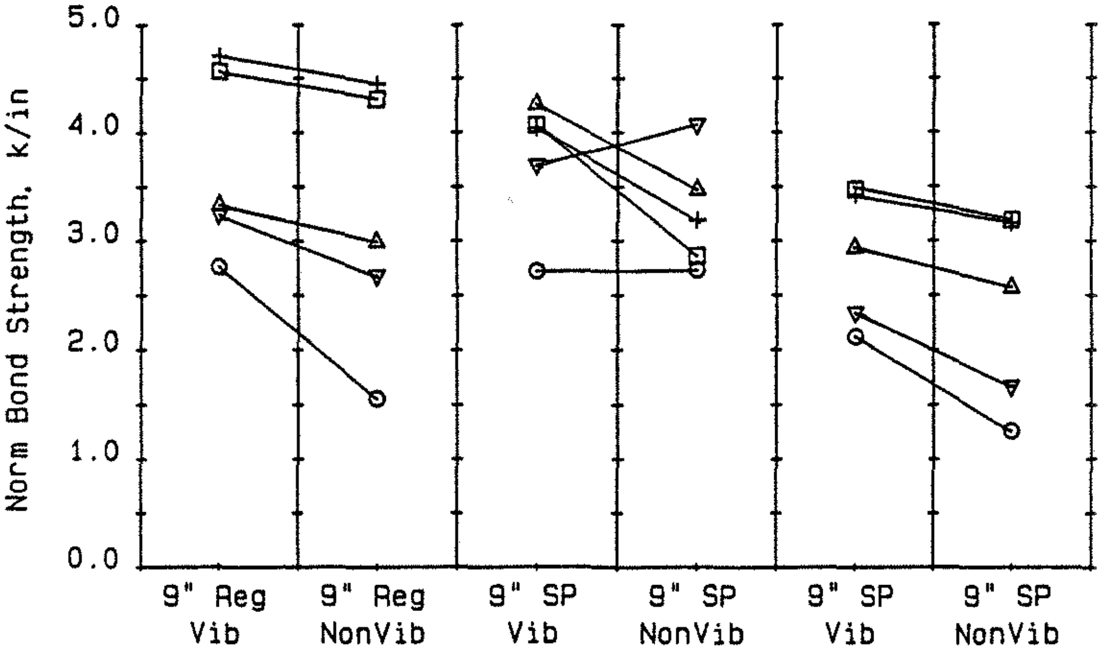

Fig. 20 Comparison of Average Normalized Bond Strengths for Vibrate
Non-vibrated High-Slump Concrete Mixes

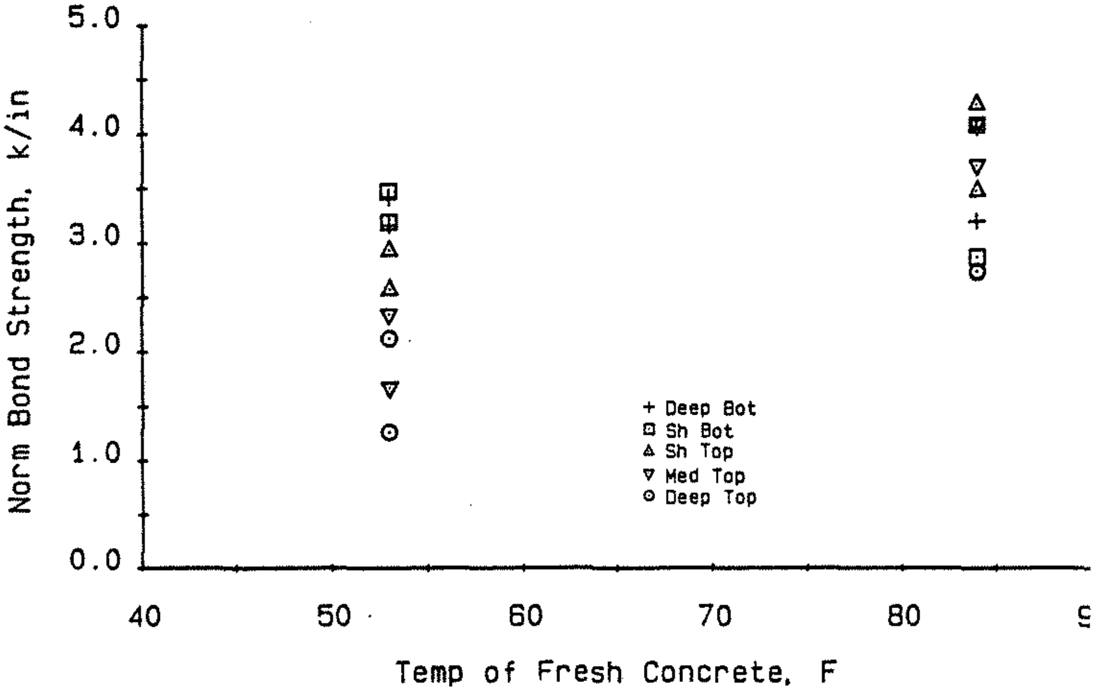

Fig. 21 Normalized Bond Strength versus Temperature of Superplasti
Concrete at Placement (Vibrated and Non-vibrated)

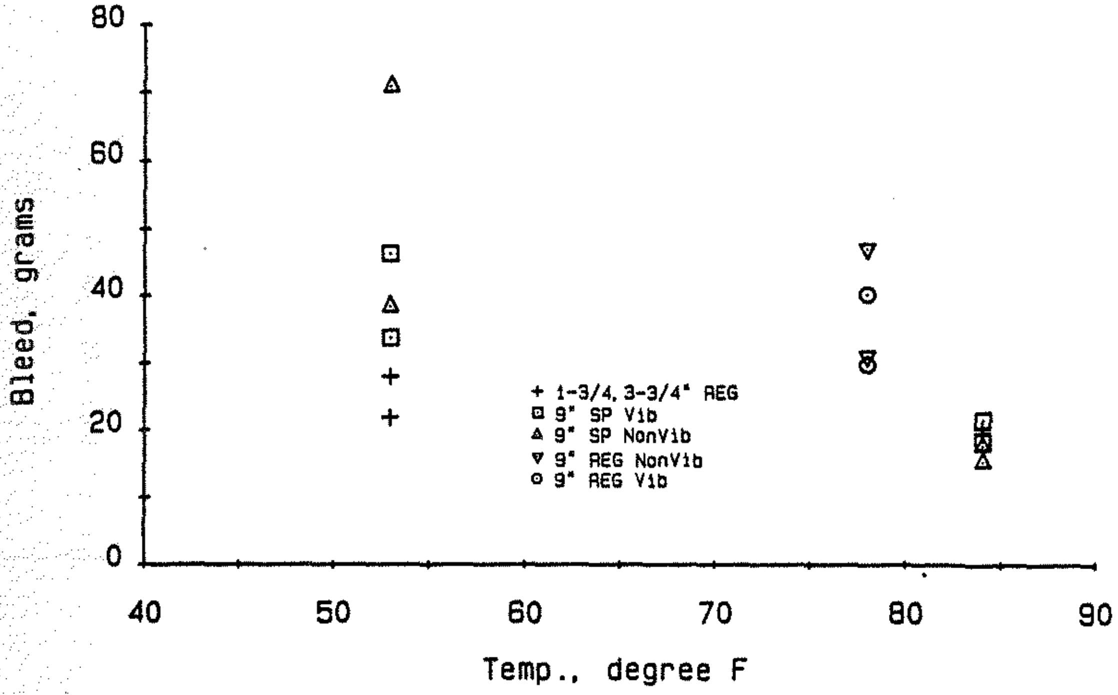

Fig. 22 90 Minute Bleed versus Temperature of Fresh Concrete

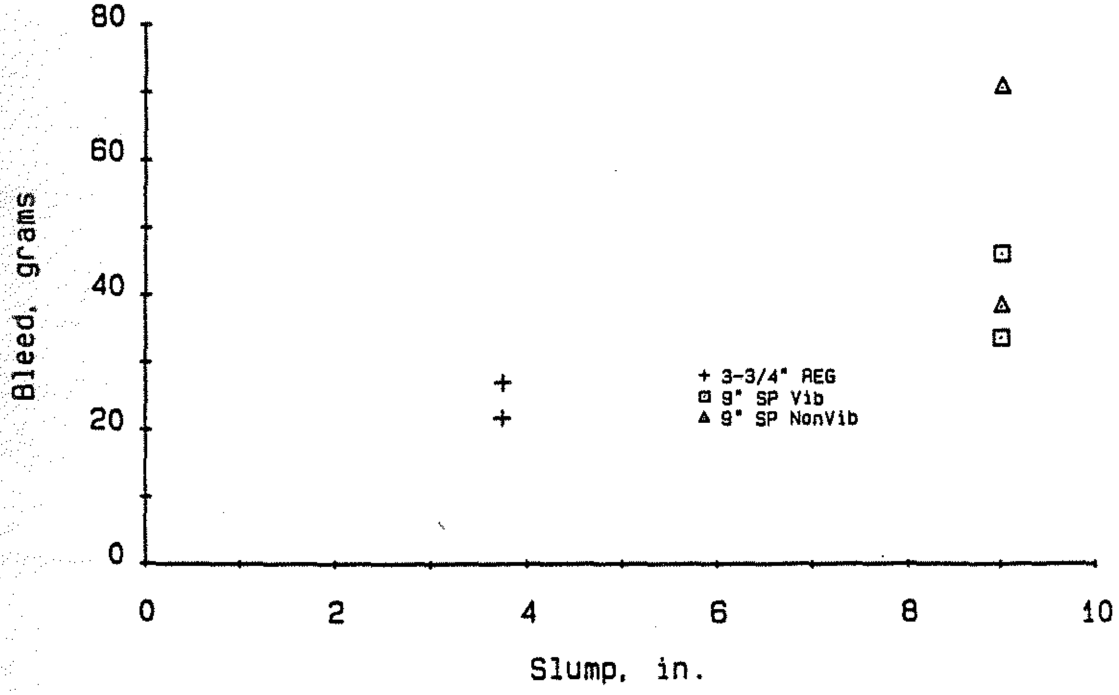

Fig. 23 90 Minute Bleed versus Slump of Lower Temperature Concrete (53^{o}F)

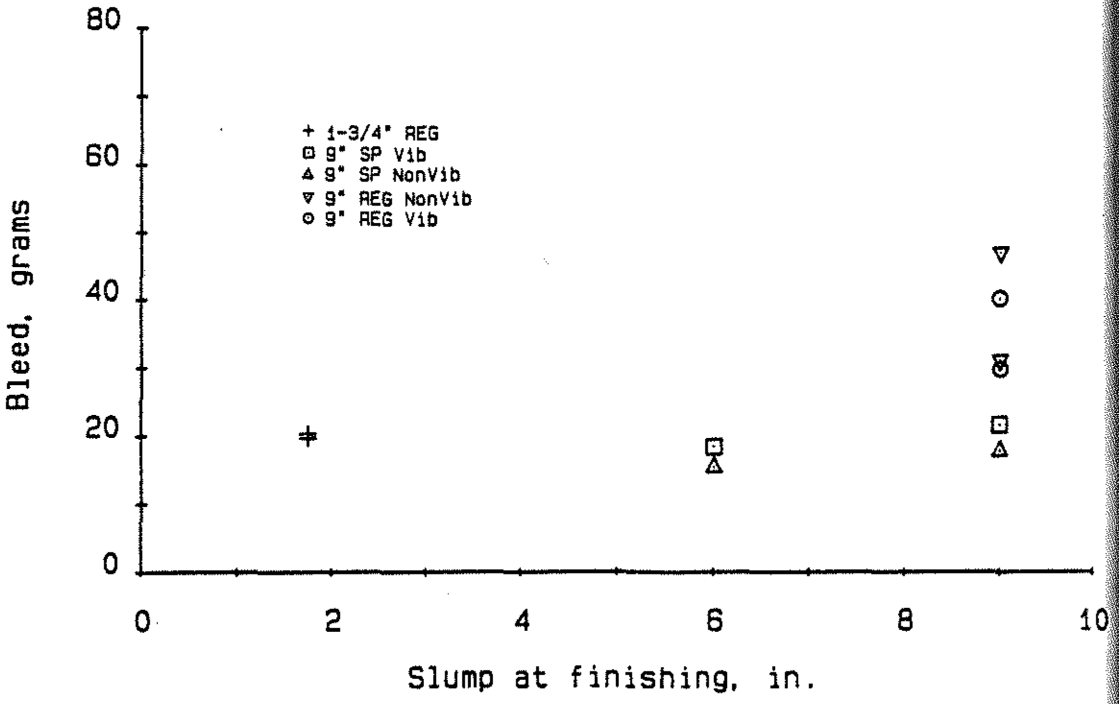

Fig. 24 90 Minute Bleed versus Slump of Higher Temperature Concretes
- 84°F)

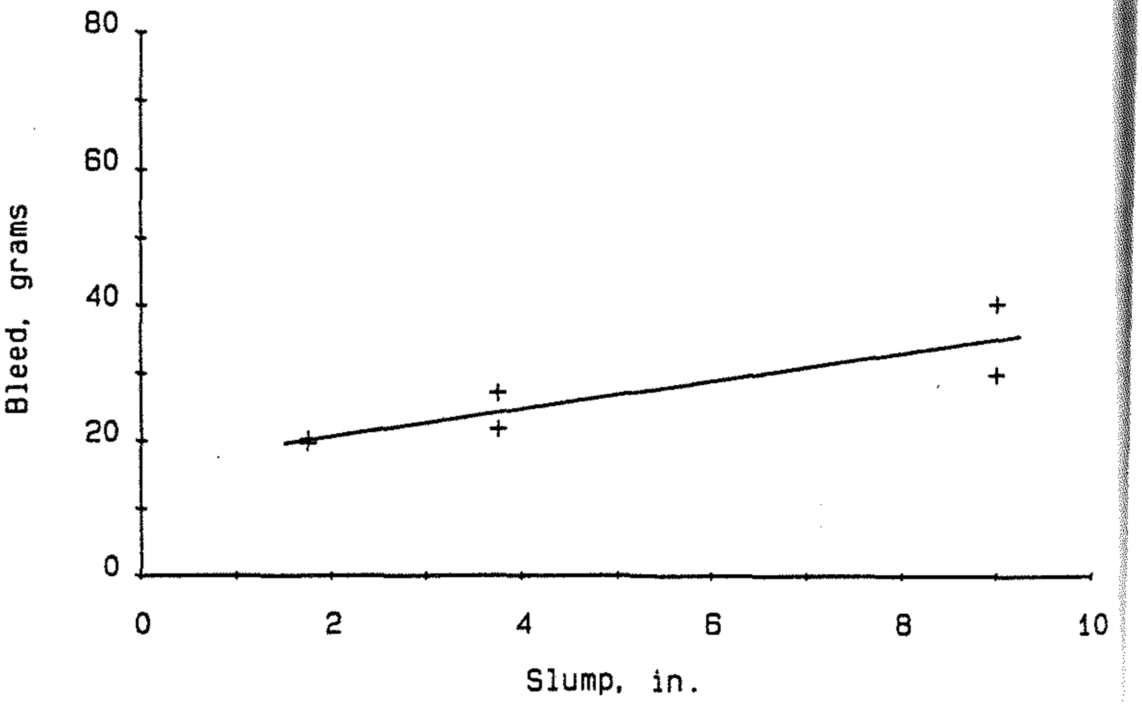

Fig. 25 90 Minute Bleed versus Slump of Regular Concretes