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PULL-OUT TESTING OF CAST IN PLACE EPOXY GROUTED REINFORCEMENT SLEEVES

College of
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PULL-OUT TESTING OF CAST IN PLACE EPOXY GROUTED REINFORCEMENT SLEEVES

A Project Presented to the
Department of Civil & Environmental Engineering
Brigham Young University

In Partial Fulfillment
of the Requirements for the Degree
Masters of Science

Glenn P. Peterson
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This project, by Glenn Paul Peterson, is accepted in its present form by the Department of Civil and Environmental Engineering of Brigham Young University as satisfying the project requirements for the degree Masters of Science.

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Date

ABSTRACT

PULL-OUT TESTING OF CAST IN PLACE EPOXY GROUTED REINFORCEMENT SLEEVES

Glenn P. Peterson

Department of Civil and Environmental Engineering

Masters of Science Degree

This report details the preparation and testing of reinforcement sleeves. The testing was based on ASTM C 234-86 bond tests. The objective was to test various reinforcement sleeves and compare the results to a control set of standard deformed bars.

A high strength concrete mix design was chosen. Average concrete strength was 8500 psi. The sleeves tested were 1" EMT conduit, 1" PVC pipe, 1" flexible plastic Carlon conduit and #6 bar control set. The testing consisted of applying tension to the reinforcement and measuring the strain and slip at 500 lb intervals. Testing was discontinued when strain ~~and slip~~ exceeded .01 in./in.

The samples were cast utilizing partitioned 6"x6"x30" flexure beam molds and a jig to hold the sleeves and bars vertical. The concrete was placed in two lifts and consolidated using a small diameter internal vibrator because of the low slump. Curing was in the BYU lab fog room for minimum of 28 days. The sleeves were cleaned before epoxying the bars in place. Testing took place after the epoxy had cured for at least 24 hours.

The EMT conduit and PVC pipe both failed at less than 30% of the bond strength and 50% total control set loads. The Carlon set failed at 50% of the bond strength and 86% of the total control set load.

Because the PVC and EMT sleeves failed by pulling out of the concrete three of each had the sleeves pulled completely out and were used to test the epoxy to concrete bond strength. The removed PVC sample failed at 55.6% of the bond and 97.9% of the total control set loads. The removed EMT set failed at 82.4% of the bond and 129% of the total control set loads.

PULL-OUT TESTING OF CAST IN PLACE EPOXY GROUTED REINFORCEMENT SLEEVES

Introduction

In order to develop structural continuity between sequential castings of reinforced concrete, the reinforcing steel is continued from one casting to the next. There are times when due to construction constraints it is desirable to not have reinforcement protruding from a foundation or footing. Situations that may require this could be the necessity of moving equipment or materials over a footing. Another specific case involves the use of air forms for the construction of thin-shell concrete domes. When installing an air form the fabric form is rolled out and attached to the exterior of the ring beam footing. The reinforcing protruding from the footing presents a potential of puncturing or tearing the fabric. The current practice is to bend the reinforcement out of the way and then straighten it back out when ready to form and cast the subsequent section. This bending and straightening of the bars raises two problems. First, the reinforcement is weakened and sometimes broken due to fatigue from the bending. Second, when large reinforcement bars are used bending them is nearly impossible.

It is accepted practice in retrofit situations to epoxy or grout bolts or reinforcement bars into drilled holes. The concept inspiring this research is to cast a sleeve into the concrete. Thereby providing a location for the reinforcement to be epoxied in just prior to forming the subsequent casting.

Project Scope

This project involves the casting and testing of various sleeve specimens. ASTM Bond strength testing was used to investigate the pull out resistance of the different sleeves. Analysis was accomplished by comparing the bond strength and total loads of the specimens with a control sample. The sleeve and control specimens were cast into standard 6" concrete cubes. The cured samples were tested by applying tension to the reinforcement bar. The slip between the specimens and concrete was measured at various levels of stress. Loading was discontinued when the slip exceeded .01". The loading was accomplished using the RIEHLE constant strain testing equipment in the BYU structures lab.

Sample Set Definition

The specimens were chosen to represent common, easily acquired building materials. The test sample sets consisted of ten 6"x6"x6" concrete cubes. The control set was cast with #6 bars in them. The remaining sets were cast with sleeves for the bars. Two sleeve specimen sets with smooth surfaces (PVC pipe and EMT conduit) and a set which provided a mechanical interlock (flexible Carlon conduit) were used.

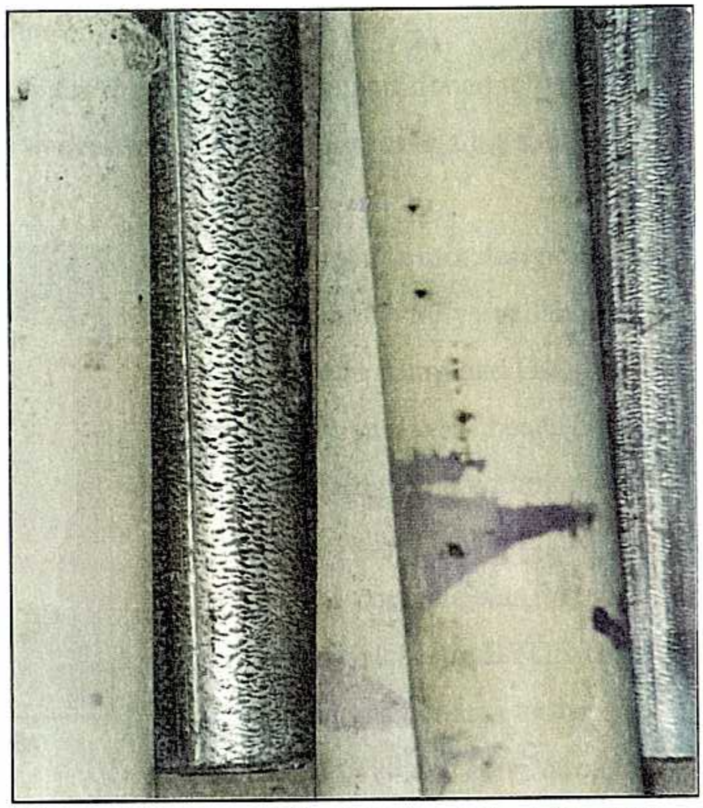

Figure 1, Representative PVC and Steel Conduit.

Three of the pipe and conduit samples were reused. After initial testing the sleeves were pulled from the cubes, to test the epoxy-concrete bond strength. The embedment length for all specimens was 6".

Test Materials

Grade 60 #6 Deformed Reinforcement Bars 30" long

1" SCH 40 PVC Pipe 6" long, see figure #1, O.D. 1.32"

1" Steel Conduit 6" long, see figure #1, O.D. 1.175"

1" Flexible Plastic Conduit (Carlon 12008-750) 6" long, see figure #2, maximum diameter 1.28", minimum diameter 1.07", average of 7 ribs/inch.

Simpson Epoxy-Tie Two Part Adhesive (ET-22), ICBO # 4945

High-Strength Portland Cement Concrete (8000 psi)

Molds and Casting Preparation

Standard 6"x6"x30" prismatic flexure beam molds were partitioned to provide 5 - 6" cube cells in each beam mold. The sleeves were held in place using a jig and the reinforcing bars (figure #3).

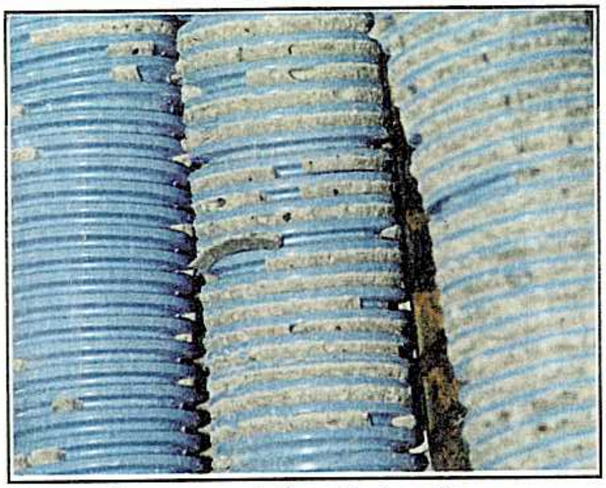

Figure 2, representative Carlon Sleeves (after testing).

The concrete mix design used was based on a commercially available high strength concrete (Burg and Ost, 1994). A high strength mix was chosen because they are becoming more common and would theoretically develop higher bond strengths. The concrete was mixed in two cubic foot batches in BYU's concrete lab using materials donated to the department of Civil and Environmental Engineering. 3 standard 4"x8" compression test cylinder samples were prepared and tested for each batch according to ASTM standards. Curing of all samples was for a minimum of 28 days at 75° ± 5° F and 90% ± 5% humidity in the BYU concrete lab fog room.

Concrete Mix Design	**Lb. / Yd^3**	**Lb. / Batch**
Type I, Cement	810	60
Coarse Aggregate, 3/4" max, SSD	1800	133.3
Fine Aggregate, SSD	1090	80.74
HRWR Type F, fl oz.	68	5
Water	324	24
Water : Cement Ratio	.40	.40

Stiff and slightly harsh mix

Slump 3/4" to 2"

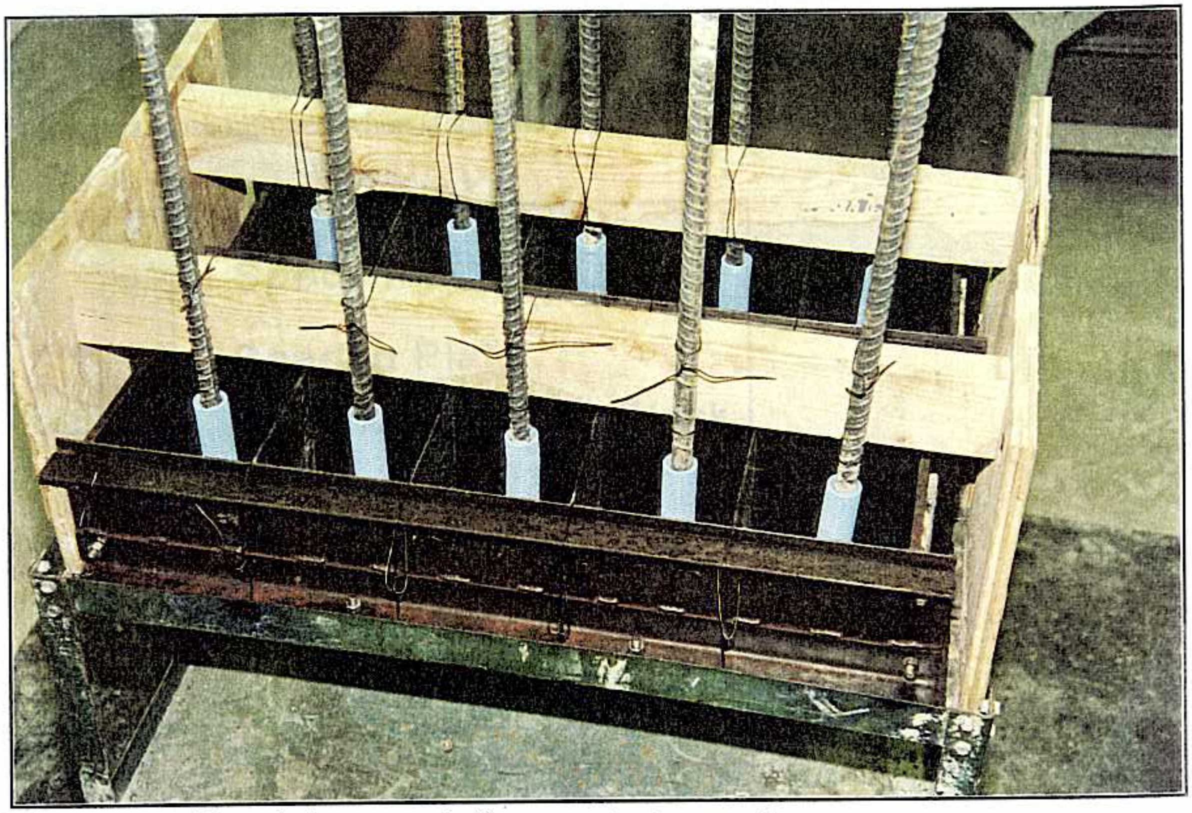

Figure 3, Molds and sleeves ready for concrete placement.

Sample Preparation

The batched concrete was placed in two lifts and consolidated with a small diameter internal vibrator. The specimen and cylinder forms were stripped after 20 hours and the specimens and cylinders were cured for a minimum of 28 days. The sleeves were cleaned of latence and debris after curing. The reinforcing bars were then epoxied into place. Testing was done after the epoxy had cured for at least 24 hours.

Testing Procedure

The specimens were tested using apparatus compliant with ASTM C 234-86. The specimen is placed on a 6" square 3/4" thick bearing plate with a 1" diameter hole in the center, this in turn rests on a spherical bearing block (figure #4). The spherical bearing block is used to provide a pure tension load. The reinforcing bar extends through the apparatus to be gripped by the jaws of the testing machine.

The reinforcing bar strain and slip in the concrete specimen was measured using dial gauges and holding apparatus. The strain and slip was recorded at 500 lb intervals. Testing was discontinued when strain and slip exceeded .01".

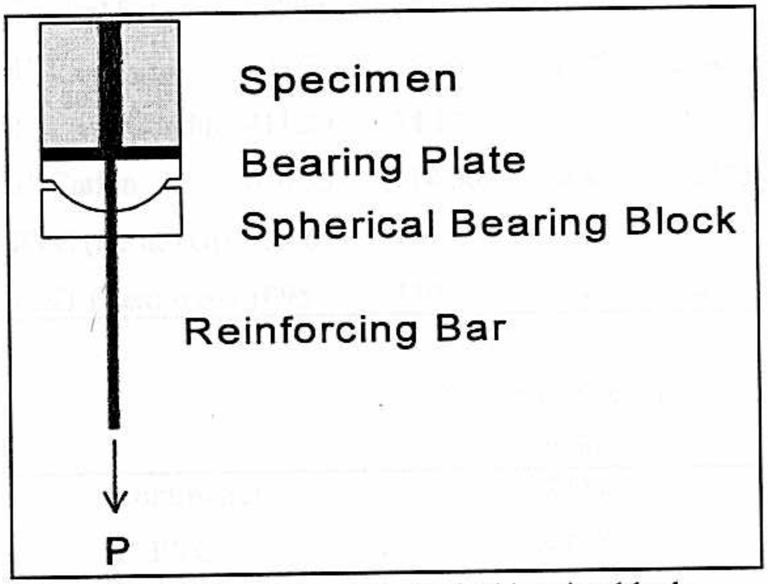

Figure 4, Bearing plate and spherical bearing block.

The strength cylinders were tested according to standard methods.

Data Analysis

The failure strengths recorded during testing were divided by the surface area to give results in load per unit area. Statistical methods were used to determine the averages, medians and standard deviations. These data points are shown in summary in the results section and graphically in the appendix of this report.

The bond surface areas for the different specimens are as follows:

Control set (#6 bars)	14.14 in^2
1" SCH 40 PVC	24.88 in^2
1" Steel Conduit	22.15 in^2
1" Carlon Flexible Conduit	24.13 in^2

(Note: the area inside of the grooves was neglected)

Results

Specimen set	Bond Strength Average lb/in²	Standard Deviation	% of Control	Total Load Average Pounds	Standard Deviation	% of Control
Control Set	1329.6	145.7	100%	18800	2060	100%
1" PVC	90.03	25.56	6.7%	2240	635.9	11.9%
1" EMT Conduit	411.29	34.17	30.9%	9110	756.9	48.5%
1" Carlon	670.33	114.36	50.4%	16175	2759	86.0%
PVC (Removed)	739.6	171.7	55.6%	18400	4270	97.9%
EMT (Removed)	1095	130	82.4%	24253	2890	129%

	Concrete Strength lb/in²	% of Control
Control Set	8724	100%
1" PVC	9778	112%
1" EMT Conduit	8933	102%
1" Carlon	7917	90.7%

Assumed failure mechanics for typical specimens are shown in figure 5.

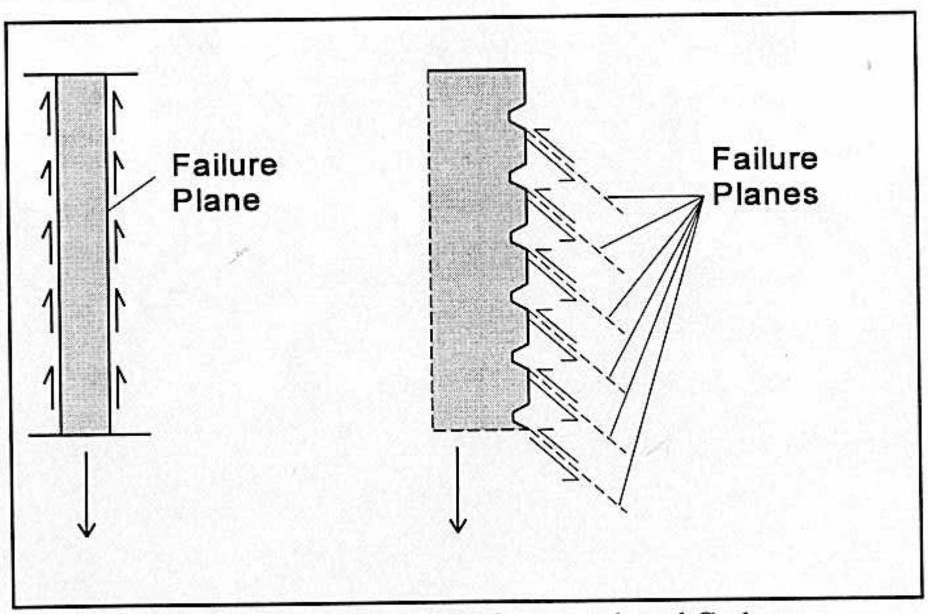

Figure 5, Theoretical failure planes for smooth and Carlon specimens. (Angles exaggerated)

Figures 6 and 7 show the results of the loss of confinement that occurred in these two sample sets and the control set.

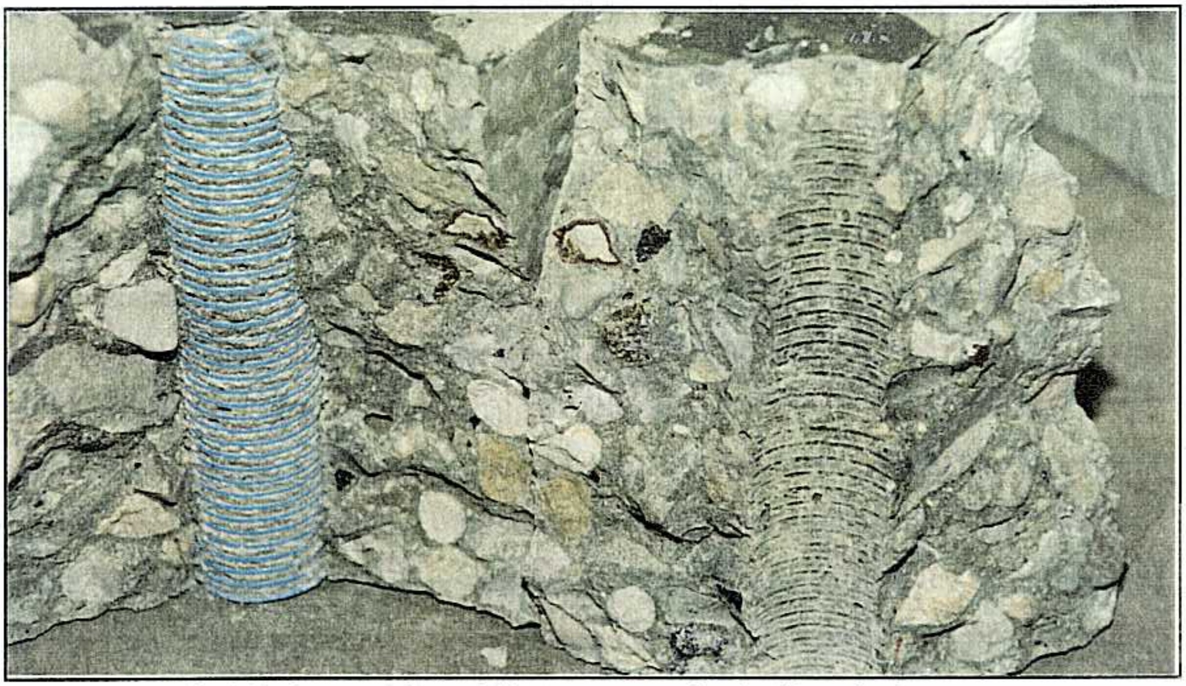

Figure 7, Typical Carlon specimen failure, note mechanical interlock.

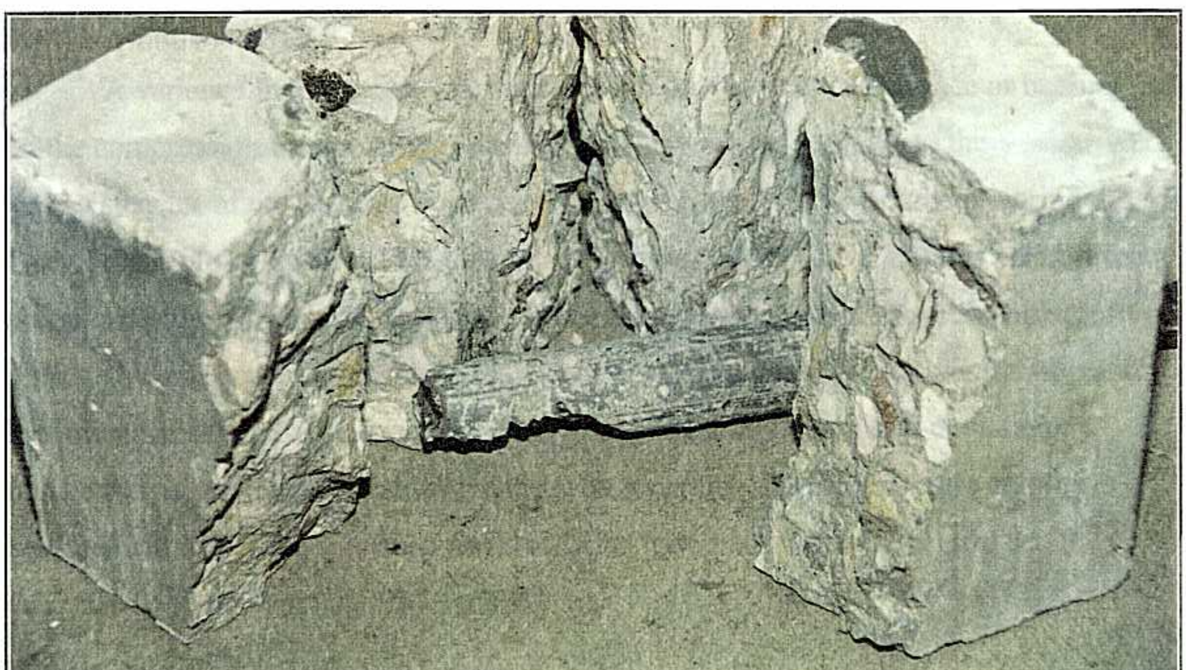

Figure 6, Typical failure of removed EMT sleeve specimen.

Discussion

Direct comparison of the bond strength from these tests is not representative of the application that this investigation is based on. This is due to the dramatically larger surface area of sleeves in comparison to the reinforcing bars. Bond strength testing is generally used for comparison of different concrete mixes or reinforcement bars. The total load is more representative of the assumed application. Both data sets are presented because, the bond strengths may be helpful in developing further tests to analyze the characteristics of reinforcement sleeves.

Manipulating the equation for development length, using l_d = 6" and f_c' = 8500psi and solving for $A_b f_y$, the expected strength of the control samples was 13829 lbs. The control set results are 136% of the expected strength. This reflects the safety factor built into the equation. Using a more common concrete strength of 4000psi the test results would be expected to 68.6% of the actual results based on the ratio of the same modified development length equation. A few of the samples actually reached the yield strength and the reinforcing began to fail plastically.

The highest strength specimens failed due to loss of confinement. It can be postulated that with confining reinforcement the failure loads would have been higher, perhaps significantly.

A variance in the results was the failure to provide a planar surface or bearing pad on the compression face of all the specimens. This problem was due to the inconsistencies of the cast specimen bearing surface. An effort was made to grind the face of the samples that would be in contact with the bearing plate, but this effort did not produce a truly planar surface. These surface imperfections would have the effect of creating stress concentrations that would cause premature crack initiation, fracture and loss of confinement of the concrete. This would increase the standard deviation and reduce the percentage of reliability in the samples which failed by fracture and confinement loss. The specimen sets that failed in fracture were the control set, the Carlon set and the removed EMT conduit set.

The control sample set results will have to be assumed to be reasonably consistent with the results of a more carefully prepared sample. More care should have been taken in final sample preparation to provide a planar compression surface.

The removed EMT conduit set was prepared so that the planar mold side was the compression face. Therefore the results of this set can be assumed to be accurate. This sample set proved to provide the greatest total load of all the specimens tested.

The removed PVC set was also prepared so that the planar mold side was the compression face. Therefore the results of this set can also be assumed to be accurate. This sample set provided the second greatest average total load of all the specimens tested.

Three of the Carlon samples were tested without grinding the compression surface. These samples were the highest and two lowest of the set. Without these samples the median increases by 250 lbs. or 1.5 %, the average increases by 539 lbs. or 3.3%, and the standard deviation decreases by 1262 lbs. or 45.7%. The reduction in the standard deviation is significant.

The PVC and EMT conduit sets each failed by slipping at a relatively low stress. These sets failed at the sleeve-concrete interface rather than by concrete fracture. Therefore the variance is not felt to be significant for these two sample sets.

It is plainly seen that greater care in sample preparation or the use of a specialty pad would have provided more reliable data and results.

The slip of the sleeves is not reported in the body of this report due to errors and difficulty in the measuring and recording. Because of the unexpected energy of the fracturing specimens several dial gauges were damaged. Without these gauges further readings were impossible. An alternative measuring system was used which varied from ASTM C 234-86, but the results were incomparable to the standard method. Therefore the slip results are included in the appendix but not the report body.

Conclusions

The results of the Carlon sample set show that a cast in place sleeve with some form of mechanical interlock can develop a significant portion of the control set strength. The results also clearly show that any smooth sleeve that is left in place will slip and pull out without developing a reasonable portion of a standard deformed bar's strength. The removed PVC and EMT sample groups show that the epoxy to concrete bond develops a dramatic percentage of a standard deformed bar's strength. Therefore the Carlon sleeve and the removed sleeves can be considered to be a reasonable alternatives to more expensive connection devices. However, further research will have to be done to verify these findings and determine the development length required for the Carlon sleeve. It can be assumed that the engineering data provided by manufacturers of drill and epoxy systems will have a close correlation to removed smooth sleeve applications of similar diameter.

A disadvantage with this sleeve-epoxy type of reinforcement placement is that the entire development length must be in a straight line. This would require that the footing or foundation must have depth sufficient to provide the entire required development length. The depth necessary could be significant for large diameter bars.

There are many available mechanical connection devices and inserts on the market which have proven to be acceptable in many situations. The drill and epoxy method has also proven to be a reliable technique. Holes that are carefully drilled and cleaned provide an acceptable surface for good epoxy adhesion. There are many manufacturers that can provide engineering data for their products and suggestions for a specific project or application.

References

Burg, R. G., and Ost, B. W., *Engineering Properties of Commercially Available High-Strength Concrete (Including Three-Year Data),* Research and Development Bulletin RD104, Portland Cement Association, Skokie, Illinois, USA, 1994

ACI Committee 318, *Building Code Requirements For Reinforced Concrete, ACI 318-89 (1992) and Commentary*, ACI 318-89 (1992), American Concrete Institute, Detroit, 1992

Carrato, P. J., Krauss, K. W. and Kim, J. B., *Tension Tests of Heavy-Duty Anchors with Embedments of 8 to 19 Inches* , ACI Structural Journal, May-June 1996, American Concrete Institute, Detroit, USA 1996

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Appendix

Concrete Strength

	Failure Load (lbs)
	8813
	9052
	9470
	9350
	10206
	9788
	8694
	8753
	6953
	7719
	8117
	6844
Average	8647
Median	8783
Std Dev	1015

#6 Bars (control)

											Average	Std Dev	Median
					Strength Cylinders		8694	8753	6953		8723.5	3595.304	8694
	Strain/ Slip .001 in												
Load (lbs)	A	B	C	D	E	F	G	H	I	J			
500	0	0									0		0
1000	0	0									0		0
1500	0	0									0		0
2000	0	0									0		0
2500	0	0									0		0
3000	0	0									0		0
4000	0	0	Damaged Dial Guages Prevented further Strain/ Slip readings.								0		0
5000	0	0									0		0
6000	0	0									0		0
7000	0	0									0		0
8000	0	0									0		0
9000	0	0									0		0
10000	1.5	0									0.00075		0.00075
11000	1.5	0									0.00075		0.00075
12000	2	0									0.001		0.001
13000	2.5	1									0.00175		0.00175
14000	3	1.5									0.00225		0.00225
15000	3.5	2									0.00275		0.00275
16000	3.5										0.0035		0.0035
17000	4										0.004		0.004
18000	4.5										0.0045		0.0045
19000	10										0.01		0.01
20000													0
Bond Strength	1357.85	1117.40	1082.04	1173.97	1195.19	1478.08	1131.54	1379.07	1163.37	1046.68	1329.56	145.74	1379.07
Failure Load	19200	15800	15300	16600	16900	20900	16000	19500	16450	14800	18800	2060.744	19500

PVC Sleeves

											Average	Std Dev	Median
					Strength Cylinders		9350	10206	9788		9778.059	4246.246	9788.006
	Strain/ Slip .001 in/in												
Loads (lbs)	A	B	C	D	E	F	G	H	I	J			
500	0	0	0	0	0	0	0	0	0	0	0		0
1000	0	0	0	0	0	0	0	0	0	0	0		0
1500	0	0.5	0.15	0	0	0	0.15	0.5	0.125	0	0.000143		6.3E-05
2000	0.125	0.5	10	0	0	0.15	15	10	5	0	0.004078		0.000325
2500	15	1		0.15	0	15				0	0.005192		0.000575
3000		15		15	0.5					0.5	0.00775		0.00775
4000					10					15	0.0125		0.0125
Bond Strength	80.39	116.56	60.29	108.52	128.62	80.39	60.29	64.31	76.37	124.60	90.03	25.56	80.39
Failure Load	2000	2900	1500	2700	3200	2000	1500	1600	1900	3100	2240	635.9245	2000

Strain/ Slip measured using alternate method

strain $= .001$ in/in $= \frac{\Delta}{L}$

$\Delta = .001(6)'' = .006''$

$\frac{\sigma}{\epsilon} = E = 29,000,000$ lb/in²

$\sigma = \epsilon E = .001(29,000,000)$

$\sigma = 29,000$ lb/in²

EMT Conduit

Strength Cylinders	8813	9052	9470	Average	Std Dev	Median
				8932.55	3952.429	9051.916

Loads (lbs)	Strain/ Slip .001 in /in A	B	C	D	E	F	G	H	I	J	Average	Std Dev	Median
500	0	0	0	0	0	0	0	0	0	0	0		0
1000	0	0	0	0	0	0	0	0	0	0	0		0
1500	0	0	0	0	0	0	0	0	0	0	0		0
2000	0	0	0	0	0	0	0	0	0	0	0		0
2500	0	0	0	0	0	0	0	0	0	0	0		0
3000	0	0	0	0	0	0	0	0	0	0	0		0
4000	0	0	0	0	0	0	0	0	0	0	0		0
5000	0	0	0	0	0	0	0	0	0	0	0		0
6000	0	0	0	0	0.5	0	0	0	0	0	5E-05		0
7000	0	0	0	0	3	0	0.5	0.0125	0	0	0.000351		0
8000	2	0	1	1	8	0	1	5	1	4	0.0023		0.001
9000	50	0	5	8	50	1	2	50	4	50	0.022		0.0065
10000		0.0125	50	50		50	50		50		0.041669		0.05
11000		50									0.05		0.05
Bond Strength	379.23	469.53	424.38	424.38	370.20	442.44	442.44	361.17	415.35	383.75	411.29	34.17	419.86
Failure Load	8400	10400	9400	9400	8200	9800	9800	8000	9200	8500	9110	756.9016	9300

Strain/ Slip measured using alternate method

Carlon Conduit

											Average	Std Dev	Median
					Strength Cylinders		7719	8117	6844		7917.94	3305.751	7718.997
	Strain/ Slip .001 in/in												
Loads (lbs)	A	B	C	D	E	F	G	H	I	J			
500	0	0	0	0	0	0	0	0	0	0	0		0
1000	0	0	0	0	0	0	0	0	0	0	0		0
1500	0	0	0	0	0	0	0	0	0	0	0		0
2000	0	0	0	0	0	0	0	0	0	0	0		0
2500	0	0	0	0	0.5	0	0	0	0	0	5E-05		0
3000	0	0	0	0	0.5	0	0	0	0	0	5E-05		0
4000	0	0	0	0	1	0	0	0.1	0	0	0.00011		0
5000	0	0	1	0	1.1	0	0	0.1	0	0	0.00022		0
6000	0	0	1	1	1.5	0.1	0.1	0.5	0	0	0.00042		0.0001
7000	0	0	1	1	2	0.5	0.3	0.5	0	0	0.00053		0.0004
8000	0	0	1	1	2	0.9	0.3	0.5	0.5	0	0.00062		0.0005
9000	0	0	1	1	2	0.9	0.3	1	0.5	0	0.00067		0.0007
10000	1	0	1	1	4	0.9	0.9	1	1	0.5	0.00113		0.001
11000	5	0	2	1.1	4.9	1	0.9	1	1	0.5	0.00174		0.001
12000		0	2	1.5	5.5	1.1	1	1.1	1.5	1	0.001633		0.0011
13000		1		1.7	6	1.5	1.3	1.5	2	1	0.002		0.0015
14000		1.5		2	8	2	1.7	1.5	2.5	1.1	0.002538		0.00185
15000		2		2		2.1	2		3	1.5	0.0021		0.002
16000		2		2.1		2.1	2		4	2	0.002367		0.00205
17000		2				2.5	3			3.5	0.00275		0.00275
18000		2				3	3.7				0.0029		0.003
19000		2									0.002		0.002
20000		3									0.003		0.003
21000													
Bond Strength	468.30	864.07	522.17	696.23	596.77	758.39	766.68	617.49	675.51	737.67	670.33	114.36	685.87
Failure Load	11300	20850	12600	16800	14400	18300	18500	14900	16300	17800	16175	2759.461	16550

Note: Strain/ Slip measured using alternate method
Samples A, B & C tested without grinding compression face smooth

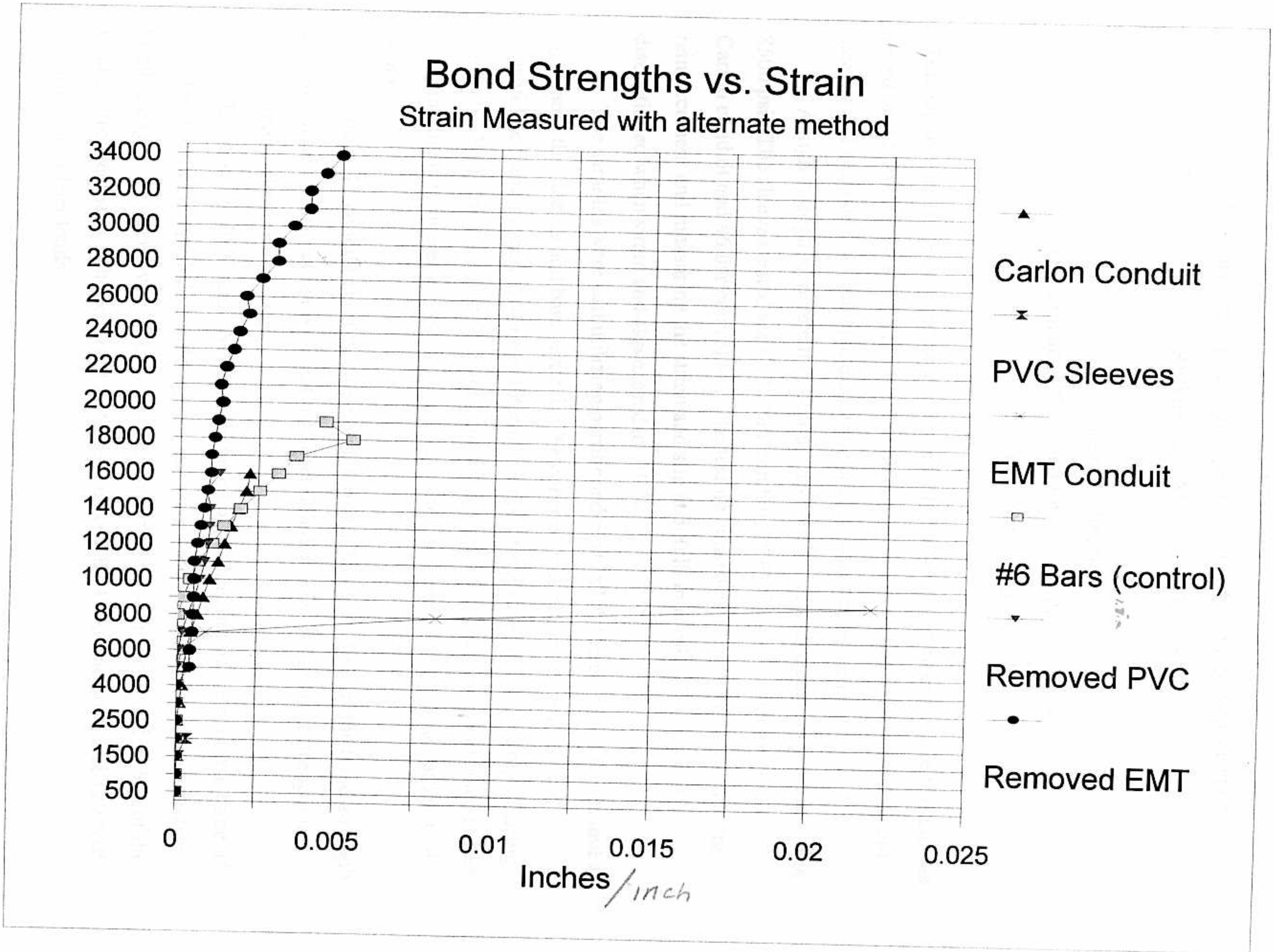
Removed EMT

						Average	Std Dev	Median
Strength Cylinders		8813	9052	9470		9111.599	271.3224	9051.916

	Strain/ Slip .001 in/in						
Load	A	B	C				
500	0	0	0		0		0
1000	0	0	0		0		0
1500	0	0	0		0		0
2000	0	0	0		0		0
2500	0	0	0		0		0
3000	0	0	0		0		0
4000	0	0	0		0		0
5000	0	0.4	0.4		0.000267		0.0004
6000	0.1	0.4	0.4		0.0003		0.0004
7000	0.5	0.45	0.45		0.000467		0.00045
8000	0.5	0.47	0.47		0.00048		0.00047
9000	0.5	0.5	0.5		0.0005		0.0005
10000	0.7	0.5	0.5		0.000567		0.0005
11000	0.9	0.5	0.5		0.000633		0.0005
12000	1	0.6	0.6		0.000733		0.0006
13000	1	0.7	0.7		0.0008		0.0007
14000	1	0.8	0.8		0.000867		0.0008
15000	1	0.9	0.9		0.000933		0.0009
16000	1	1	1		0.001		0.001
17000	1.1	1	1		0.001033		0.001
18000	1.1	1.1	1.1		0.0011		0.0011
19000	1.1	1.2	1.2		0.001167		0.0012
20000	1.1	1.3	1.3		0.001233		0.0013
21000	1.1	1.4			0.00125		0.00125
22000	1.3	1.5			0.0014		0.0014
23000	1.5	1.8			0.00165		0.00165
24000	1.6	2			0.0018		0.0018
25000	1.6	2.6			0.0021		0.0021
26000	2				0.002		0.002
27000	2.5				0.0025		0.0025
28000	3				0.003		0.003
29000	3				0.003		0.003
30000	3.5				0.0035		0.0035
31000	4				0.004		0.004
32000	4				0.004		0.004
33000	4.5				0.0045		0.0045
34000	5				0.005		0.005
Bond Strength	1235.21	1128.67	920.99		1094.96	130.48	1128.67
Failure Load	27360	25000	20400		24253.33	2890.044	25000

Removed PVC

					Average	Std Dev	Median
Strength Cylinders		9350	10206	9788	9778.059	349.2699	9788.006
	Strain/ Slip .001 in						
Load (lbs)	A	B	C				
500	0	0	0				
1000	0	0	0		0		0
1500	0	0	0		0		0
2000	0	0	0		0		0
2500	0	0	0		0		0
3000	0	0	1		0		0
4000	0	0	1		0.0002		0
5000	0	0	1		0.0002		0
6000	0.1	0	1		0.0002		0
7000	0.1	0.09	1		0.00022		2E-07
8000	0.5	0.35	1.1		0.000238		9E-05
9000	0.9	0.5	1.4		0.00039		0.00035
10000	1	0.7	1.7		0.00056		0.0005
11000	1	0.9	1.9		0.00068		0.0007
12000	1	0.9	2		0.00076		0.0009
13000	1.1	1	2		0.00078		0.0009
14000	1.5	1	2.1		0.00082		0.001
15000	45	1	6		0.00092		0.001
16000		1.1	20		0.0104		0.001
17000		1.5			0.005278		0.000555
18000		1.7			0.000502		5.3E-06
19000		1.9			0.000567		5E-07
20000		2			0.000634		5.7E-07
21000		2			0.000667		6.3E-07
22000		2.1			0.000667		6.7E-07
23000		2.5			0.0007		6.7E-07
24000		5			0.000834		7E-07
25000		50			0.001667		8.3E-07
26000							
Bond Strength	594.86	980.71	643.09		739.55	171.66	643.09
Failure Load	14800	24400	16000		18400	4270.831	16000



Bond Strengths vs. Strain
Strain Measured with alternate method
34000
32000
30000
28000
26000
24000
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2500
1500
500
0
0.005
0.01
0.015
0.02
0.025
Inches/inch
Carlon Conduit
PVC Sleeves
EMT Conduit
#6 Bars (control)
Removed PVC
Removed EMT