Report

EXPERIMENTAL INVESTIGATION OF PIPE-PILE SPLICES FOR 30" HOLLOW CORE PRESTRESSED CONCRETE PILES

by

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1. General

Prestressed concrete piles are common structural components in bridge foundations. Depending upon soil conditions and pile loads, piles may extend for great depths below the ground surface. Deep pile foundations require the installation of either single, long pile units or several shorter pile sections spliced together. Using continuous single pile members eliminates the need to perform field splicing. However, if piles are too long they may be difficult to transport or drive. To avoid such difficulties, spliced pile sections are often used. In addition, pile splicing may be attractive when the- required pile lengths for a particular job are uncertain due to changing soil conditions, thus, the actual installed pile lengths are potentially uncertain throughout the construction.

At the present time, national design guidelines for prestressed concrete pile splices do not exist. However, it is generally accepted that an ideal spliced pile should be of equal or better strength and performance than that of an equivalent unspliced pile. Several splice details (both patented and non-patented) have been proposed for prestressed concrete piles. While literature is available on research performed in the 1970's and 1980's on the subject, limited research has been performed with respect to the performance of such splices. There are obvious advantages to a cost and time efficient splicing technique. These advantages may include reduced construction time, equipment, labor and materials. Yet adequate structural strength and safety are even more important than time and money.

The Florida Department of Transportation uses a standard splice detailed for square prestressed concrete piles. This splice detail consists of steel dowels and epoxy mortar. The length of the dowels varies depending upon whether the piles will be driven or not. The size and number of dowels depends on the crosssectional area of the piles. The FDOT has used this dowel splice detail since the early 1980's. In the mid-1980's, FDOT engineers improved the Department's pilestandard. However, the true strength and performance of the splice are still questionable. In the past, the FHWA sponsored a Pile Demonstration Project, and producing a publication providing a table (Table 20-1) that shows a summary of splices for precast concrete piles. This table is the same one presented by Bruce and Hebert (1974).

In this research project, the performance of a steel pipe-pile splice for prestressed piles under various load conditions (both laboratory and field-testing) will be investigated. The investigation will include bending, shear and driving load tests.

A commonly available steel pipe, fixed on place with non-shrink construction grout are used in connecting two pile sections to form the splice, as proposed by Mr. Henry Bollmanni of the Structures Design Office. A similar splice is used successfully in Norway (Gerwick, 1971), as well as another similar splice used in Orlando, Florida (PCI, Jan-Feb. 1974). Based on the results of the proposed investigation, recommendations for the design and construction details for the steel pipe-pile splice will be developed. This report presents a summary of the results for the steel pipe-pile splice project.

2. Objectives of Study

The overall objectives of this study are as follows:

- Investigate existing/current pile splices
- Test steel pipe-prestressed concrete pile splicing systems
- Evaluate the installation of different pile splices
- Develop recommendations for the FDOT tested pipe-pile splice detail

3. Present Engineers

The engineers and staff of the Florida DOT/Structures Research Center conducted the pile-splice tests in the presence of Florida DOT/Structures Design Office Engineers: Mr. Jerry Potter, Mr. Henry Bollmann, Mr. Robert Robertson, Mr. Paul Passe, Dr. Joe Bhuvasorakul, Mr. Nasser Ziyuni, and Mr. Ned Kawar. Also, Mr. John Grant of the Florida DOT/State Roadway Design and Mr. Doug Edwards of the FHWA witnessed the pile-splice test.

4. Pile Flexure Test (Control Pile)

A 30 x 30 inch prestressed hollow-core pile was tested in flexure. The purpose of this test was to provide a control for future comparison with pile splice test specimens. Appendix A shows the test setup and the typical experimental results.

5. 30" Prestressed Concrete Piles

The pile specimens came from the FDOT SR20 project in Blountstown, Florida. The segments provided were cut-offs from the driven piles. Some pile segments already had micro/minor hairline cracks prior to testing. Some deformity in the 18" hollow core was also visible in some pile segments.

6. Bond Stress Test

The purpose of this test was to determine the splice length necessary to develop the desired moment capacity. The splice had to belong enough so that the bond stress at the splice to pile interface would be sufficient to develop the structural capacity of the section. Appendix B shows the test setup and the typical experimental results.

The ultimate axial load (slip/failure load) applied to the test specimen was 187 kips. The calculation of the average bond stress was based on a load of 176 kips. For this load (176 kips), the average bond stress at the 18" pile-to-grout interface was 310 psi. The average bond stress at the 14" steel pipe-to-grout interface was 400 psi.

7. Steel Pipe-Pile Splice Fabrication

The step-by-step procedure for the fabrication of the steel pipe-pile splice is presented in Appendix C. These pictures show and explain the entire installation and fabrication procedure.

8. Pile Splice Test No. 1

Once installed, the spliced pile was set up for testing with a clear span of 22 feet. Hydraulic jacks were placed 2.5 feet from either side of the splice. This load configuration is used as it creates a region of constant moment in the spliced region. Appendix D shows the test setup and some typical experimental results as well as the mode of failure.

During the test, an unexpected event occurred. The pile began to crack horizontally (in the direction of the span) at approximately 30 kips. That is, rather than developing flexural cracks that originate at the bottom of the member and propagate vertically, the pile :developed- horizontal cracks that originated from the centerline of the splice, indicative of initial micro splitting cracks at pile mid-depth.

This continued until the splice yielded the pile spiral reinforcement. The spiral reinforcement on the south end yielded and the splice split out the bottom of the pile from the joint to the end of the splice member.

The failure of the confinement steel occurred at a moment capacity of 580.5 k-ft. The calculated nominal capacity of the unspliced pile section was 1000 k-ft., therefore this splice developed 58.1 % of the nominal moment capacity of the pile.

9. Pile Splice Test No. 2

The spliced pile was set up for testing with a clear span of 30 feet. Hydraulic jacks were placed 5 feet from either side of the splice. This load configuration is used as it creates a region of constant moment in the spliced region. Appendix E shows the test setup and some typical experimental results as well as the mode of failure. The ultimate test moment capacity observed in the test was 840 k-ft. The calculated nominal capacity of the unspliced pile section was, again 1000 k-ft, and therefore this splice developed 84% of the nominal moment capacity of the pile. The calculated nominal capacity of the spliced pile section was 913.9 k-ft (see appendix F). The pile splice - developed 92% of the calculated spliced moment capacity.

10. Nominal Moment Capacities

The nominal moment capacities for the spliced and unspliced sections of the 30" square hollow core prestressed concrete piles are presented in Appendix F.

11. Conclusions and recommendations

The following conclusions can be drawn from this study:

- The calculated nominal moments of the pile sections match the test moments. (control pile)

- Splice number one developed 58.1%' of the nominal moment capacity of the pile section. The lower moment capacity of this splice is due to the initial splitting micro cracks during the field pile driving.

- Splice number two developed 84.0% of the nominal moment capacity of the pile and 92% of the calculated splice moment capacity.

- The experimental average bond stresses of 310 and 400 psi are much higher than the assumed value of 250 psi by the ACI Code.

- The steel pipe-pile splice moment capacity is 27% higher than the current standard cement-dowel splice.

- This type of splice and detail can be used for testing the moment connection of the 30" prestressed concrete pipe-pipe to pile cap for vessel collision.

- The pipe-pile splice will produce consistent results during construction. Where is the dowel splice currently used by the department may not produce consistent results.

Below are the following recommendations that can be drawn from this research project:

- The steel .pipe-pile splice can be used for splicing hollow core prestressed concrete piles. Figure 1 shows the details of the splice. (splice number 2 is recommended).

- Use 12 foot long, 14" diameter steel pipe with minimum yield strength of 42 ksi.

- The top segment of the pile splice can be prefabricated with the steel pipe and then inserted on the existing driven pile to form the splice.

- Field epoxy grout can be used instead of non-shrink grout to optimize the installation time. (see Ref. 8)

- Use the splice detail and the bond stress results for testing the moment connection of the 30" prestressed concrete pipe-pile to pile cap for vessel collision. (Phase II - Research in progress)

- Monitor the behavior and the splice integrity while the piles are driven in the field. (use two specimens)

12. Acknowledgments

This project was made possible by the support and cooperation of many individuals. The following members assisted in this project: M. Shahawy, T. Beitelman, A. El-Saad, F. Cobb, A. Fishburn, G. Johnston, H. Bollmann, S. Cai, S. Hurston, T. Brown, B. Hubbard, B. Wallace and S. Beddy. The author thanks them all.

13. References

1. ACI Committee 543. "Recommendations for Design, Manufacture, and Installation of Concrete Piles", ACI 543R-74, ACI Manual of Concrete Practice 1981, Part 4, ACI, Detroit, 1981, pp. 543R-1 to 543R-39.

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10. FDOT Construction Office. Special Provisions to the Standard Specifications-A4550512, Concrete Piling - Extensions and Buildups, Subarticle 455-5.12, pp. 1-50.

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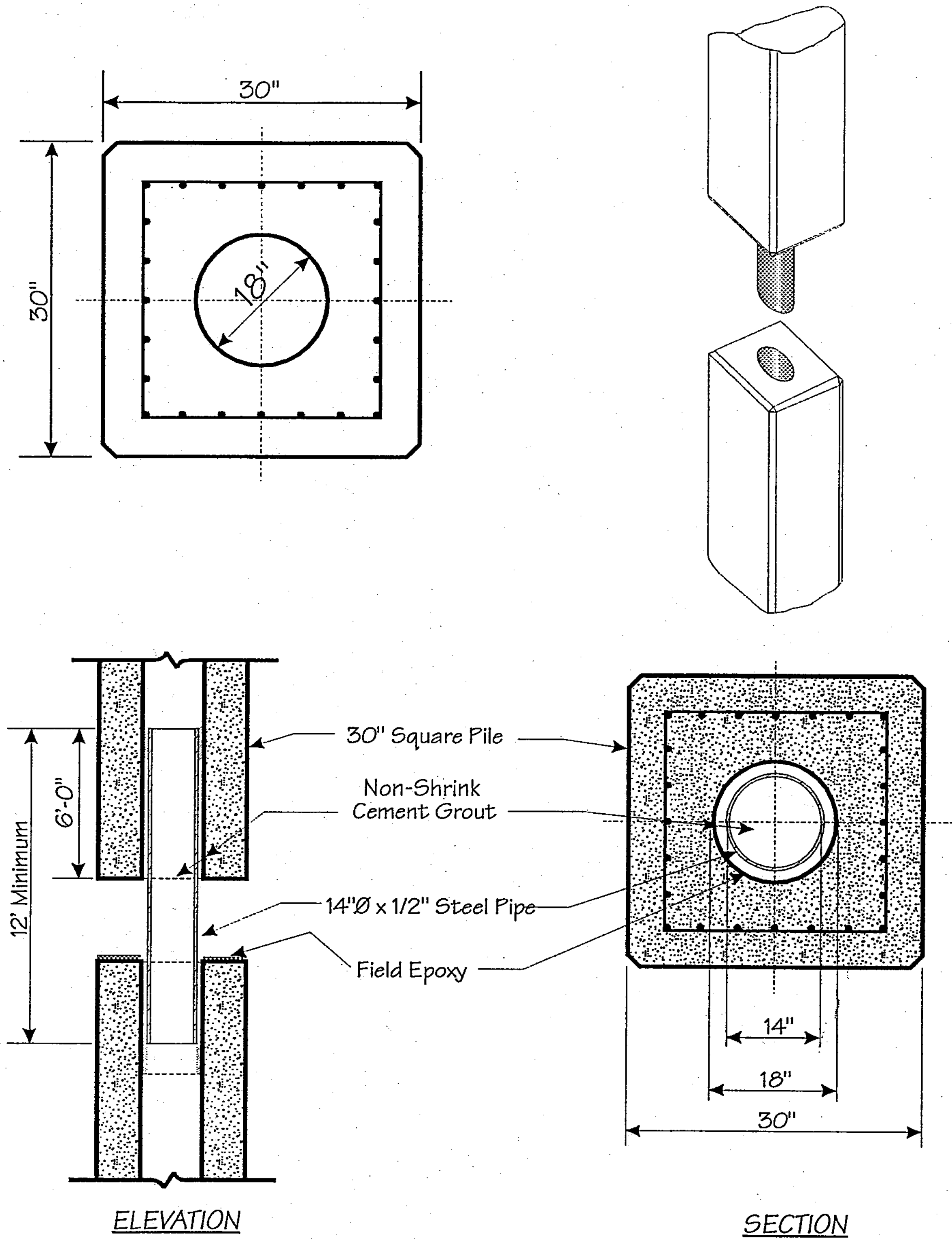
12. FDOT Structures Design Office - District IV. Plan Sheet AB-5, Roosevelt Bridge - 30" Prestressed Special Concrete Pile Detail, Project number 89010-3541/3548, July 1993.

TABLE 20-1 SUMMARY OF PRECAST CONCRETE PILE SPLICES*

Name of Splice	Type	Origin	Approximate Size Range, in.	Approximate Field Time, min.	Strength		
					Percent Compressive	Percent Tensile	Percent Flexural Cracking
Marier	Mechanical	Canada	10-13	30	100	100	100
Herkules	Mechanical	Sweden	10-20	20	100	100	100
ABB	Mechanical	Sweden	10-12	20	100	100	100
NCS	Welded	Japan	12-47	60	100	100	100
Tokyu	Welded	Japan	12-47	60	100	100	100
Raymond Cylinder	Welded	USA	36-54	90	100	100	100
Bolognesi-Moretto	Welded	Argentina	Varied	60	100	55	100
Japanese Bolted	Bolted	Japan	Varied	30	100	90	90
Brunsplice	Connector ring	USA	12-14	20	100	20	50
Anderson	Sleeve	USA	Varied	20	100	0	100
Fuentes	Welded Sleeve	Puerto Rico	10-12	30	100	100	100
Hamilton Form	Sleeve	Usa	Varied	90	100	75	100
Cement Dowel	Dowel	USA	Varied	45	100	40	65
Macalloy	Post-Tensioned	England	Varied	120	100	100	100
Mouton	Combination	USA	10-14	20	100	40	100
Raymond Wedge	Welded Wedge	USA	Varied	40	100	100	100
Pile Coupler	Connector ring	USA	12-54	20	100	100	100
Nilsson	Mechanical`	Sweden	Varied	20	100	100	100
Wennstrom	Wedge	Sweden	Varied	20	100	100	100
Pogonowski	Mechanical	USA	Varied	20	100	100	100

* After Bruce and Hebert, 1974



30" X 30" VOIDED PRESTRESSED PRECAST SPLICES
TYPICAL PIPE-PILE SPLICE DETAIL

Figure 1

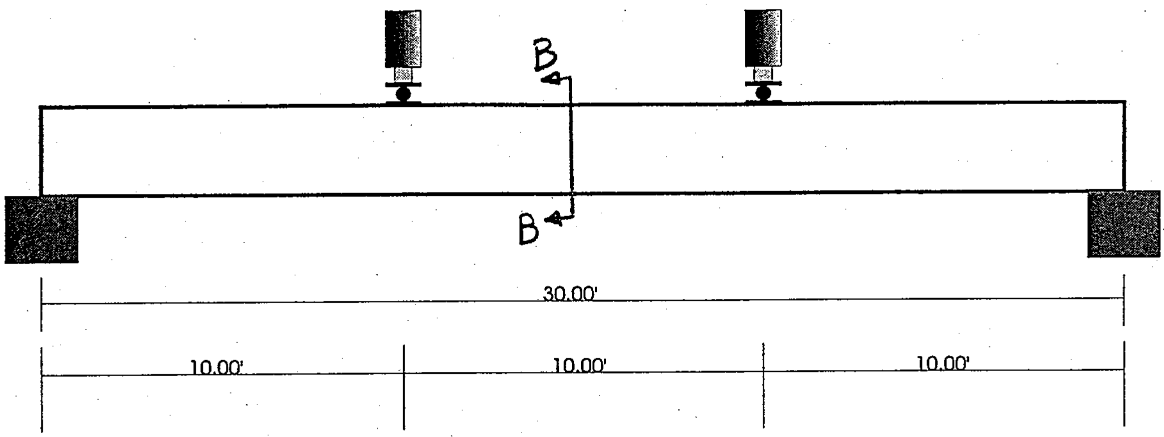
Appendix A

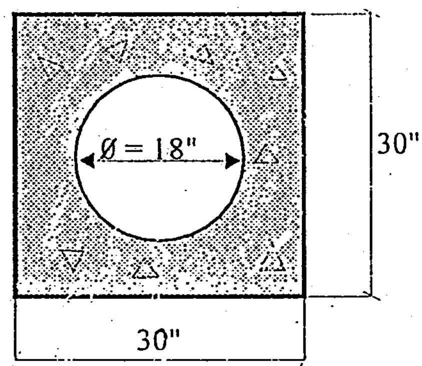
Pile Flexure Test

Span Length = 30'

Control Pile - No Splice

Pile Flexure Test Setup
Span Length = 30'
Control Pile – No Splice



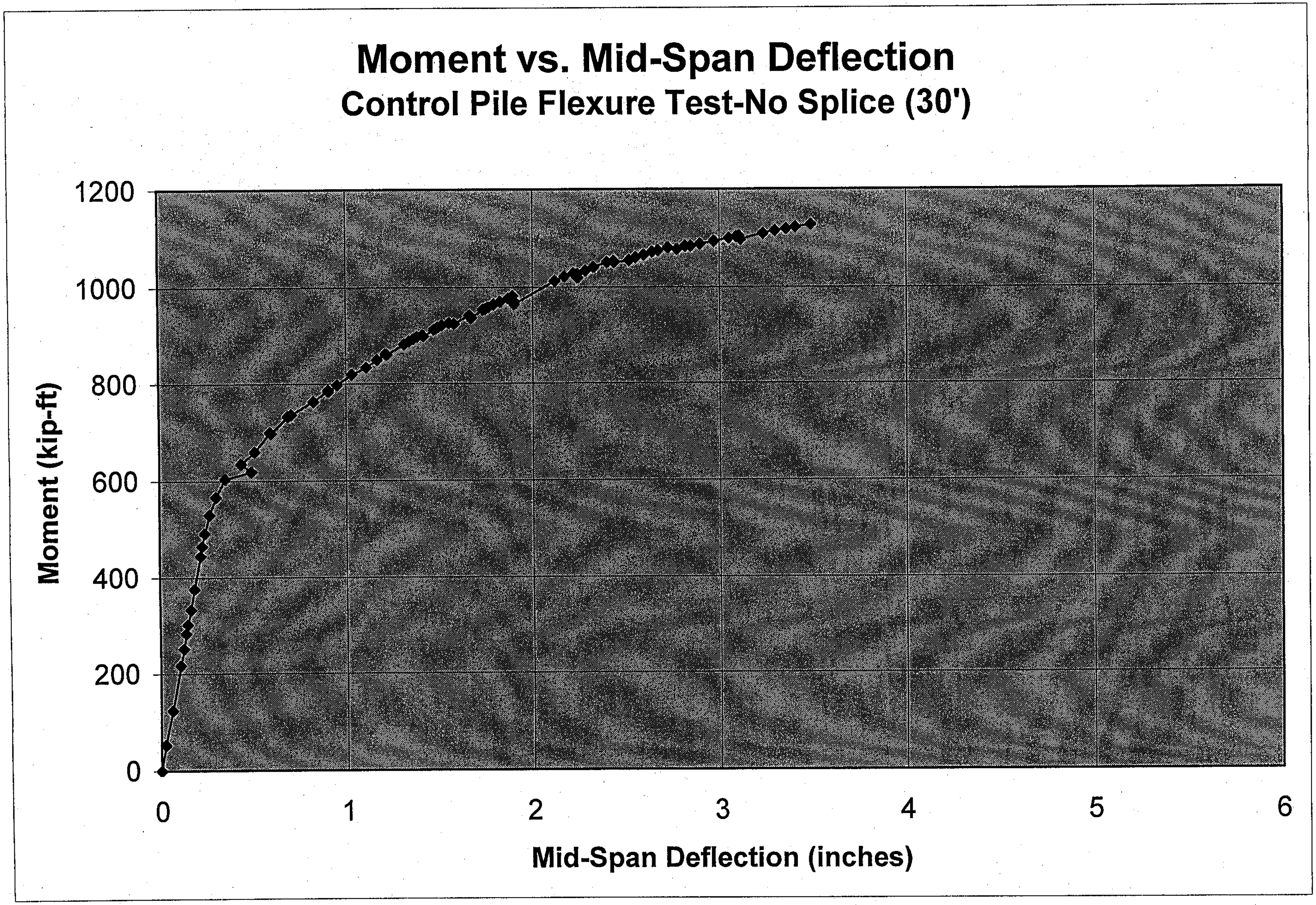


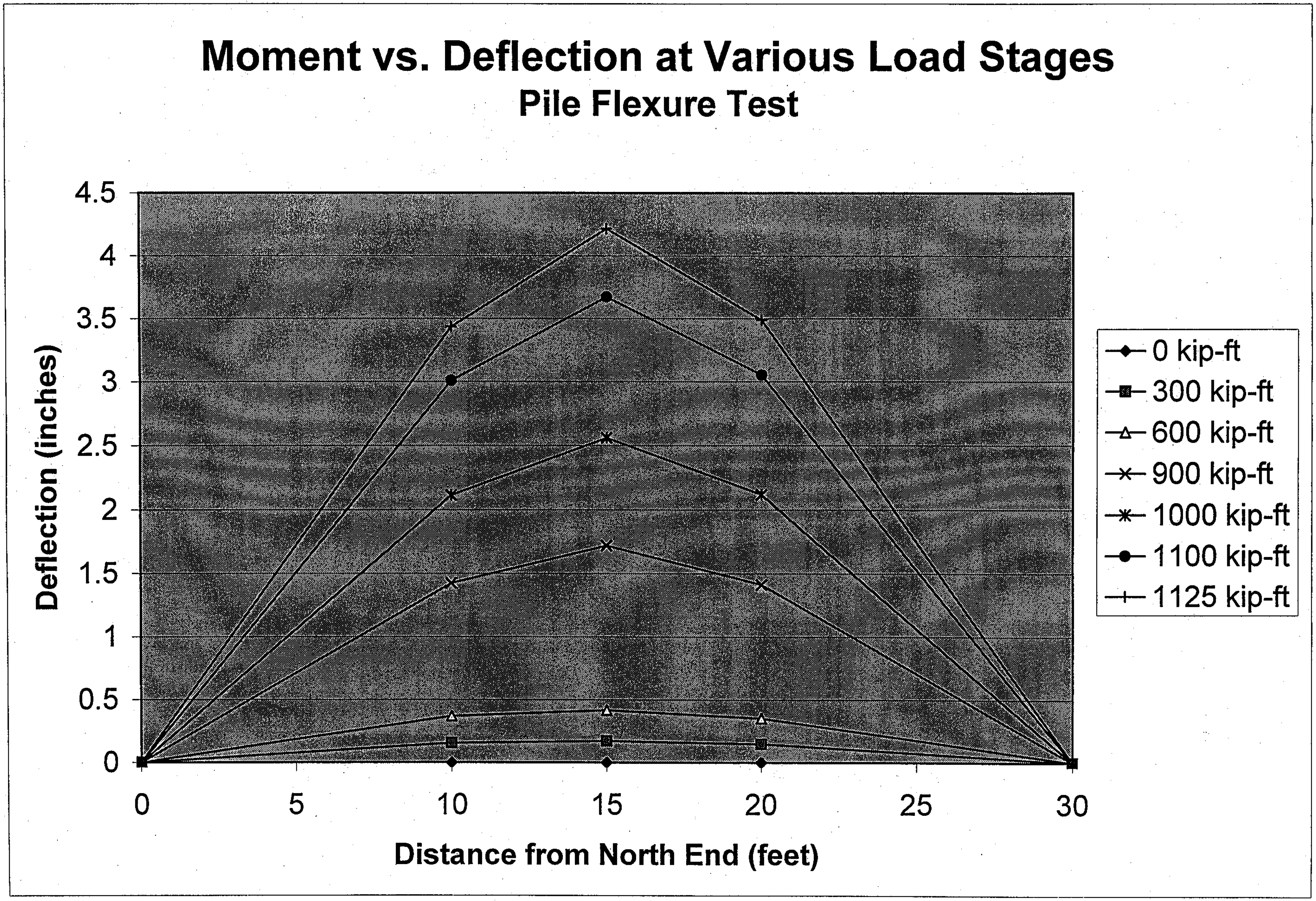
SECTION B

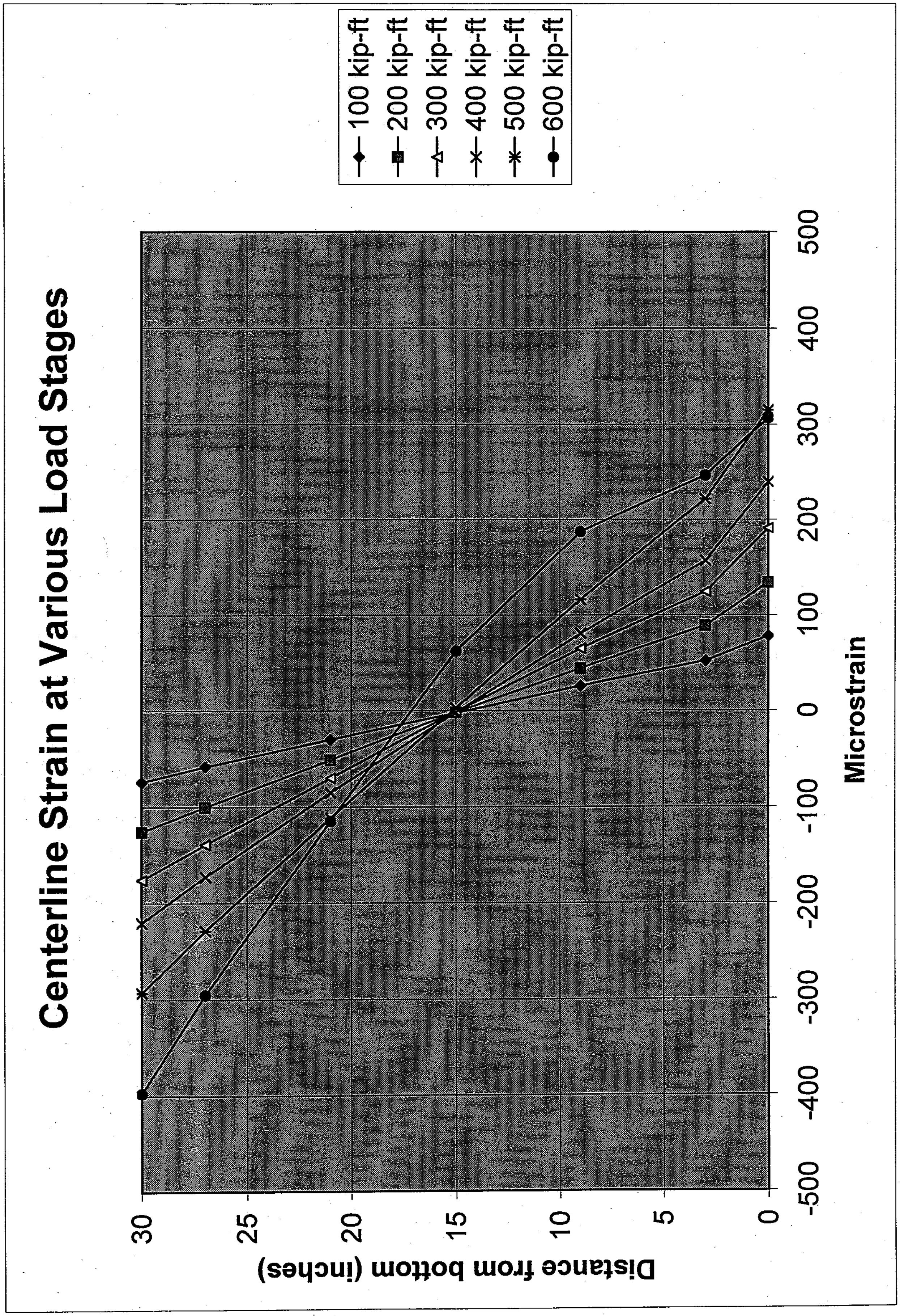
Cracking Moment = 580 K-ft.

Ultimate Test Moment = 1,126.00 K-ft.

Maximum Deflection at Mid-Span = 4.33 in.


Moment vs. Mid-Span Deflection
Control Pile Flexure Test-No Splice (30')
Moment (kip-ft)
0
200
400
600
800
1000
1200
0
1
2
3
4
5
6
Mid-Span Deflection (inches)


Moment vs. Deflection at Various Load Stages
Pile Flexure Test
Deflection (inches)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
5
10
15
20
25
30
Distance from North End (feet)
0 kip-ft
300 kip-ft
600 kip-ft
900 kip-ft
1000 kip-ft
1100 kip-ft
1125 kip-ft

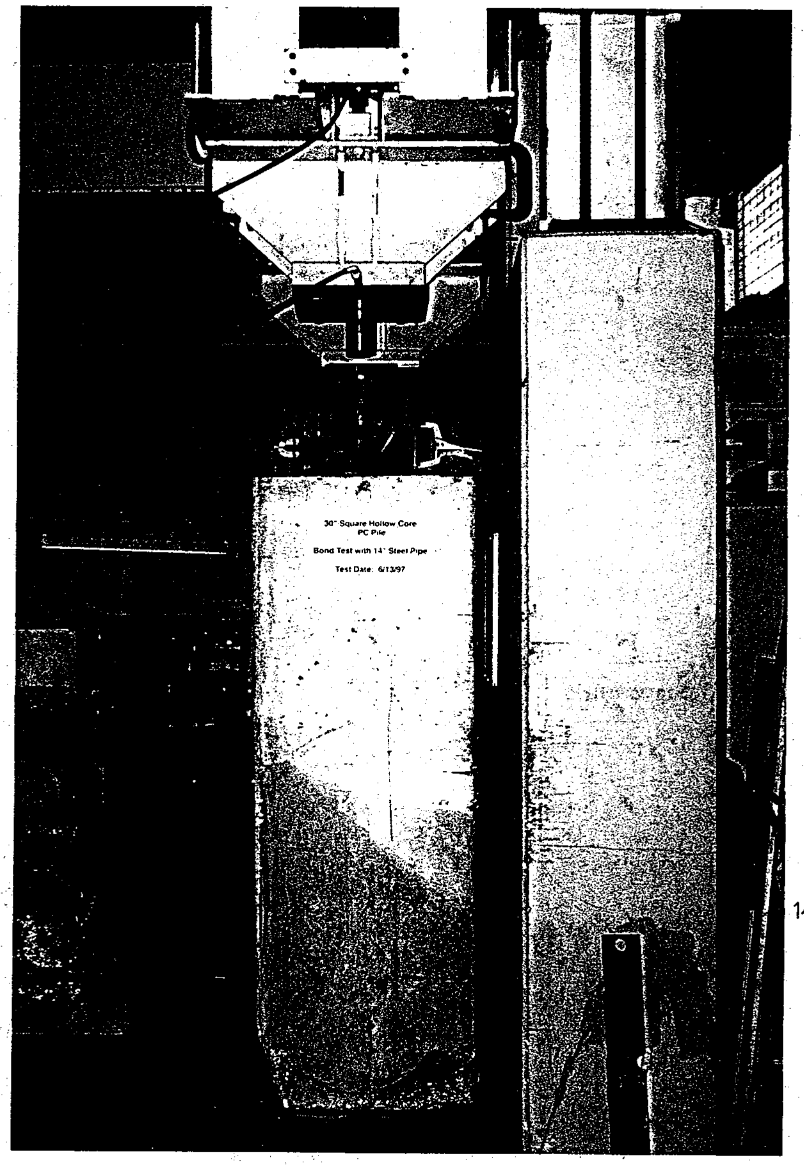


Centerline Strain at Various Load Stages
Distance from bottom (inches)
Microstrain
100 kip-ft
200 kip-ft
300 kip-ft
400 kip-ft
500 kip-ft
600 kip-ft

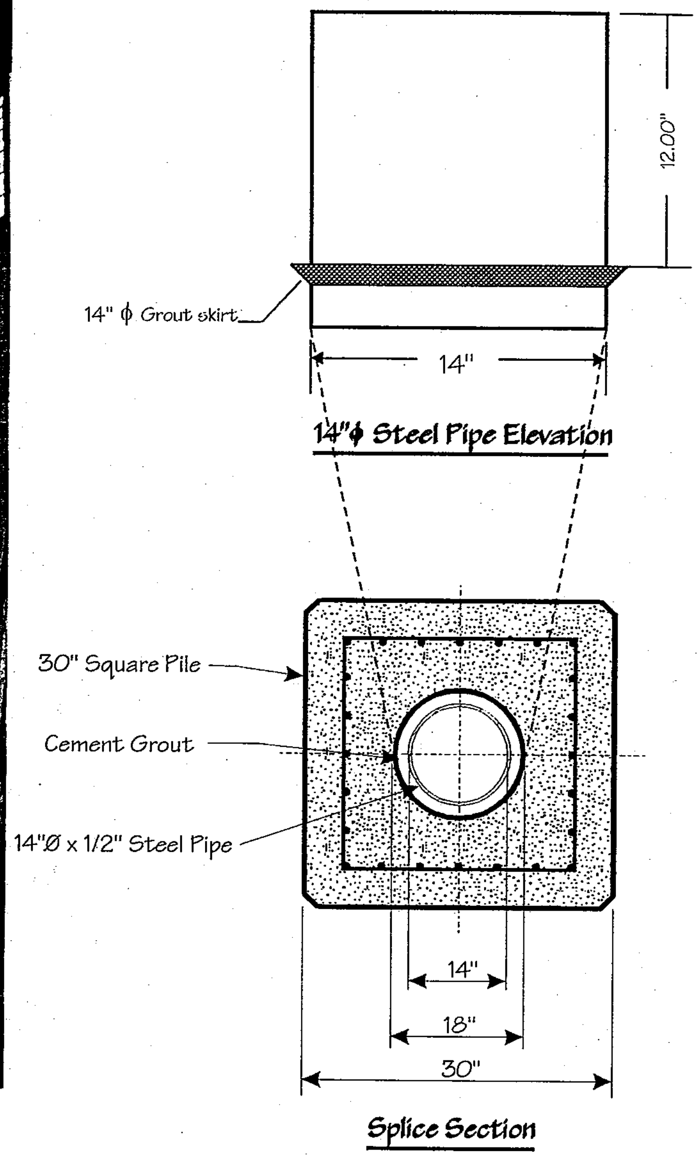
Appendix B

Bond Stress Test

Steel Pipe-Pile Splice

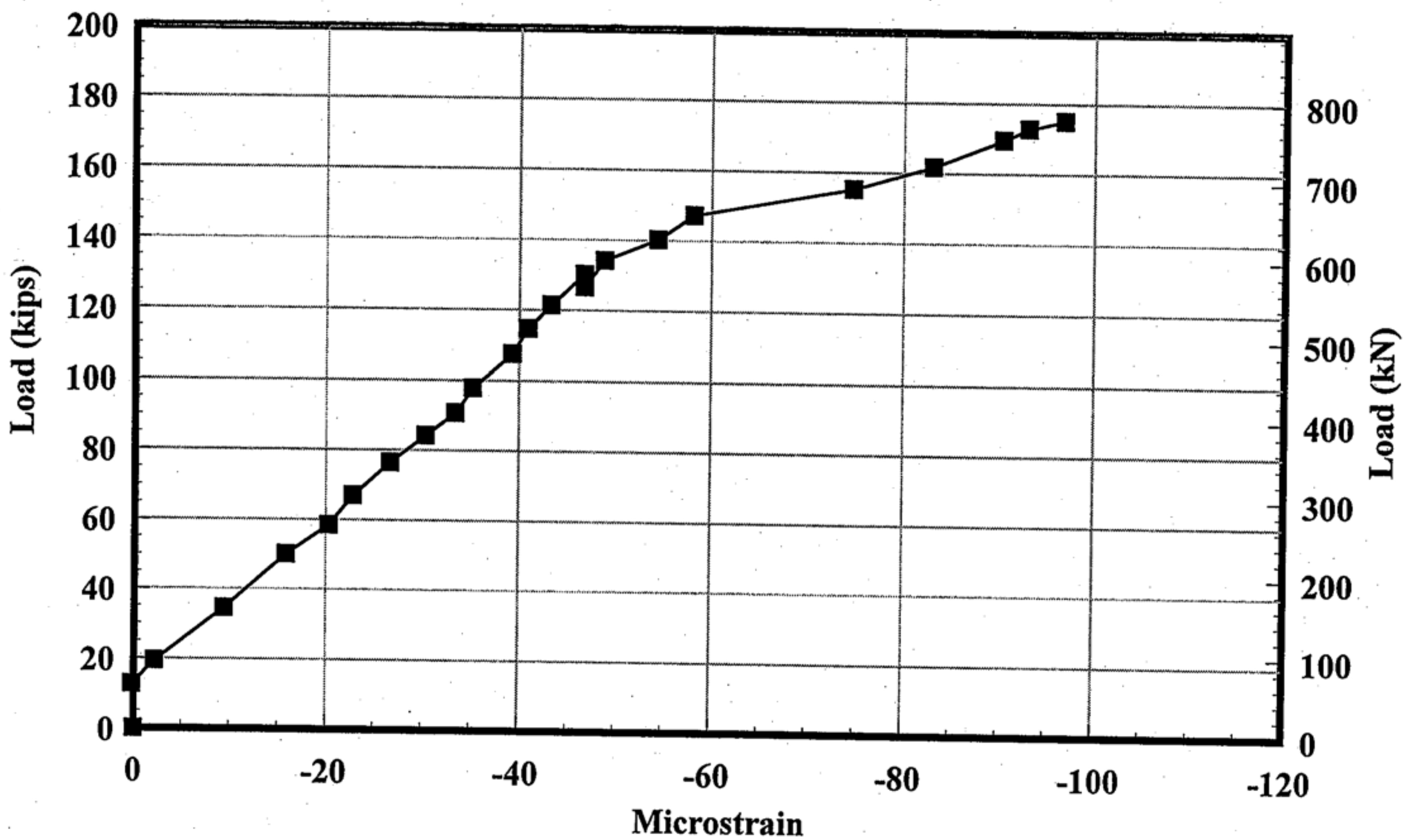


Test Setup

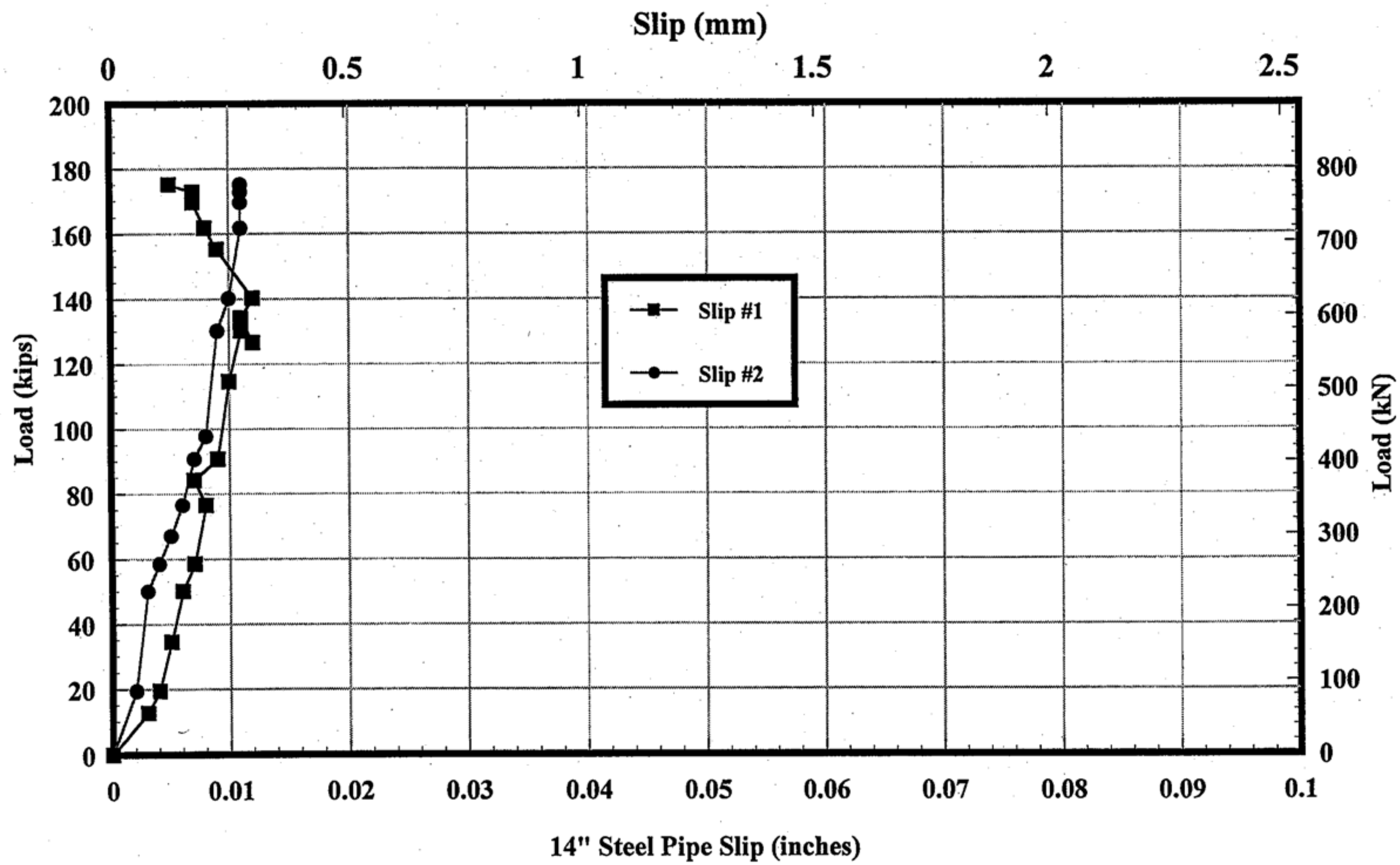


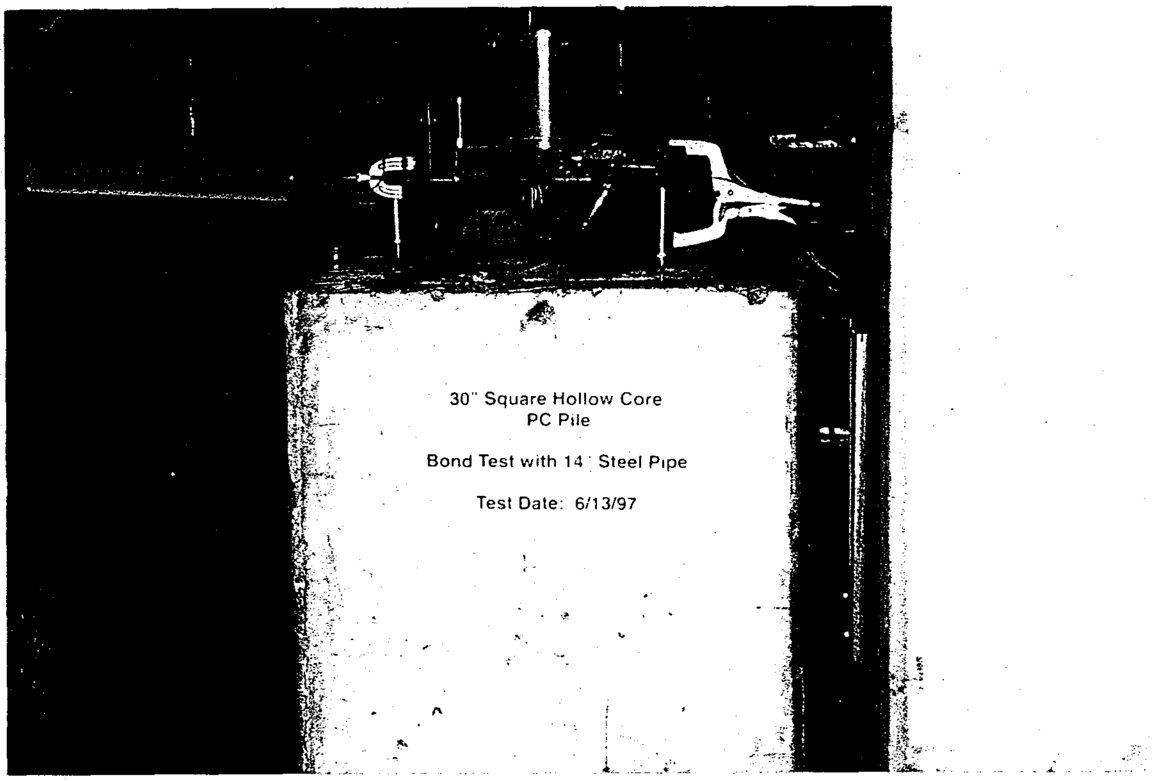
Test Setup and Pipe-Pile Splice Details

Bond Stress Test
Load vs. Average Strain

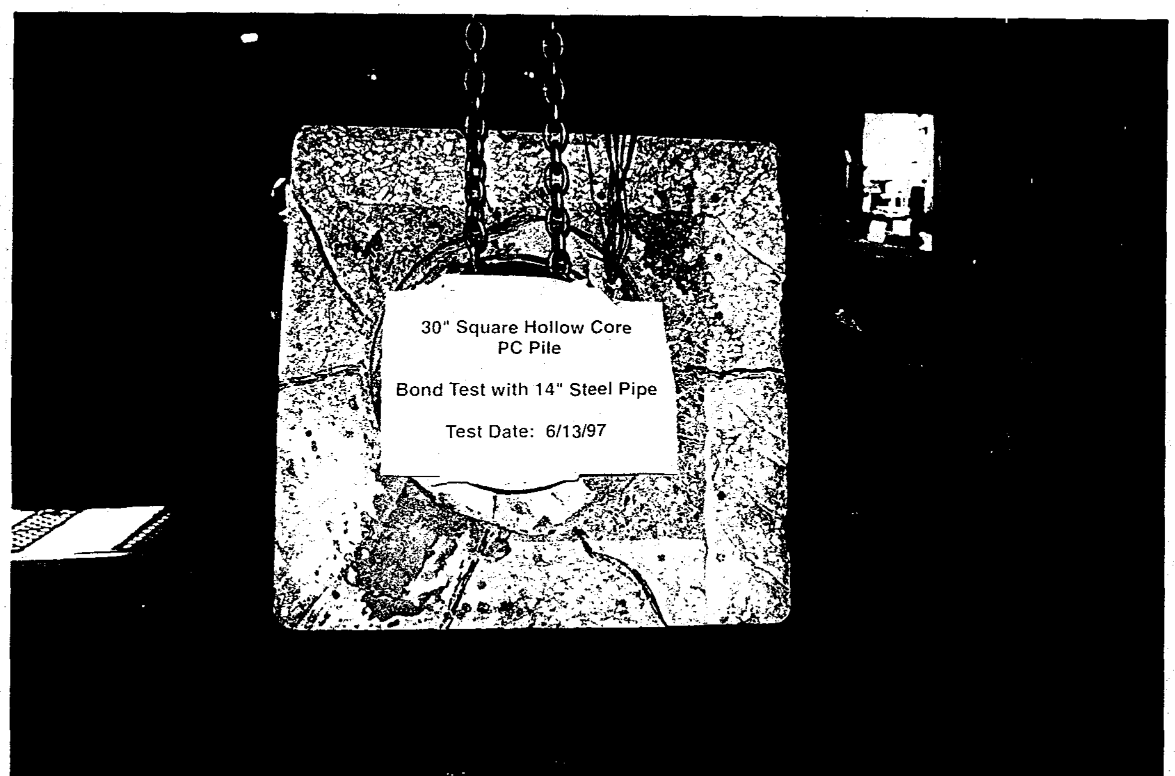


Bond Stress Test
Load Vs. 14" Steel Pipe Slip





Test Setup and Instrumentation

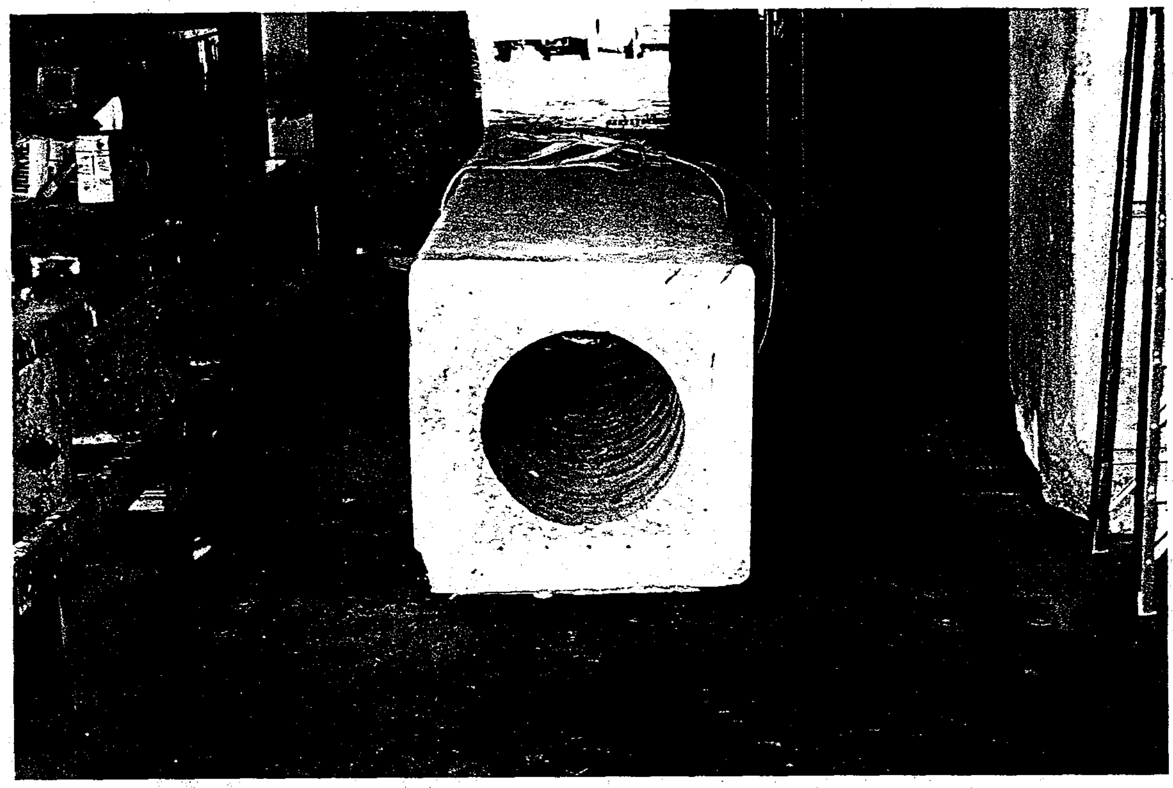


Mode of Failure

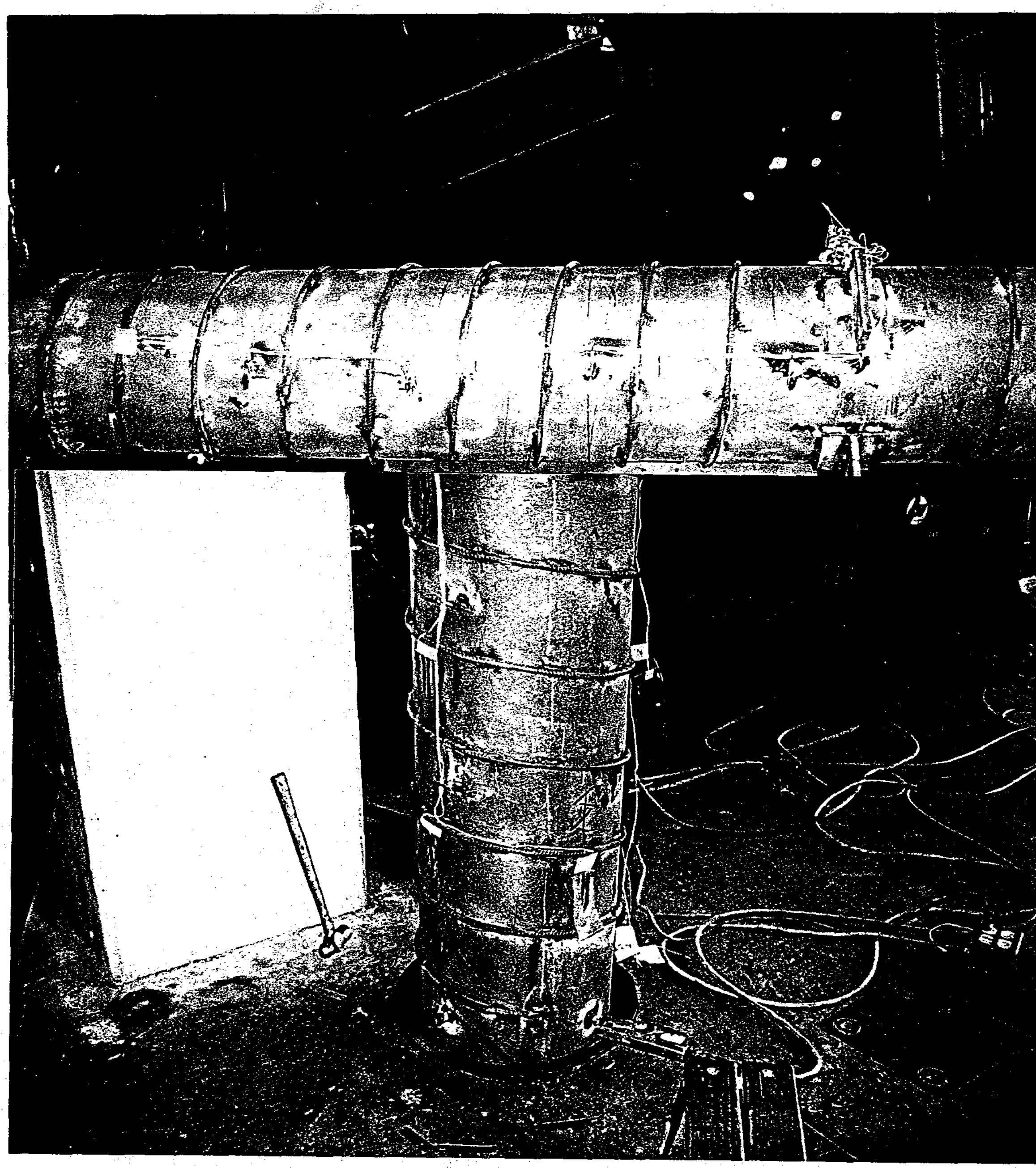
Appendix C

Steel Pipe Pile Splice

Step by Step Fabrication Procedure

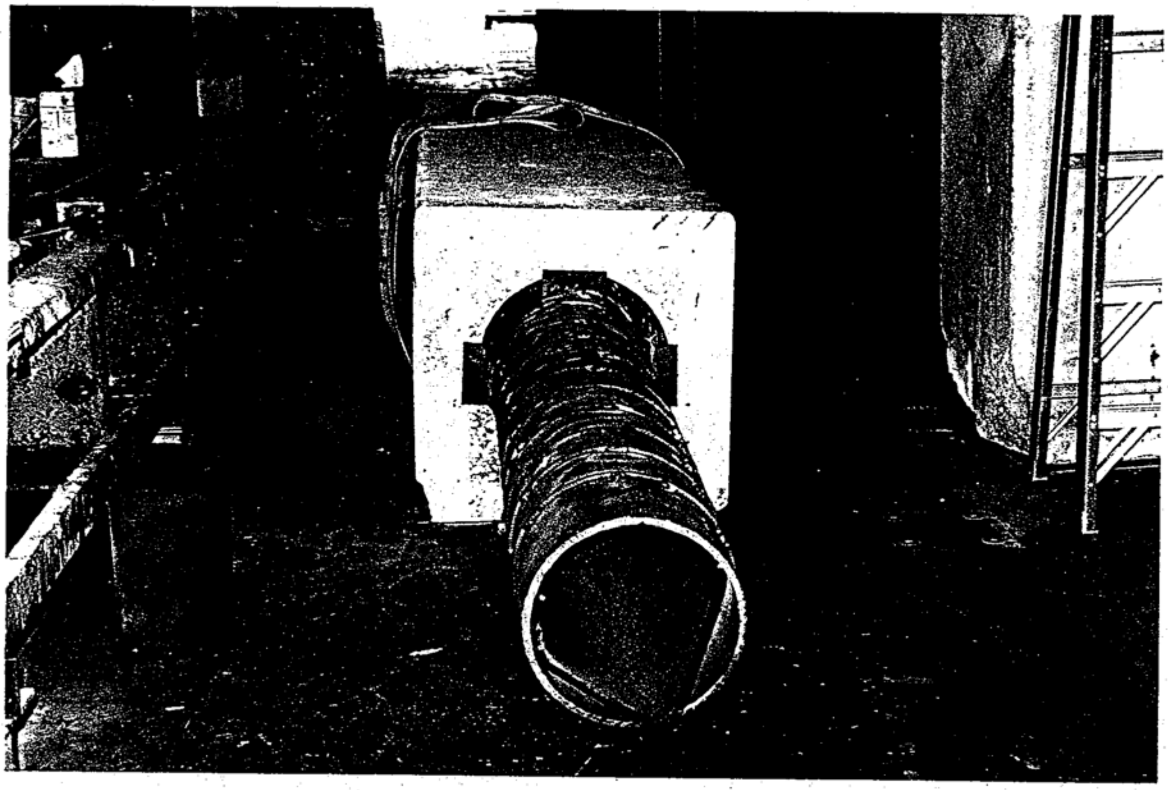


- Remove the Card Board from the core through the use of a pressure washer for a distance of at least 6.5'.

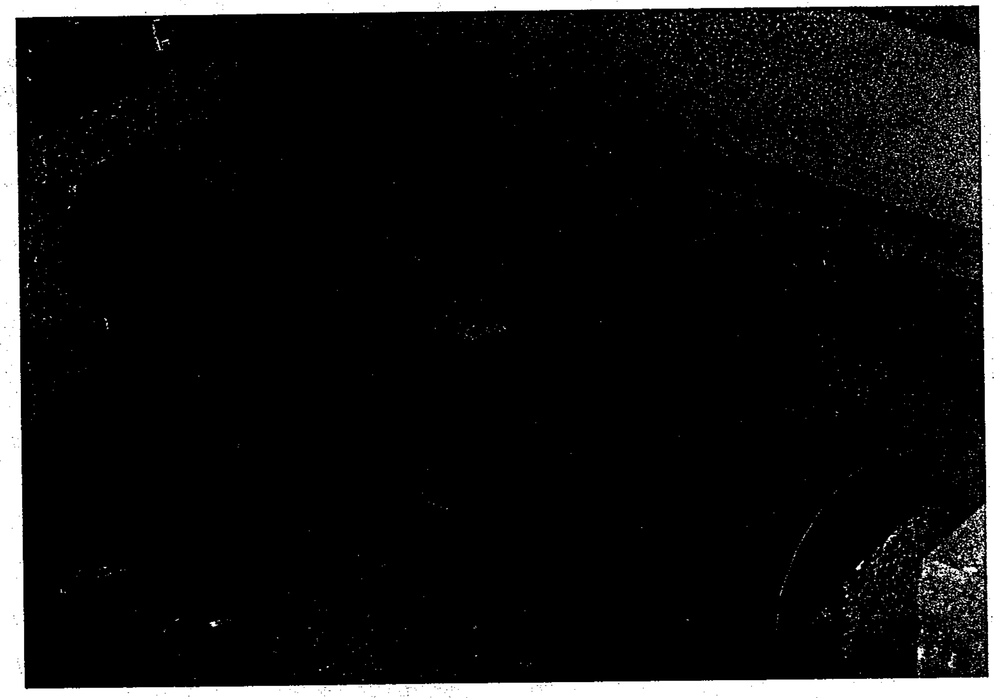


Pile Splice No. 1

- Use a 12' - 14" ϕ - ½" steel pipe (f_y = 42 ksi minimum).
- Weld a No. 4 Rebar in a spiral configuration at a pitch of 6".
- Cut to required diameter and insert an old 14" ϕ tire to act as a seal between 14" ϕ steel pipe and 30" pile.

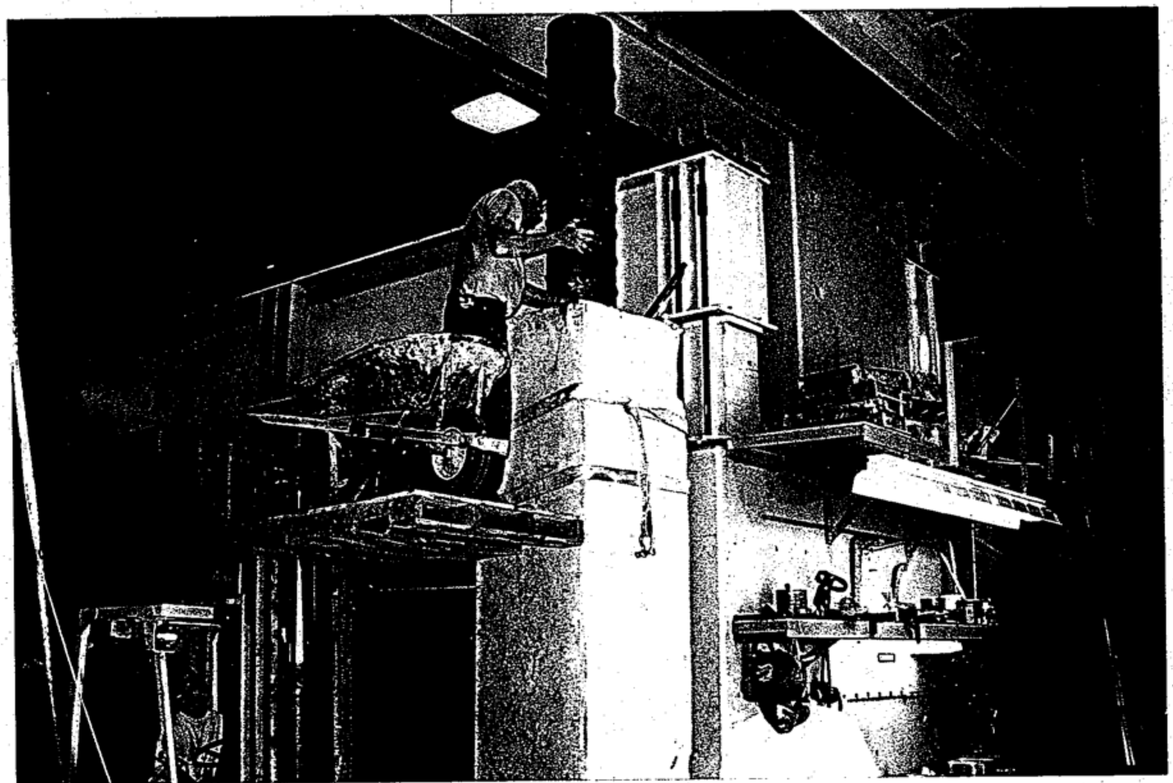


- Insert the 14" ϕ steel pipe into the 30" square pile.
- Weld spacers to the 14" ϕ steel pipe for installation purposes.
- Weld 4 - ½" steel lugs at mid-length of 14" ϕ steel pipe for support while in a vertical position.

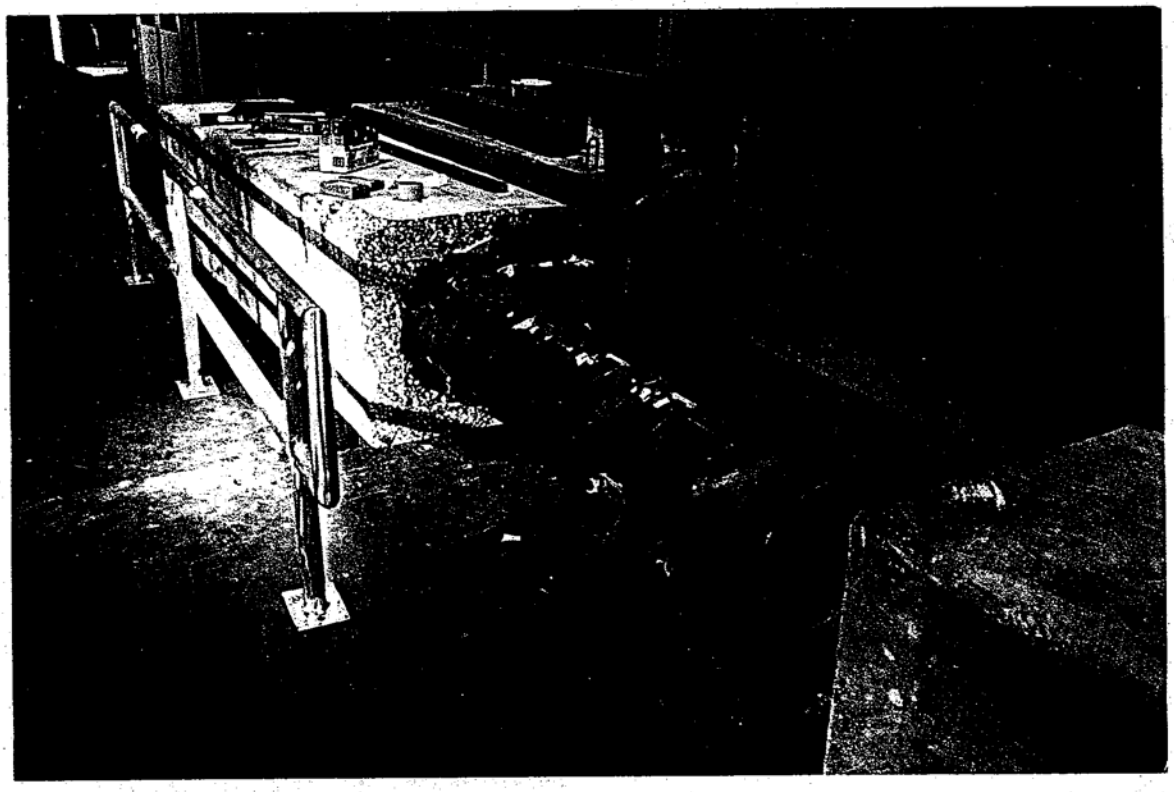


<u>Pile Splice No. 2</u>

- Fill the 14" ϕ steel pipe with concrete.
- Weld 5 No. 4 rebars equally spaced around the diameter of the 14" ϕ steel pipe as shown in the picture.
- Weld spacers to the 14" ϕ steel pipe.

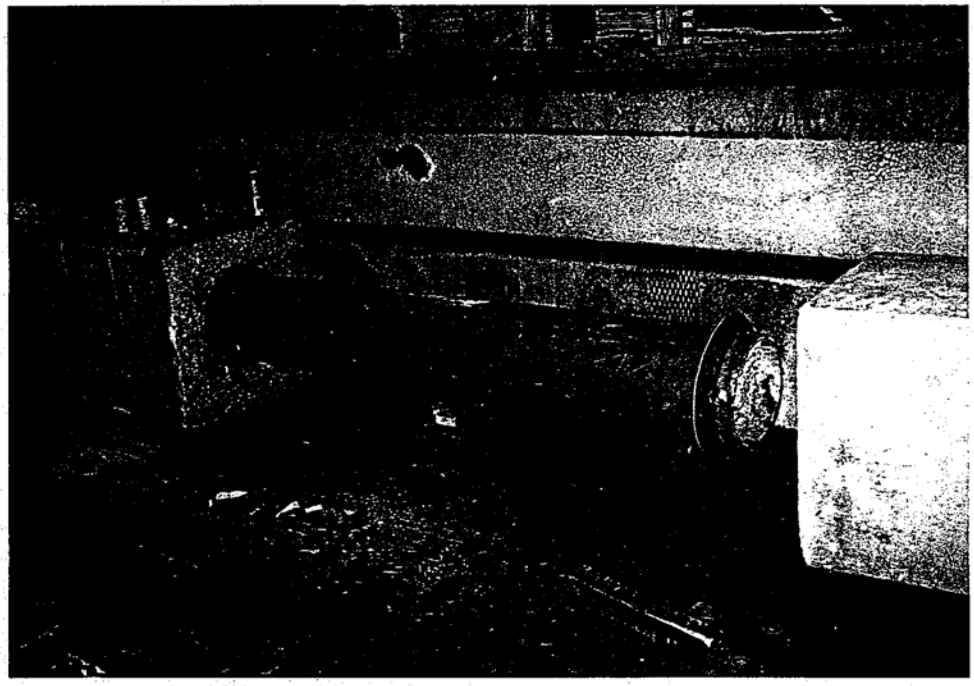


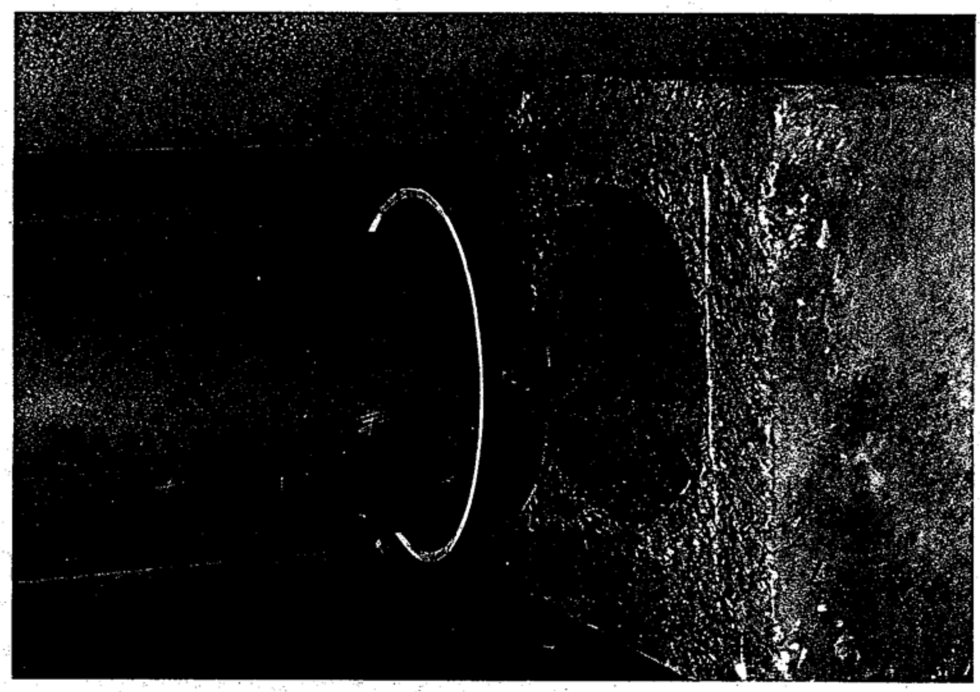
- Use Grout (FDOT approved) between the 30" pile and the 14" ϕ steel pipe.



- After grouting the first pile segment, lay it horizontally and mate it with the second pile segment.
- Seal and form the splice between the two segments.

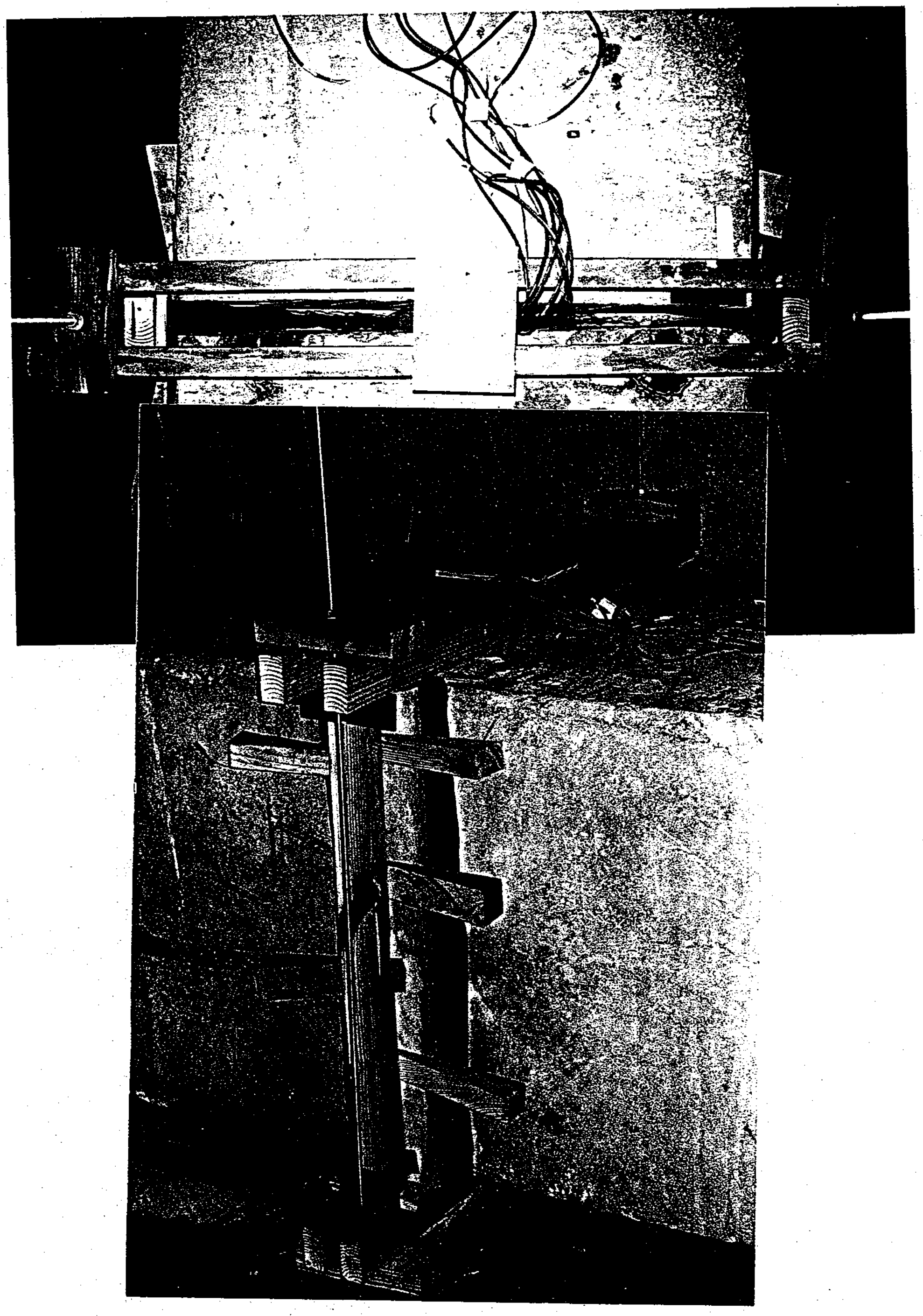
<u>(Note)</u> - The pile was grouted horizontally due to a height restriction at the lab.



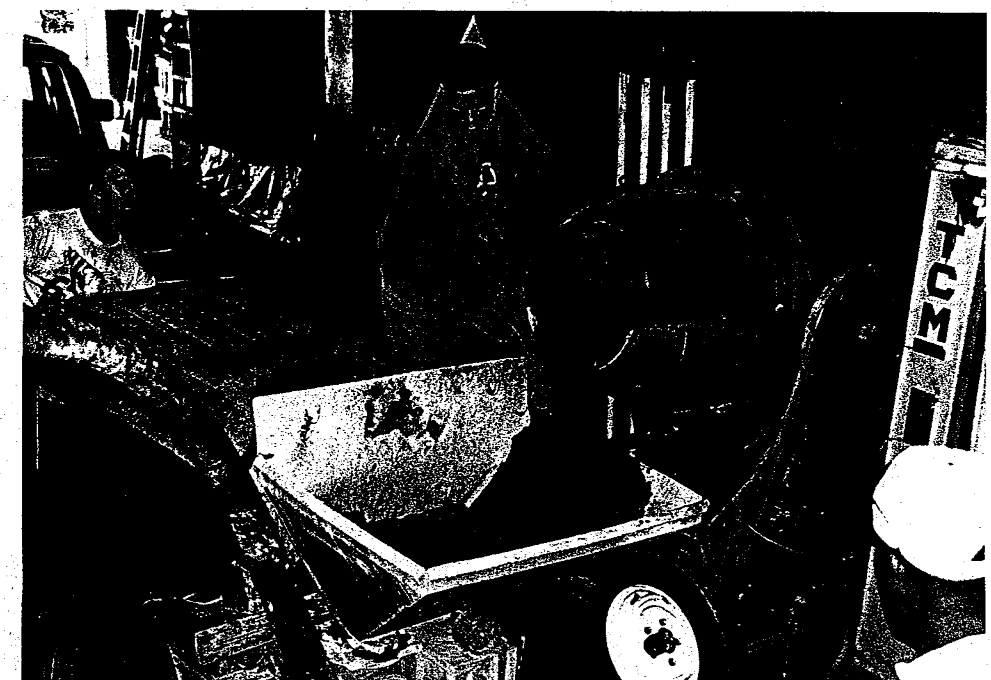


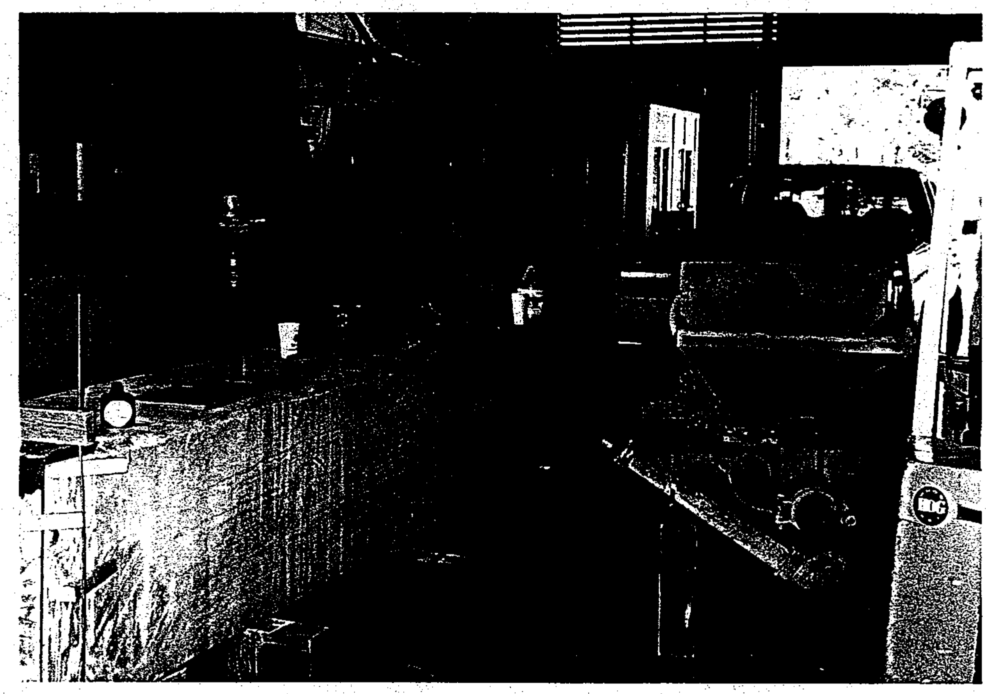
<u>Pile Splice No.2</u>

- Mate the two segments horizontally as shown.



- Form and seal the splice between the two segments as shown.
- Drill 2" ϕ grout and weep holes as needed. (Minimum of 2 holes)





- Grouting process requires the use of a concrete pump.

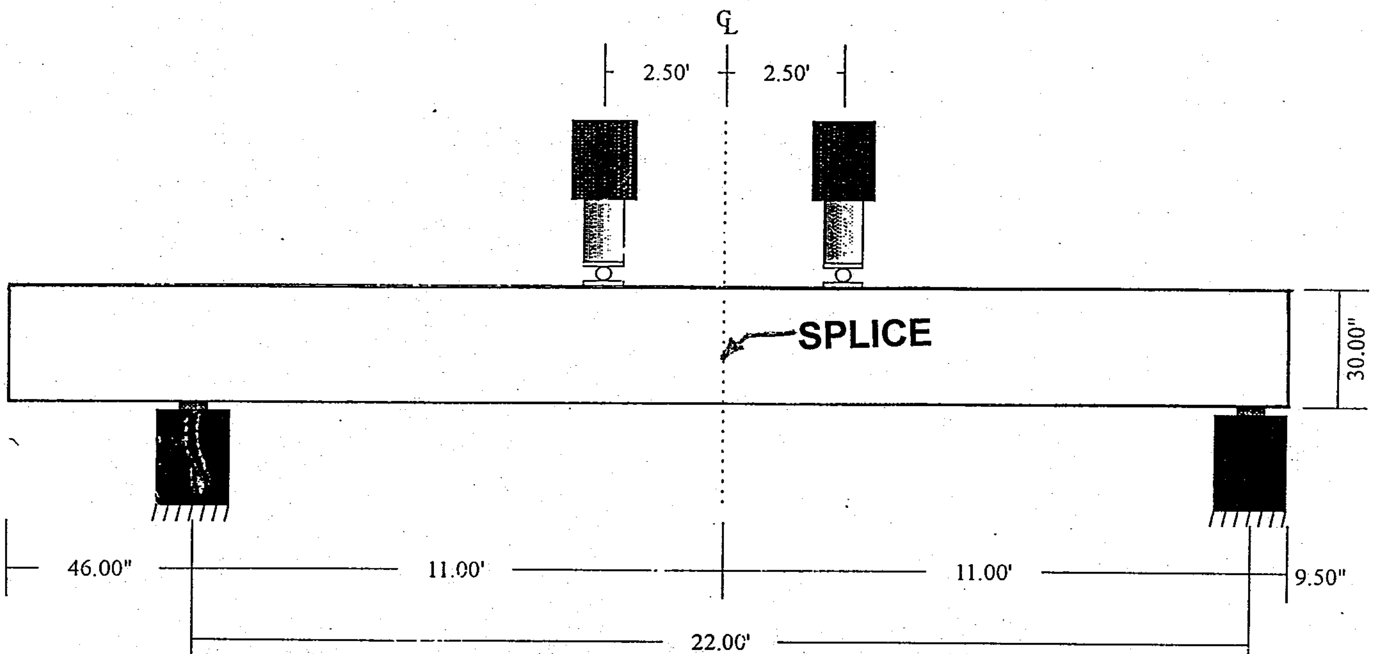
Appendix D

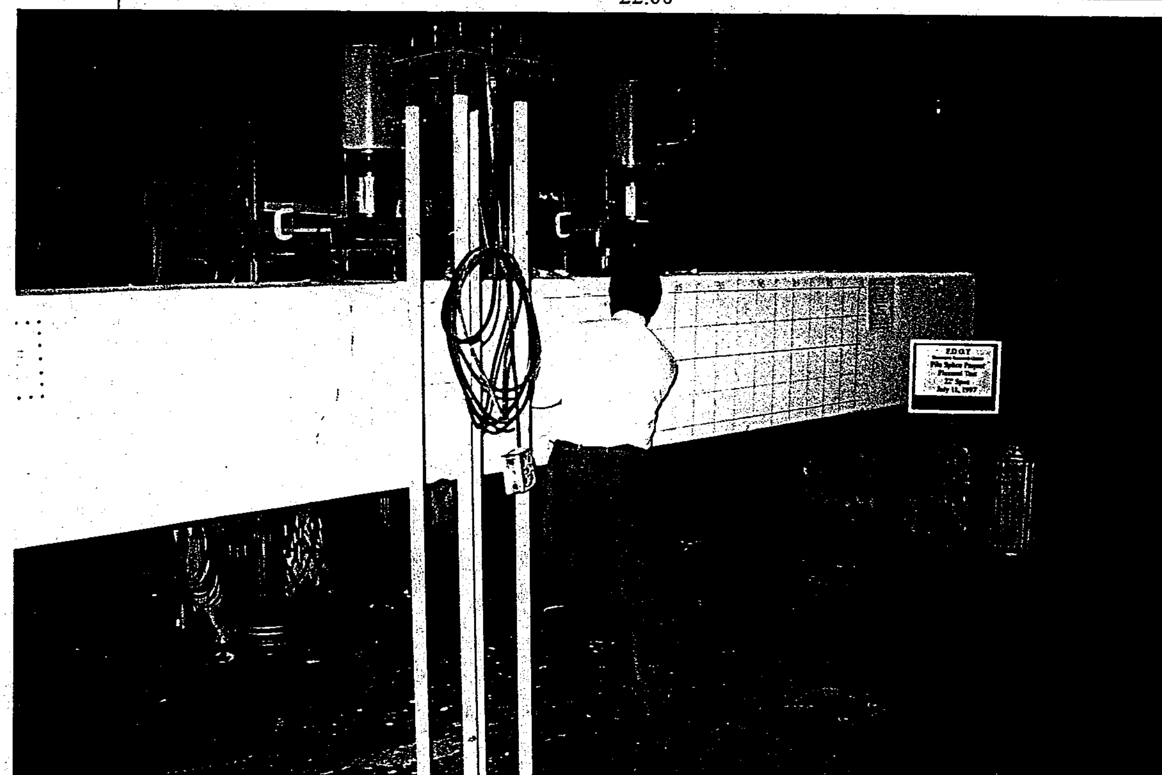
Pile Splice No. 1

Span Length = 22'

Splice Length = 10'

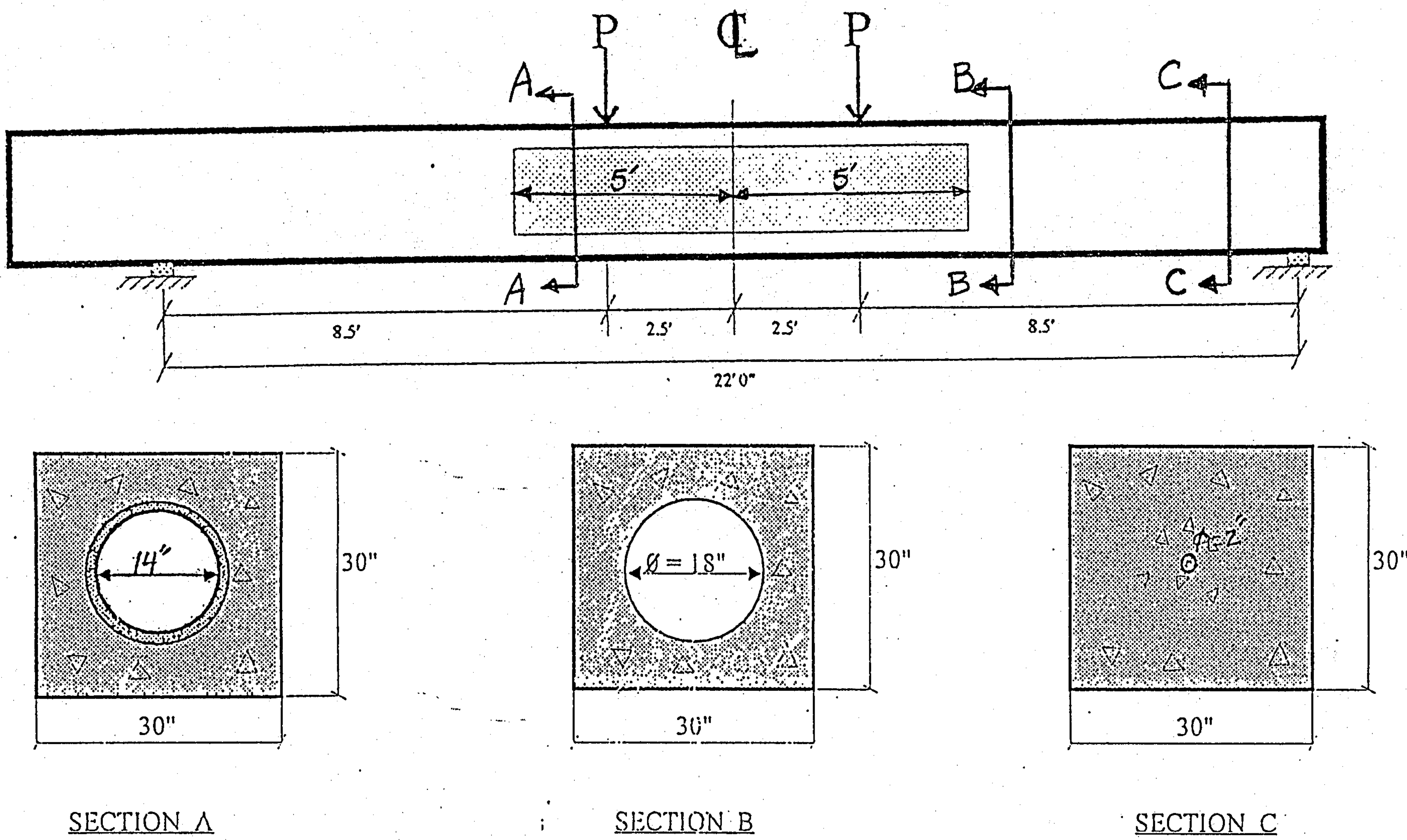
Pile Splice #1
Test Setup-Span Length = 22'
Splice Length 10'



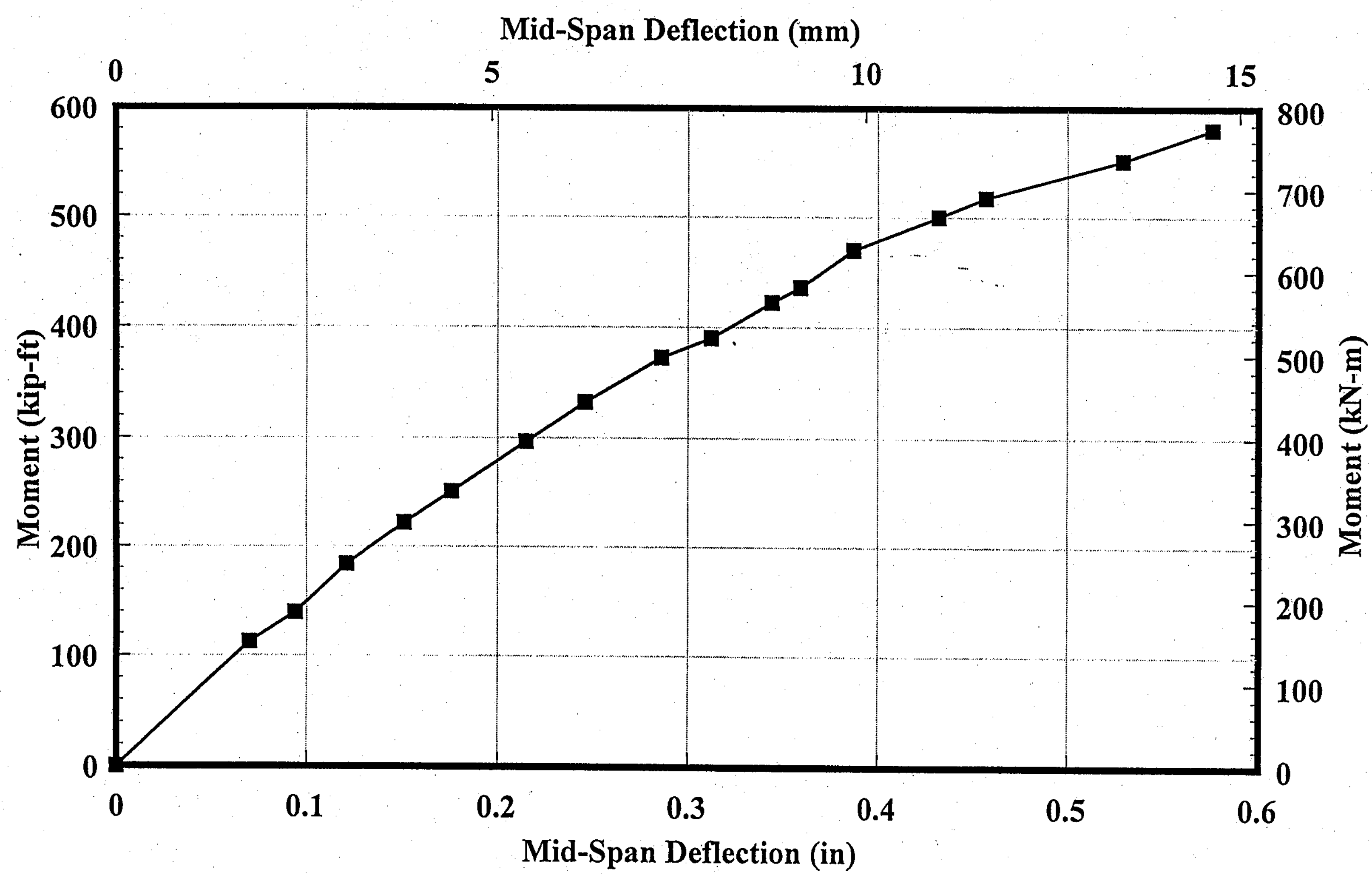


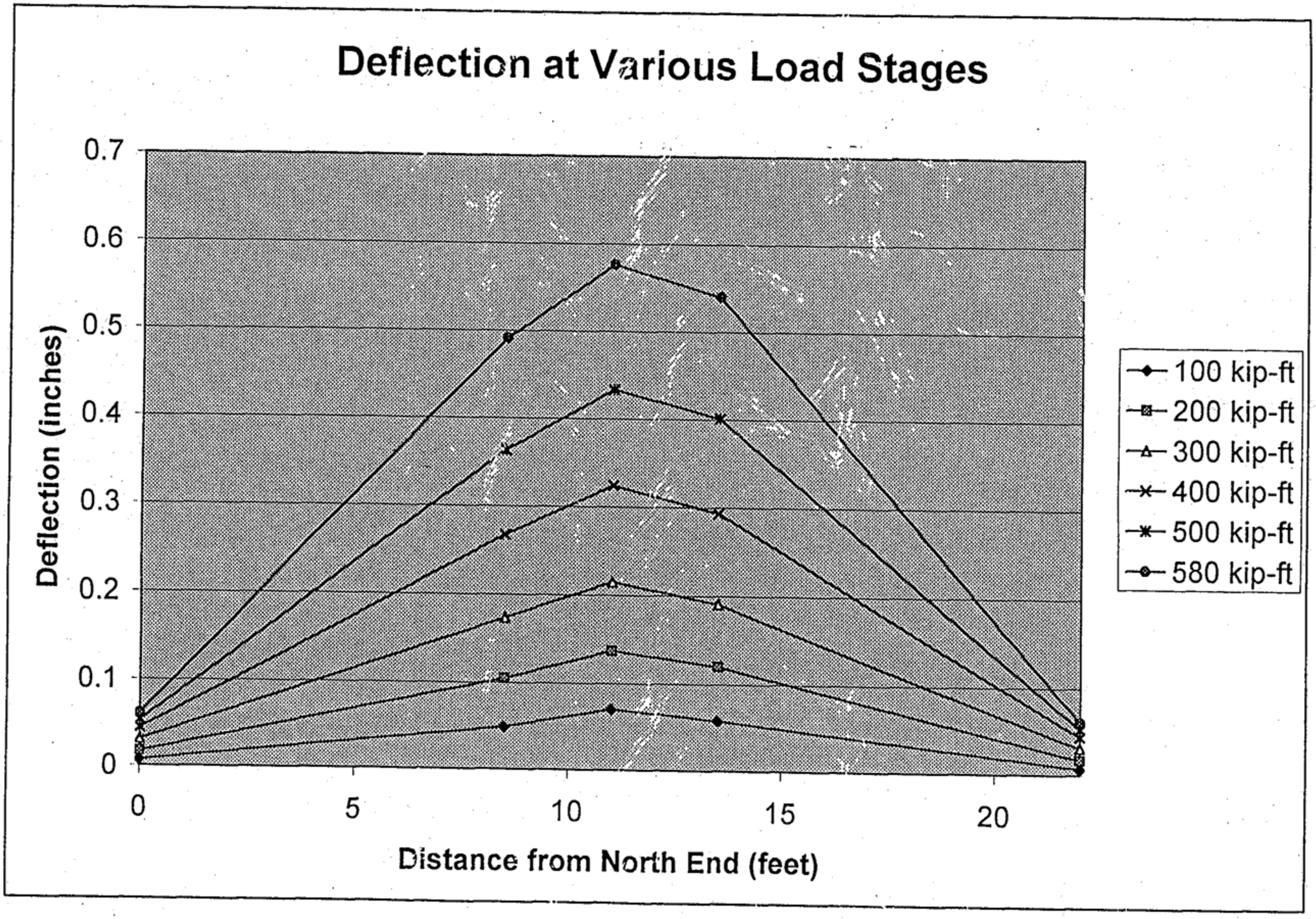
Ultimate Test Moment = 580.50 K-ft.
Maximum Deflection at Mid-Span = 0.58 in.

Pile Splice #1
Test Setup-Span Length = 22'
Splice Length 10'

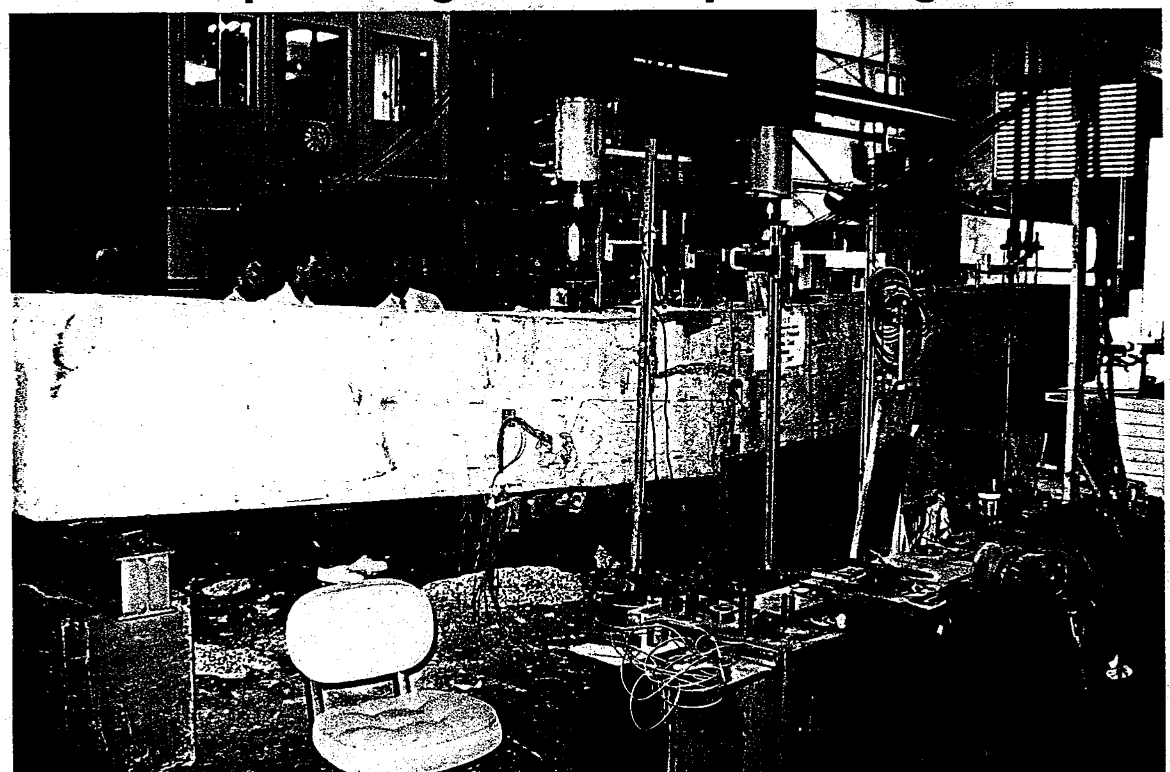


Pile Splice # 1
Moment vs. Mid-Span Deflection




Deflection at Various Load Stages
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Deflection (inches)
0
5
10
15
20
Distance from North End (feet)
100 kip-ft
200 kip-ft
300 kip-ft
400 kip-ft
500 kip-ft
580 kip-ft

Pile Splice #1
Mode of Failure
Span Length = 22' - Splice Length 10'



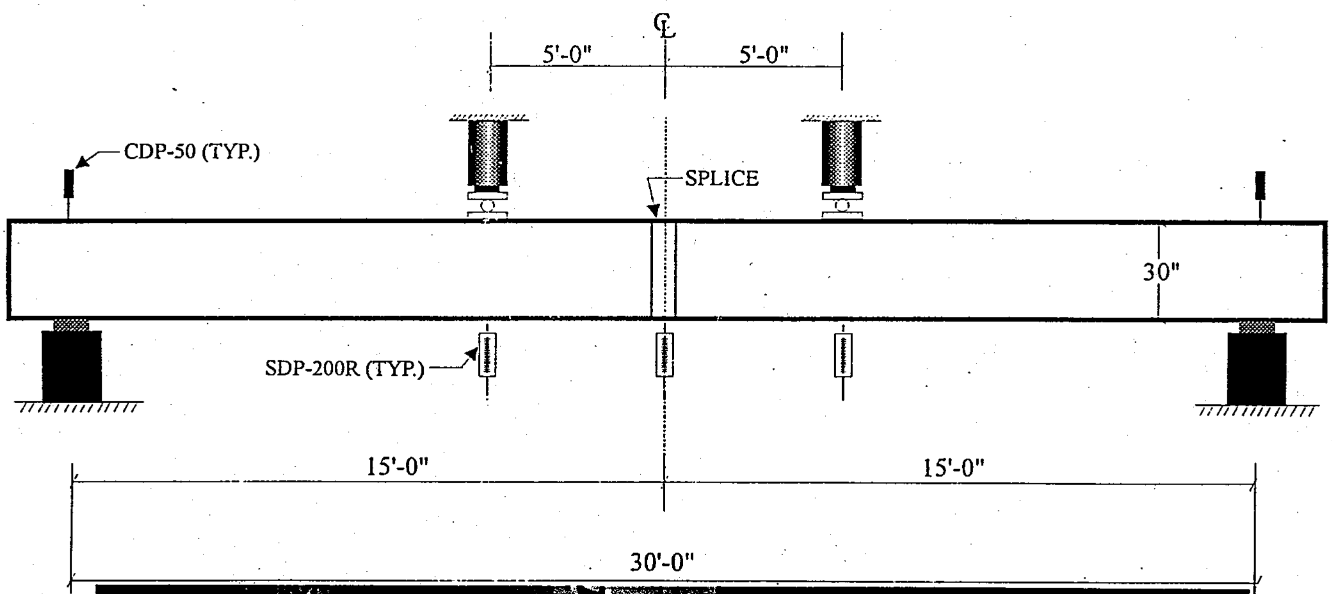
Appendix E

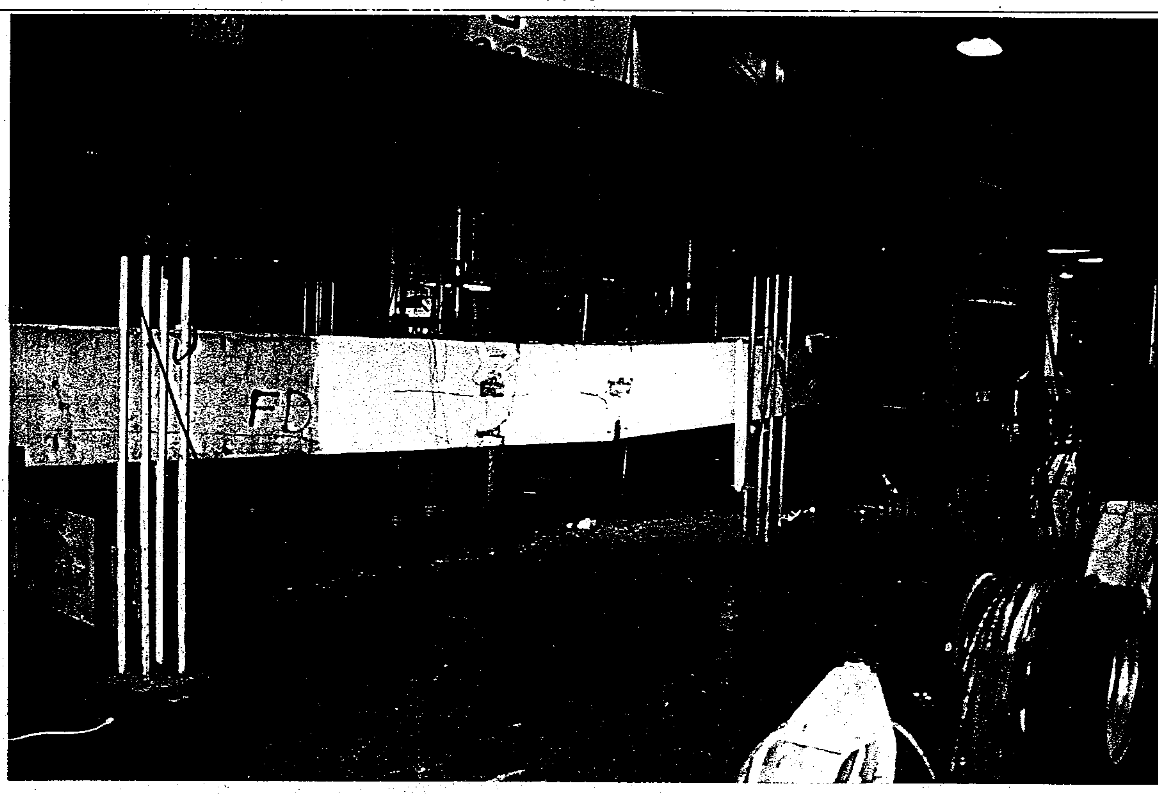
Pile Splice No. 2

Span Length = 30'

Splice Length = 15'

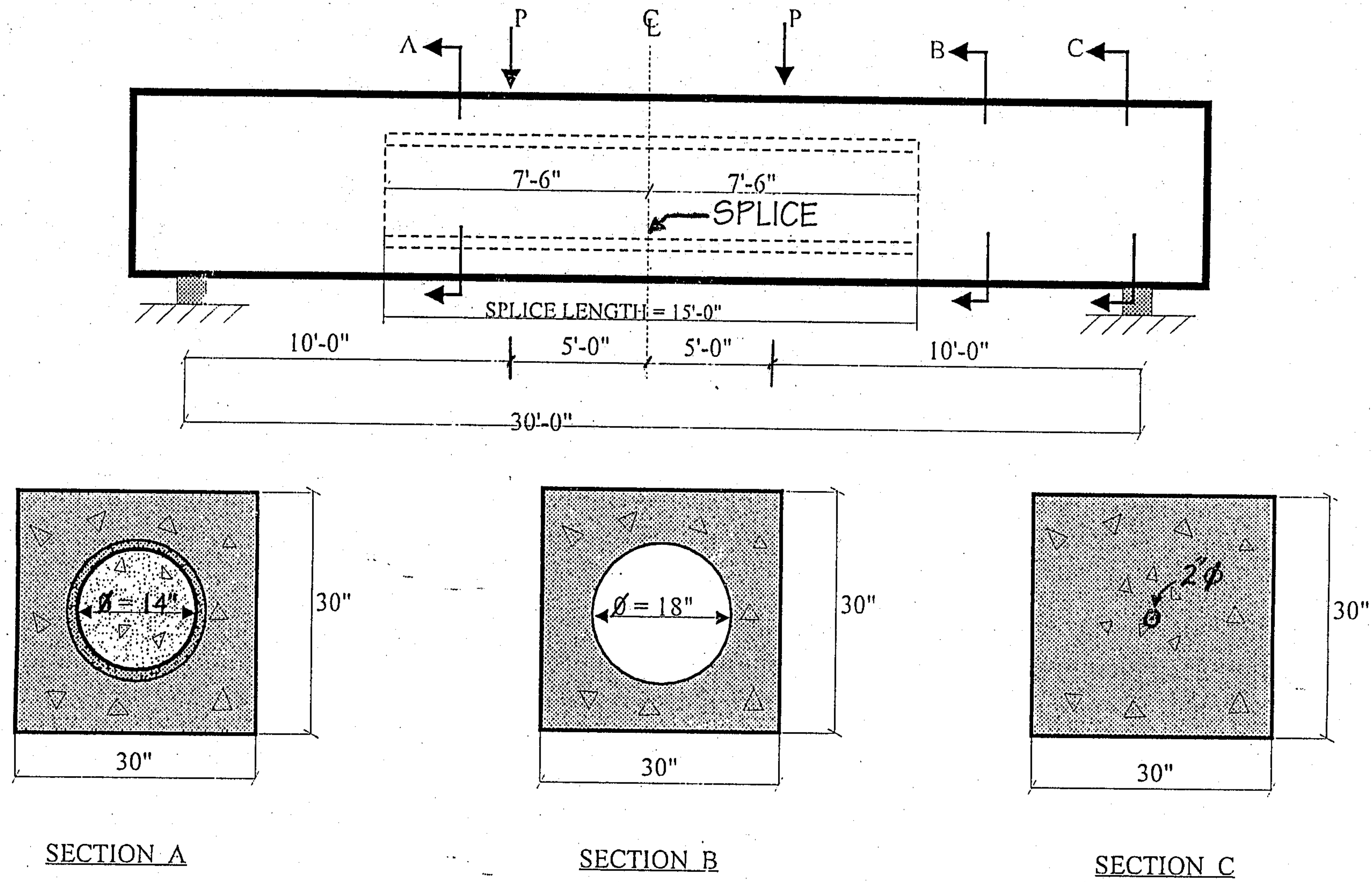
Pile Splice #2
Test Setup-Span Length = 30'
Splice Length 15'



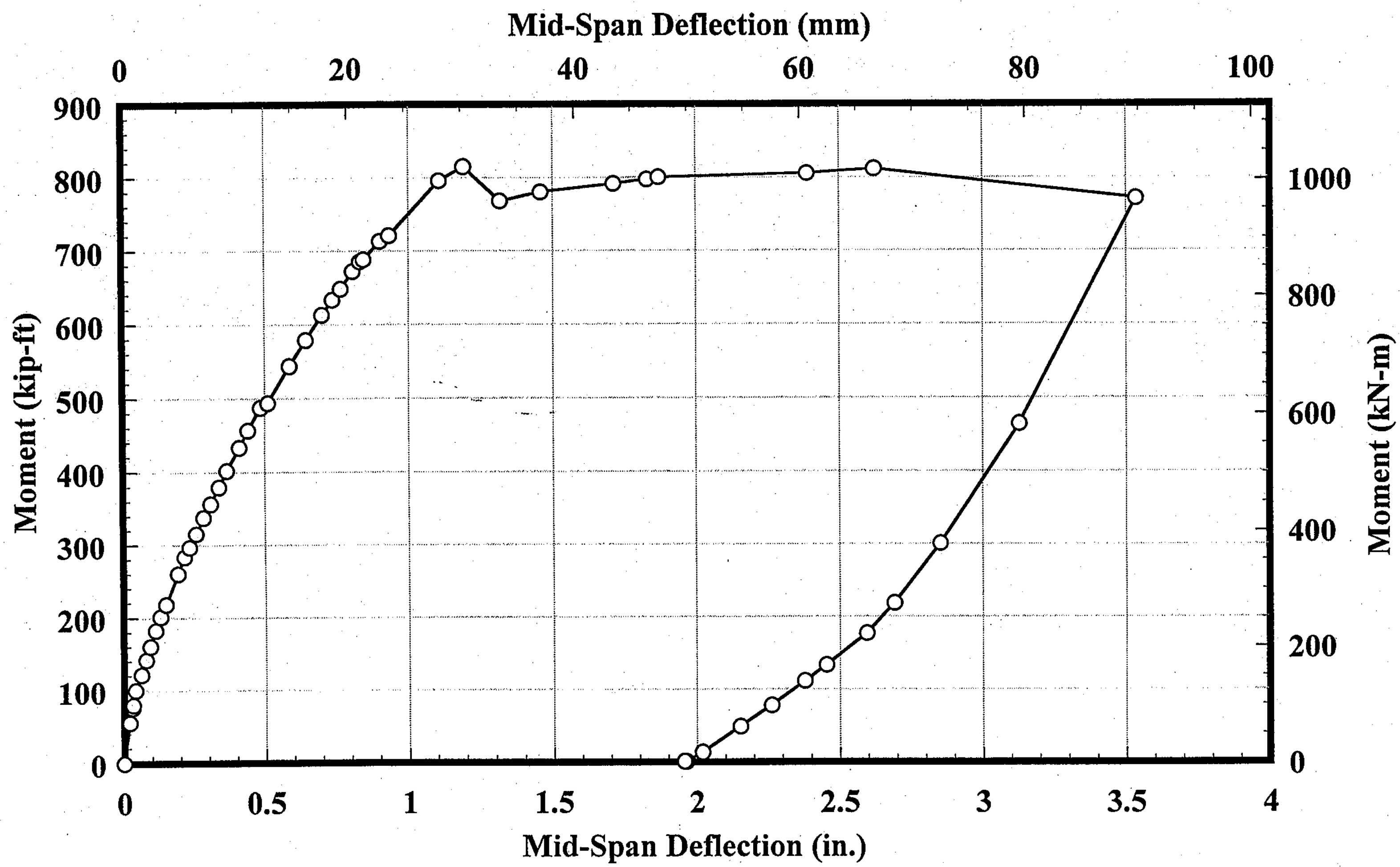


Ultimate Test Moment = 840.00 K-ft.
Maximum Deflection at Mid-Span = 3.52 in.

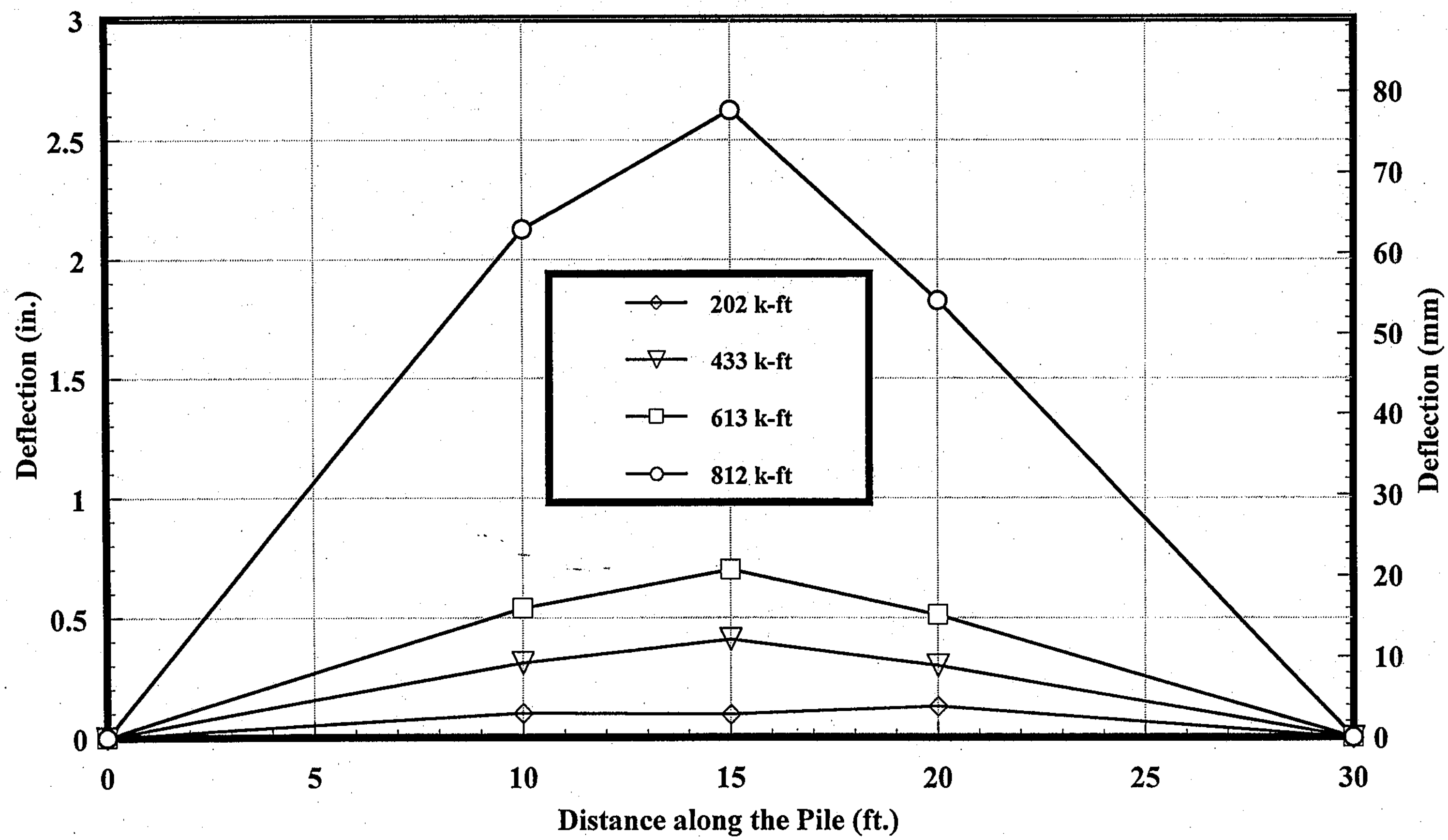
Pile Splice #2
Test Setup-Span Length = 30'
Splice Length 15'



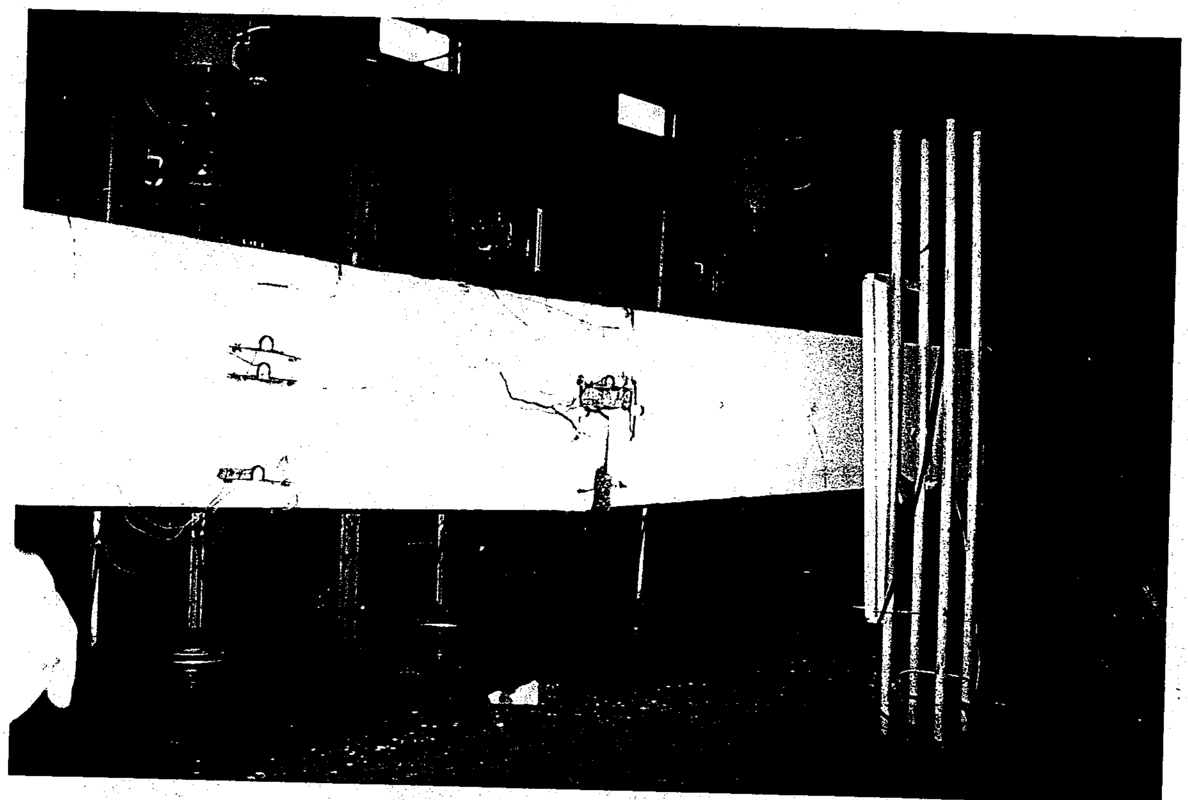
Pile Splice #2
Moment vs. Mid-Span Deflection



Pile Splice #2
Deflection at Vartious Locations on the Beam



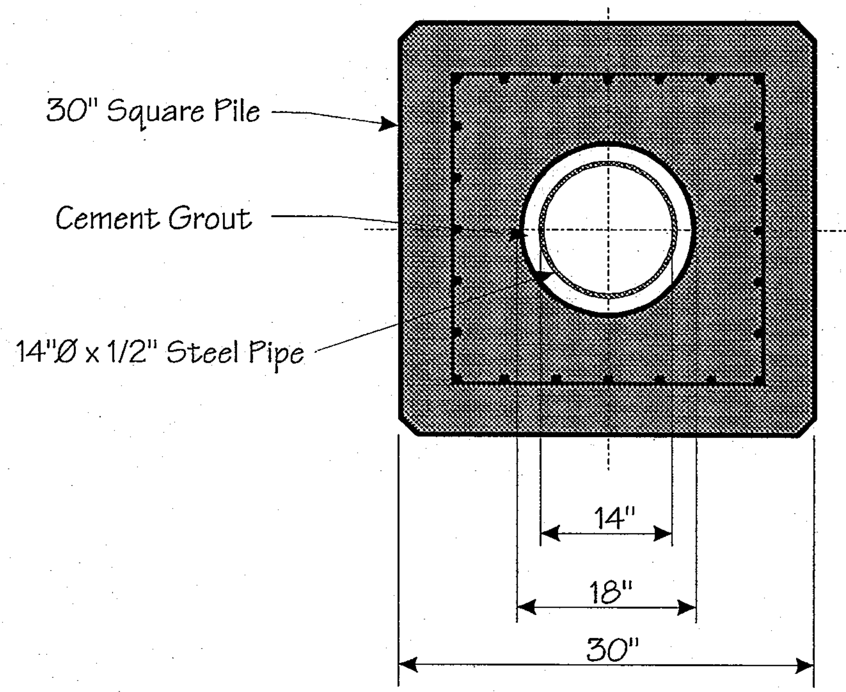
Pile Splice #2
Mode of Failure
Span Length = 30' - Splice Length 15'



Appendix F

Calculations
Of
Nominal Moment Capacities

Nominal Moment Capacity of Pipe-Pile Splice



Pile

$b := 30 \cdot in$

$h := 30 \cdot in$

$d := 15 \cdot in$

$$fc := \begin{bmatrix} 2.5 \\ 3 \\ 3.5 \\ 4 \\ 4.5 \\ 5 \\ 5.5 \\ 6 \\ 6.5 \\ 7. \end{bmatrix} ksi$$

$$I := \frac{b \cdot h^3}{12} - \frac{\pi \cdot d^4}{64}$$

$I = 6.501 \cdot 10^4 \, in^4$

$$\beta_i := if\left[fc_i \le 4, 0.85, if\left[fc_i > 8, 0.65, \left[0.85 - 0.05 \cdot \left(\frac{fc_i - 4}{1}\right)\right]\right]\right]$$

ACI Equation 10.2.7.3

$\beta =$

	0
0	0.85
1	0.85
2	0.85
3	0.85
4	0.825
5	0.8
6	0.775
7	0.75
8	0.725
9	0.7

Splice

$d_o := 14 \cdot in$ $\quad d_i := 13 \cdot in$ $\quad f_y := 42 \cdot ksi$

$$A_s := \frac{\pi \cdot \left(d_o^2 - d_i^2\right)}{4}$$

$A_s = 21.206 \, in^2$

$T := A_s \cdot f_y$ **Assume Tension Steel Yielded**

$T = 890.642 \, kip$ **(this force will be used in determining development length of the splice)**

Depth of compression

$$a_i := \frac{(A_s \cdot f_y)}{0.85 \cdot (fc_i \cdot ksi) \cdot b}$$

a =

	0
0	3.971
1	1.642
2	9.979
3	8.732
4	7.762
5	6.985
6	6.35
7	5.821
8	5.373
9	4.99

·in

Depth of Neutral Axis

$$c_i := \frac{a_i}{\beta_i}$$

c =

	0
0	16.436
1	13.697
2	11.74
3	10.273
4	9.408
5	8.732
6	8.194
7	7.762
8	7.412
9	7.128

·in

Moment capacity of the section

$$M_n := A_s \cdot f_y \cdot \left(d - \frac{a}{2}\right)$$

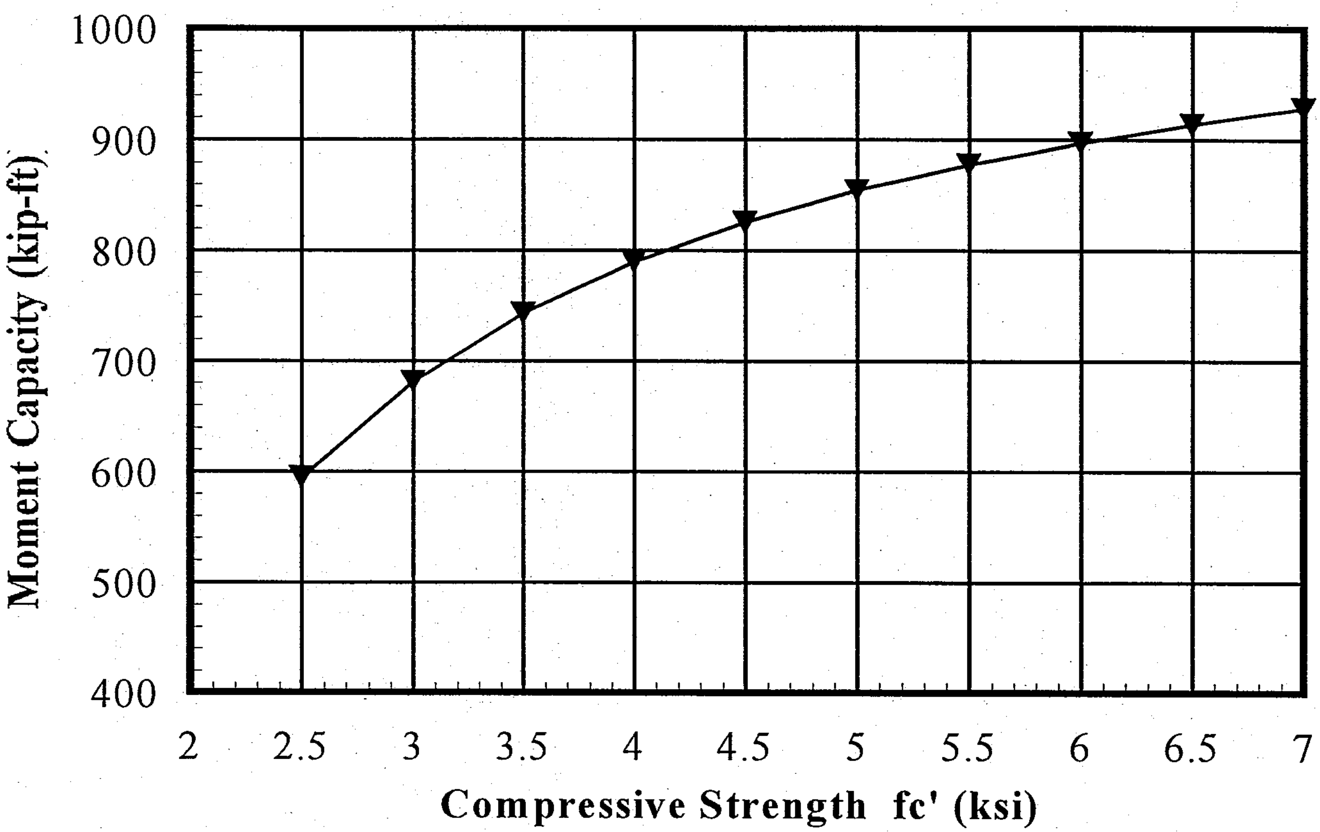
Due to discontinuity of the pile at the splice location, the prestressing in the pile have no effect on the flexural capacity of the splice.

$$fc := \begin{bmatrix} 2.5 \\ 3 \\ 3.5 \\ 4 \\ 4.5 \\ 5 \\ 5.5 \\ 6 \\ 6.5 \\ 7. \end{bmatrix} ksi$$

M_n =

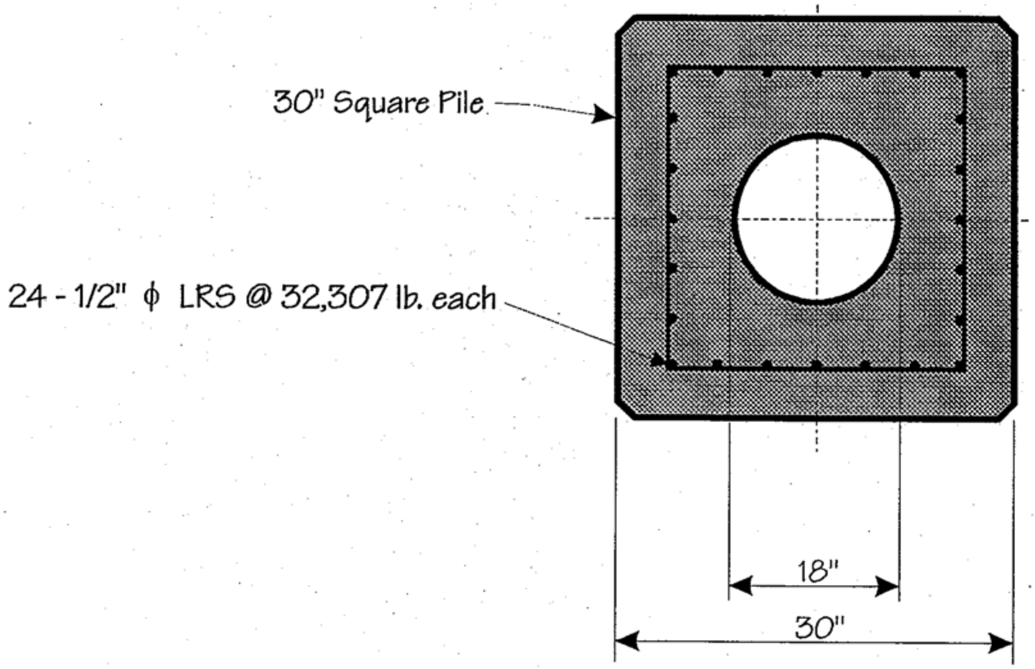
	0
0	594.843
1	681.253
2	742.974
3	789.265
4	825.269
5	854.072
6	877.639
7	897.277
8	913.895
9	928.138

·kip·ft



1000
900
800
700
600
500
400
Moment Capacity (kip-ft)
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
Compressive Strength fc' (ksi)

Nominal Moment Capacity of a 30" Splice Pile



$f'_c := \begin{bmatrix} 6500 \\ 7000 \\ 7500 \end{bmatrix} \cdot psi$ $\quad f_{pu} := 270 \cdot ksi$ $\quad f_{ps} := 261 \cdot ksi$ $\quad A_{s1} := .153 \cdot in^2$ $\quad A_{st} := 15 \cdot A_{s1}$

Neglecting Effect of Compression Steel

$y_p := \frac{((7 \cdot 3) + 2 \cdot (7 + 11 + 15 + 19))}{15} \cdot in$ $\quad d := 30 \cdot in - y_p$ $\quad a := \frac{A_{st} \cdot f_{pu}}{.85 \cdot f'_c \cdot (30 \cdot in)}$

$y_p = 8.333 \cdot in$ $\quad d = 21.667 \cdot in$ $\quad a = \begin{bmatrix} 3.738 \\ 3.471 \\ 3.24 \end{bmatrix} \cdot in$

$M_n := A_{st} \cdot f_{ps} \cdot \left(d - \frac{a}{2}\right)$

$M_n = \begin{bmatrix} 988.214 \\ 994.878 \\ 1.001 \cdot 10^3 \end{bmatrix} \cdot kip \cdot ft$ for f'c = 6500 psi; for f'c = 7000 psi; for f'c = 7500 psi