Final Report

DESIGN OF TEST INSTALLATION FOR BITUMEN COATED PILES

by

Richard P. Long
Associate Professor

Project 74-4 JHR 76-96
February 1976

This research was sponsored by the Joint Highway Research Advisory Council of the University of Connecticut and the Connecticut Department of Transportation, and was carried out in the Civil Engineering Department of the University of Connecticut.

TABLE OF CONTENTS

DESIGN OF TEST INSTALLATION FOR BITUMEN COATED PILES

By

Richard P. Long, Assoc. Prof.

Introduction

If the soil around in-place piles settles, friction forces mobilize between the soil and the pile. These forces, called negative skin friction or downdrag, often act on piles supporting highway bridge abutments because the fill behind the abutment causes the soil to settle. Conditions producing downdrag were anticipated at the two bridges on the proposed State Road 597 over the Quinnipiac River. These bridges were part of Project 25-82.

In December 1974 the Joint Highway Research Advisory Council approved a research project in the Department of Civil Engineering U Conn. for the design of a test pile installation that was to be included with the construction project for State Road 597. The construction of this state road has since been cancelled. However, it was still considered necessary to develop a design for a test installation to evaluate the friction perameters between soil and pile and the effectiveness of bitumen pile coatings in reducing downdrag. The design is developed for a test installation involving two end bearing "H" piles. One pile will be bare steel and will be used to measure the downdrag developed by the compressible soil underlying the area. The other pile will be coated with a layer of bitumen to determine the effectiveness of this coating in reducing downdrag on steel H piles.

Background

Bitumen has been effective in reducing downdrag in several locations throughout the world (1),(2),(3),(4),(5),(6). Shell International has done extensive laboratory and field testing on the use of Bitumen for this purpose and has identified the required properties (3), (4),(5).

1. Downdrag on Uncoated Piles

Downdrag develops along a bare pile. The soil surrounding the pile consolidates inducing a relative vertical movement between the soil and pile causing shear stresses acting downward on the pile.

Garlanger (8) indicates that the equation for shear stresses can be written:

$$\tau_{max} = \beta\bar{\sigma}_v \tag{1}$$

where τ_{max} = the shear stress along the pile at the point of interest;

$\bar{\sigma}_v$ = the effective stress in the vertical direction at the same point;

β = a coefficient that must be determined from field data and includes, the friction between pile and soil, correction for reduction of vertical stress and coefficient of lateral earth pressure.

To compute the total downdrag force, Eq. 1 must be integrated over the area of the pile in the zone moving down along the pile. This is normally done by determining the area under the vertical effective stress curve and multiplying by β and the perimeter of the pile.

2. Reduction of Downdrag with Bitumen

An "H" pile coated with bitumen is illustrated in Fig. 1. As the soil consolidates, shear stresses develop between the soil and the bitumen causing the bitumen to flow according to the equation: (3)

$$\tau = \eta \frac{v}{h} \tag{2}$$

where: v = the rate of downward movement at a point in length/time

τ = shear stress developed between soil and bitumen in force/unit Area

η = viscosity of the bitumen at the soil temperature (5-10°C) or (40-50°) in units of length^2/force-time

h = thickness of bitumen layer in same units of length as in v.

The shear stress transferred to the pile through the bitumen layer will also equal τ. Equation 2 indicates that for a given rate of settlement (v), the shear stress can be regulated by selecting a bitumen with an appropriate viscosity (η) and applying the bitumen to the pile with sufficient thickness "h".

Design of the Bitumen Slip Layer

The basic design of the slip layer was based on the following assumptions:

1. That 3 inches of settlement would occur in ten (10) days.
2. That the maximum force in the pile must be limited to four (4) TONS.

These conditions could be satisfied with a bitumen layer 2 mm thick, having a viscosity at 10°C (50°F) between 2.0 and 5.0 x 10^8 poise. However, a layer 2 mm thick is not adequate because of irregularities in the pile surface. A thickness of 5 mm is minimum. A thicker layer allows the bitumen to be more viscous. This temperature was selected because it is the approximate temperature of the soil below the frost zone in Connecticut.

The investigations by Shell (3),(4),(5) identified other considerations required for a successful installation of a bitumen coated pile. The conditions include handling, storing and driving the pile.

3. Storage - The piles will be stored at ambient temperature which can be assumed to be about 20°C (68°). During storage there will be some flow of the bitumen which should not exceed 0.5 to 1 cm. in 3 days. At higher temperatures provision must be made to wet the piles with water and perhaps whitewash them to

reflect sunlight. Another way of stating this criterion is: the bitumen must resist motion under a shear stress of approximately 0.6 gm/cm^2 which is imposed by its own weight.

4. Driving - To withstand the driving stresses without being stripped off the pile, the bitumen strains must be compatible with pile strains. Bitumen strains are controlled by a property known as the stiffness modulus which is computed with the aid of a nomograph.
5. Handling - Provisions must be made to repair any damage to the bitumen layer during handling.
6. Adhesion - The steel must be free of excessive rust or mill scale, then coated with a prime coat consisting a blend of aromatic white spirit and bitumen to build up a coating weighing about 0.1 to 0.2 kg/m^2 (4).
7. Squeezing - The bitumen must not allow penetration by coarse particles into itself in a reasonable time.

Selecting the Bitumen

The required properties are not found in readily available asphalt cements. However, a bitumen meeting these requirements can be produced by heating a soft asphalt and blowing air through it. Forcing air through the hot asphalt removes the volatiles thereby changing the engineering properties of the asphalt. Bitumen is prepared in this way for roofing and shingle applications. The progress of the changes in the bitumen during this process are monitored by two standard bitumen tests; the softening point (ring and ball) (11) and the penetration at 25°C (77°F) (12). Monitoring the progress periodically during the several hours of processing, results in a "blow-down curve" an example of which is shown in Fig. 2. When the process begins, the bitumen has the properties indicated by the upper left hand portion of the curve. As the blowing continues, the bitumen properties proceed down the curve to the right, the penetration decreases and the softening point increases. The "blow down" curve shown in Fig. 2 was supplied by the Tilo Company of Stratford, Ct. and is for the Venezuelan asphalt refined by Shell.

To select a bitumen for this application, several samples, blown to different points of the Curve, were obtained from the Tilo Company. Tests on each sample included viscosity measurements at 10°C and 20°C (13), penetration tests at two temperatures and determination of the softening point. The viscosity was used to check each sample against the requirements for flow under stress and storage.

The penetration tests were used to compute the penetration index according to the formula: (7)

$$\frac{20 - PI}{10 + PI} = 50 \frac{\log \text{pen} @ T_1 - \log \text{pen} @ T_2}{T_1 - T_2} \tag{3}$$

where: PI = penetration index, and T_1 and T_2 = the temperatures (°C) at which the penetration tests were made.

After computing the PI, the stiffness modulus is determined from the nomograph supplied by Shell and shown in Fig. 3 (7). The assumed loading time was 0.02 sec. and represents the loading time during pile driving. The $T_{800 \text{ pen}}$ was assumed equal to the softening point (ring and ball) as recommended by Shell.

In this way, the desired bitumen properties could be related to the appropriate point on the "blow down" curve and the amount of processing for this asphalt determined. The source of the asphalt is important since for different sources the blown-down curves and the engineering properties of the asphalt will be completely different, and the testing will have to be repeated with the new asphalt.

The Tilo Company has agreed to supply up to 100 gallons of the bitumen which should be sufficient for the test installation. For coating a large number of piles, bitumen with the correct properties can be obtained from one of the major oil refiners. The refiners are however reluctant to process less than 75 tons of product, and for this reason the bitumen for the test installation should be obtained from Tilo Co. The two gentlemen with whom we have been in contact are Mr. Link and Mr. Reed.

The Test Installation

a. General

A test installation should consist of two steel "H" piles, one driven with a bitumen coating, and the other without a coating. The test piles must strain a measurable amount. The smallest pile size that will not buckle under the anticipated load should be used. The bitumen design should take up to 80 strokes per minute from the pile hammer. This sample design is developed for the site shown in Fig. 4. As indicated by boring S16-1, the soil in the vicinity of Station 887+00 is approximately 110 feet deep. The soil within 5 feet of the surface soil consists of sand, silt, and gravel. A layer of loose silt about 65 feet thick is directly beneath this upper layer and rests on a brown fine sand of medium density. The brown fine sand is about 36 feet thick and underlain by a thin layer of till on rock. The compression of the silt layer will develop a great amount of downdrag. The test installation should be located where the load from the fill will significantly increase the effective stresses throughout the compressing layer; in this case, the loose silt. Total-load cells should be placed in the vicinity of each pile before filling begins. Piezometers should also be installed midway between pile locations.

b. Bitumen Slip Layers

The pile coating shall consist of a bitumen layer 0.5 cm thick having a penetration at 77°F (25°C) between the limits 52 to 56 and a softening point (ring and ball) between 138 to 140 with the crude originating from Venezuela. Table I shows the characteristics of the bitumen samples obtained from the Tilo Company. Only those samples that showed some promise of being acceptable were tested completely. Either samples B or D would be acceptable for this installation.

The characteristics of the bitumen selected for our installation are compared with Shell's recommendations in Table II. Recently Shell began producing four (4) grades of "Slip-Layer Compound" for use on bearing piles. These grades are not commercially available in the U.S.A. as of Fall 1975. None of the grades are suitable for this installation, as the settlements will occur too quickly. Therefore the bitumen from Tilo Company should be used.

The surface of the pile must be cleaned and primed to receive the bitumen slip layer. Cleaning must be accomplished by wire brushing to remove loose scale then the surface must be wiped clean to remove dust and dirt particles. The surface must be primed with a mixture of bitumen and solvent at about (50-50) by weight.

The bitumen slip layers can be formed in easily handled sections by pouring heated bitumen into paper backed molds as shown in Fig. 5. When the bitumen is sufficiently cool the mold is removed. The mold should be the thickness of the final bitumen layer. The paper backing, either Kraft® or some silicone treated paper, may remain with the bitumen on the side away from the pile.

The bitumen layers can be attached to the primed pile surface as shown in Fig. 6. The bitumen layer and the pile surface must be heated simultaneously and the slip layer attached. This technique is not practical for production piles. Shell Oil indicates that other techniques are available for coating large numbers of piles and new techniques are being developed. Shell Oil should be contacted about these techniques if the test installation proves satisfactory.

c. Pile instrumentation

Both piles will be instrumented to measure strain and the measuring system will include both mechanical and electrical gages. The instrumentation details are shown in Figs. 7 through 13. Readings of the gages should be frequent during the filling process. A truck with a bucket lift might be useful for installing and reading the gages at the top of the pile.

Figure 7 shows the layout of the strain-measuring system along the length of the pile. The devices should be positioned to measure strains throughout the portion of the pile embedded in the compressing layer. The electrical strain gauges will be attached before driving and protected by one-half round steel pipes welded the length of the pile web. The position of these steel pipes in the center of the web is shown in Fig. 8. Also shown in Fig. 8 are one-quarter round steel pipes welded to form an open space between the flanges and webs of the pile for the mechanical gauges. The mechanical gauges will not, however, be set into place until after the piles are driven. The perimeter generally used in computation for "H" piles equals 2 times flange width plus 2 times depth of web. The measurements with this system should give some indication of the validity of this assumption.

Details for attaching the steel pipe sections onto the piles are shown in Fig. 9. At each location for an electrical strain gauge, a space of 3 inches will be allowed on the web for attaching the gauge. After the gauge has been attached and the wires threaded through the pipe section, a 2-inch I.D. pipe section 6 inches long will be welded as shown in Fig. 9.

It may be necessary to spice the pile at several locations. Details for handling the connections of the steel pipe sections across the splice are shown in Fig. 10. The pipe sections will be stopped short of the end of the pile section to facilitate the spice weld. The open spaces will be covered by pipe sections welded into place after the pile has been spliced.

Details for the mechanical system are shown in Figs. 11, 12, and 13. The mechanical system is designed to function if the pile is straight or has taken a slight curvature during driving. A flexible wire inside a casing is used as the constant length against which the strain in the pile is measured. The casing is similar to the type used for automobile choke cables and must be stiff enough against torsion to turn the weight on the bottom of the cable into the anchorage welded to the bottom of the conduit and shown in Fig. 11. The wire inside the casing will extend above the conduit and be attached to dial gages mounted on the pile as shown in Fig. 12 and 13. The wire will be attached to the dial gauge plunger. The other end of the plunger will be attached to a weight over a pulley. The weight keeps the wire under tension. The thermal effects on this system are kept to a minimum by measuring the strains at the top of the pipe section. In addition shade must be provided to keep the sunshine from the top of conduit and gauge.

The mechanical system can also be used by weighting the bottom of the wire casing. This will be an alternate solution if the casing becomes dented during driving so that the threaded plug on the bottom of the casing can not be lowered to the fitting at the bottom of the steel pipe section. In this case sufficient weight can be added to the bottom of the casing to hold it at whatever elevation it can be lowered and the measurement made from this elevation.

Summary

A design has been presented for instrumenting steel H piles to measure forces due to downdrag. The design is sufficiently general to be adapted to many locations and includes electrical and mechanical strain gauges.

The mechanism by which bitumen reduces downdrag has been presented and discussed. The design of a bitumen layer for one installation has been presented with sufficient information to design for other installations.

Table I

Sample No.	Softening Point °F	Penetration @ 77°F (25°C)	P.I.	Stiffness Modulus + 5°C Kg/cm^2	Viscosity 10°C poise	Viscosity 20°C poise
A	110	150	+- 2.0			
B	140	52	2.0	400	7.5×10^8	3×10^7 poise
C	(not done)	44	2.0			
D	138	56	2.0	350	6×10^7	2×10^7 poise
E	133	67	2.0	300	3×10^7	9×10^6 poise
F	151	43	2.0	600	1×10^9 (estimate)	4×10^7 poise

Table II

Property	Samples B and D	Shell's Recommendations
Viscosity at 20°C	2-3 x 10^7 poise	> 1.5 x 10^7 poise
Viscosity at 10°C	6 x 10^7 to 7.5 x 10^3 poise	< 10^{10} poise
Stiffness Modulus @ +5°C and 0.02 sec.	350 to 400	< 1000 kg/cm^2
Penetration Index	2.0	$\leq$ 2.0
Penetration at 77°F (25°C)	52-56	53-70
Softening Point (R&B) °F	138-140	131-149

References:

1. Bjerrum, L., Johannessen, I.J. and Eide, O., "Reduction of Negative Skin Friction on Steel Piles to Rock", Proceedings 7th ICSMFE Vol. 2 Mexico, 1969, pp 27-33.

2. Hutchinson, J.H. and Jensen, "Loading Tests on Piles Driven Into Estuarine Clays at Port Khorramshahr, Iran, and Observations on the Effect of Bitumen Coatings on Shaft Bearing Capacity", Norwegian Geotechnical Institute Publication 78, 1968, pp. 1-12.

3. Claessen, A.I.M. and Horvat, E., "Reduction of Negative Friction on Bearing Piles by Bitumen Slip Layers". Proc. ASCE Jour. of Geotechnical Engr., Vol. 100, No. GT8, Aug. 1974, pp. 925-44.

4. Edwards, J.M. and Visser, W., "Bitumen Slip Layers for Construction Piles (Bearing Type)" Report MOR 475. Shell International Petroleum Co., Ltd., 1969, pp. 1-12.

5. Claessen, A.I.M. and Gelok, J.J., "Reduction of Negative Friction on Bearing Piles by Bitumen Slip Layers". Koninklijke/Shell-Laboratorium, Amsterdam, (M59/71), 1971.

6. Taylor, R., "Bituminous Coating for Bearing Piles". Shell Bitumen Review 43, 1973, pp. 2-3.

7. Heukelom, W. "Improved Nomograph for Bitumen" Shell Bitumen Review 43, 1973, pp. 8-9.

8. Garlanger, J., "Prediction of the Downdrag Load at Cutter Circle Bridge". A report presented at a seminar on Cutter Circle Bridge, M.I.T., 1973.

9. Long, R.P. and Healy, K.A., "Final Report, Negative Skin Friction on Piles", Dept. of Civil Engr. U CONN., Rep. No. JHR 74-77, March, 1974.

10. Visser, W. "Bitumen Slip Layers for Bearing Piles, Selection of Grade of Slip Layer Compound and Calculation of Magnitude of Negative Friction". SIPC(MKB/521), Koninklijke/Shell Labratorium, Amsterdam, 1974.

11. ASTM - Standard Method of Test for Softening Point of Bituminous Materials (Ring and Ball Method), D 36-26, American Society for Testing Materials, ASTM Standards Part 4, 1958, pp. 1030-1032.

12. ASTM-Standard Method of Test for Penetration of Bituminous Materials, D5-52, American Society for Testing Materials, ASTM Standards Part 4, 1958, pp. 1003-1005.

13. Fink, D.F. and Griffin, R.L. "Measurement of the Consistency of Paving Cements at 140°F with the Sliding Plate Microviscometer" American Society for Testing and Materials, ASTM-STP No. 309, 1961, pp. 79-94.

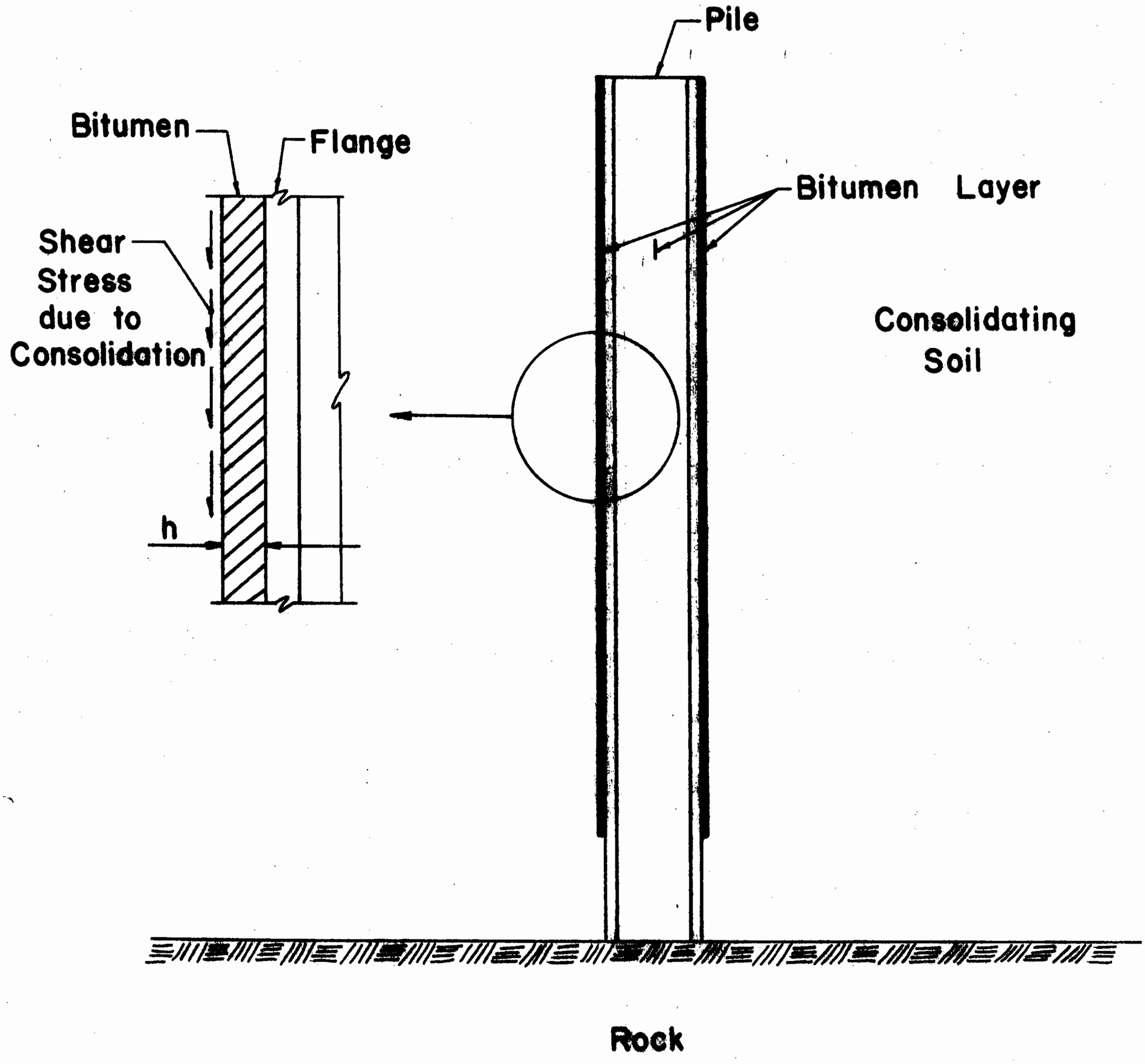

Pile
Bitumen
Flange
Bitumen Layer
Shear Stress due to Consolidation
Consolidating Soil
h
Rock

FIGURE 1

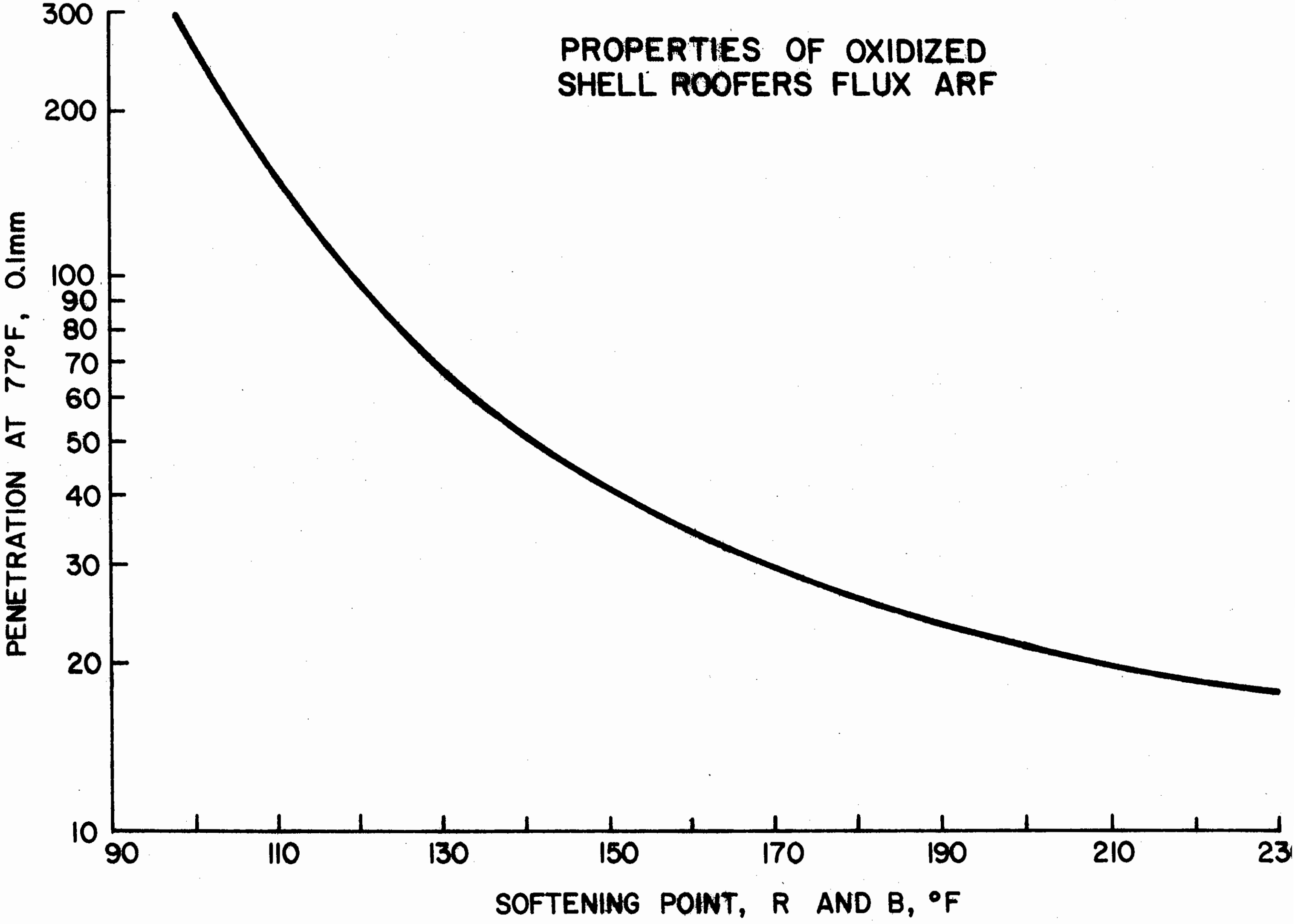
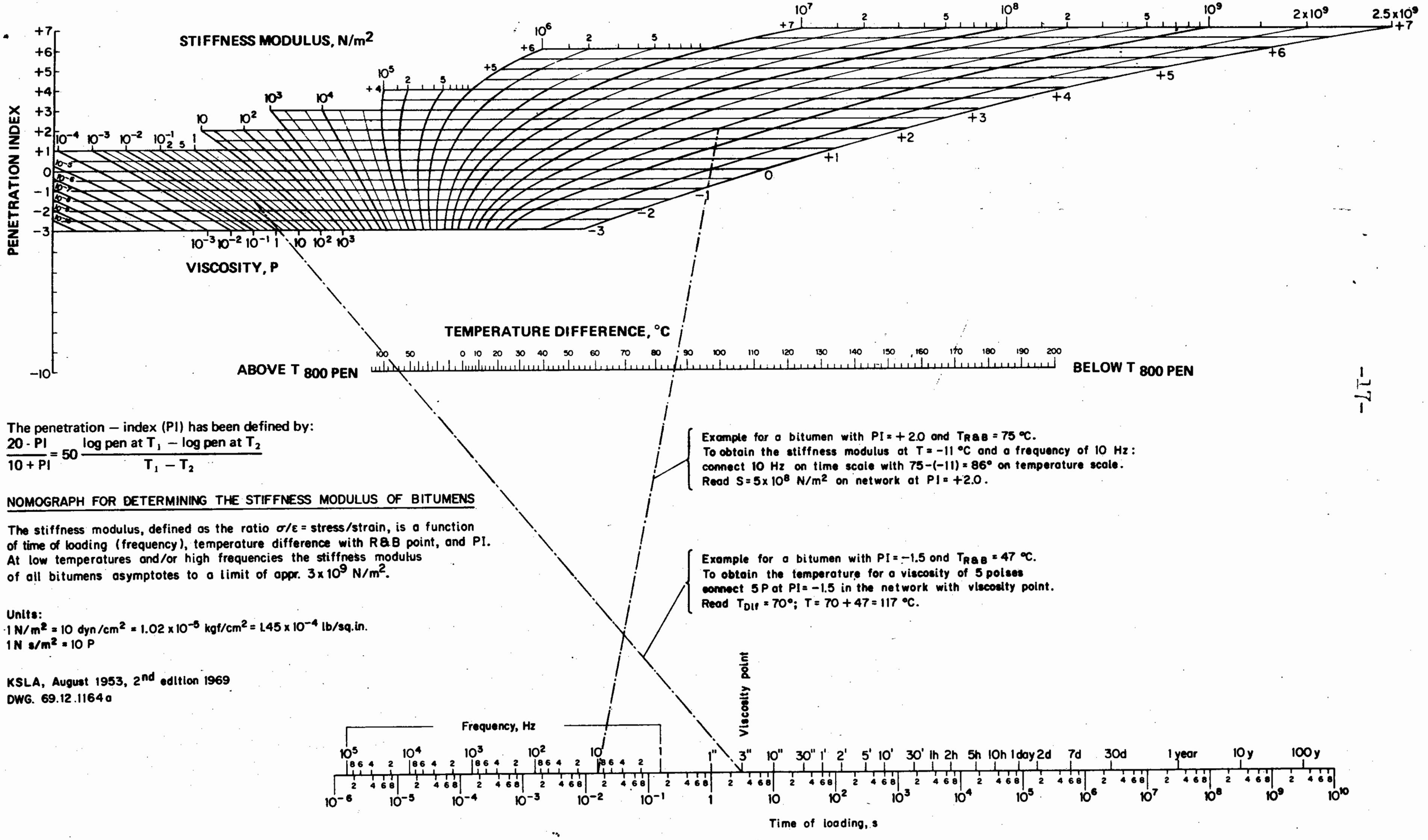

PROPERTIES OF OXIDIZED
SHELL ROOFERS FLUX ARF
PENETRATION AT 77°F, 0.1mm
300
200
100
90
80
70
60
50
40
30
20
10
90
110
130
150
170
190
210
23
SOFTENING POINT, R AND B, °F

FIGURE 2



The penetration – index (PI) has been defined by:

$$\frac{20 - PI}{10 + PI} = 50\,\frac{\log \text{pen at } T_1 - \log \text{pen at } T_2}{T_1 - T_2}$$

NOMOGRAPH FOR DETERMINING THE STIFFNESS MODULUS OF BITUMENS

The stiffness modulus, defined as the ratio σ/ε = stress/strain, is a function of time of loading (frequency), temperature difference with R&B point, and PI. At low temperatures and/or high frequencies the stiffness modulus of all bitumens asymptotes to a limit of appr. 3×10^9 N/m².

Units:
$1\ \text{N/m}^2 = 10\ \text{dyn/cm}^2 = 1.02 \times 10^{-5}\ \text{kgf/cm}^2 = 1.45 \times 10^{-4}$ lb/sq.in.
$1\ \text{N s/m}^2 = 10$ P

KSLA, August 1953, 2nd edition 1969
DWG. 69.12.1164a

Example for a bitumen with PI = +2.0 and $T_{R\&B}$ = 75 °C.
To obtain the stiffness modulus at T = −11 °C and a frequency of 10 Hz:
connect 10 Hz on time scale with 75−(−11) = 86° on temperature scale.
Read S = 5 x 10⁸ N/m² on network at PI = +2.0.

Example for a bitumen with PI = −1.5 and $T_{R\&B}$ = 47 °C.
To obtain the temperature for a viscosity of 5 poises
connect 5 P at PI = −1.5 in the network with viscosity point.
Read T_{Dif} = 70°; T = 70 + 47 = 117 °C.

FIGURE 3

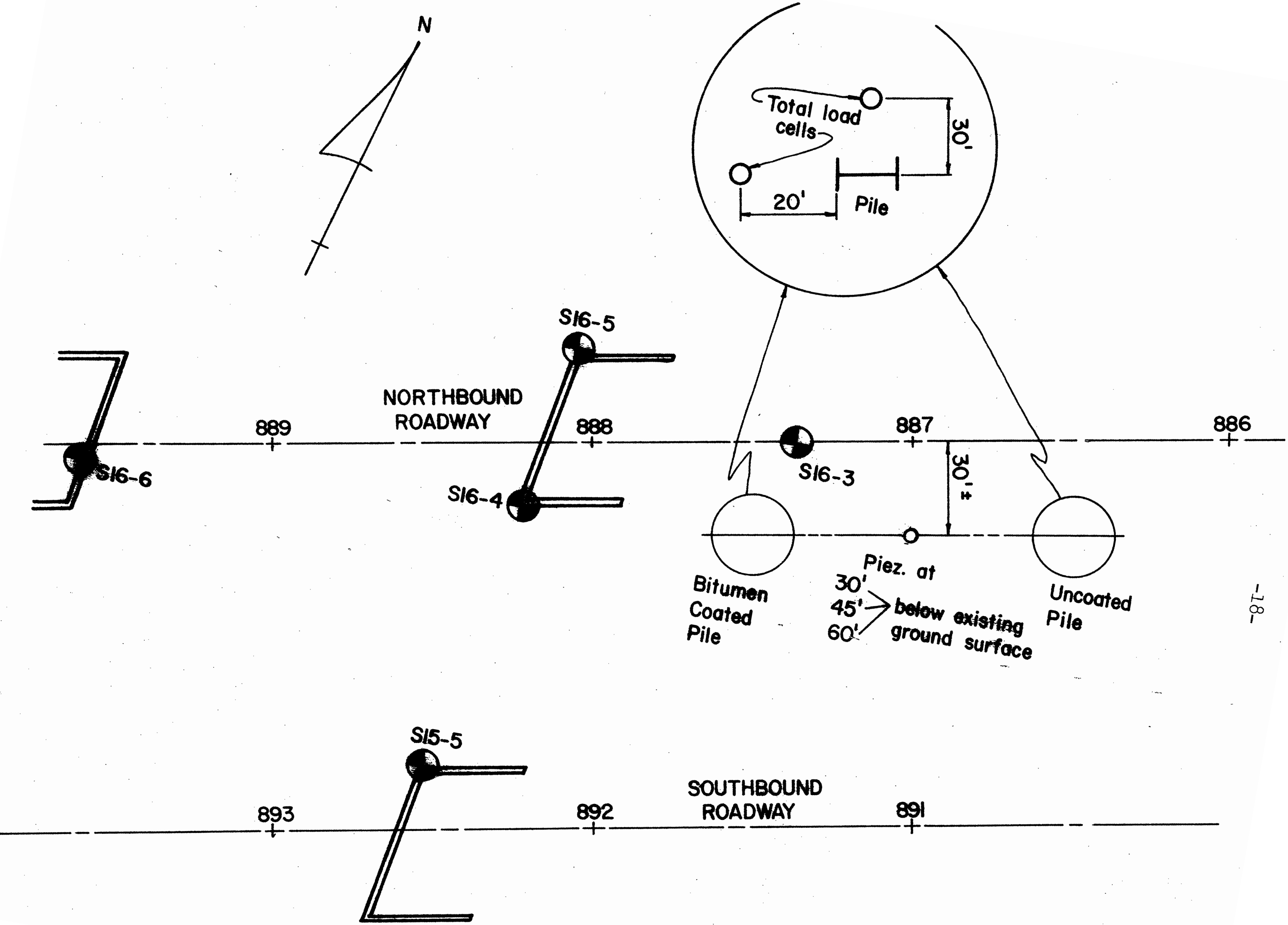
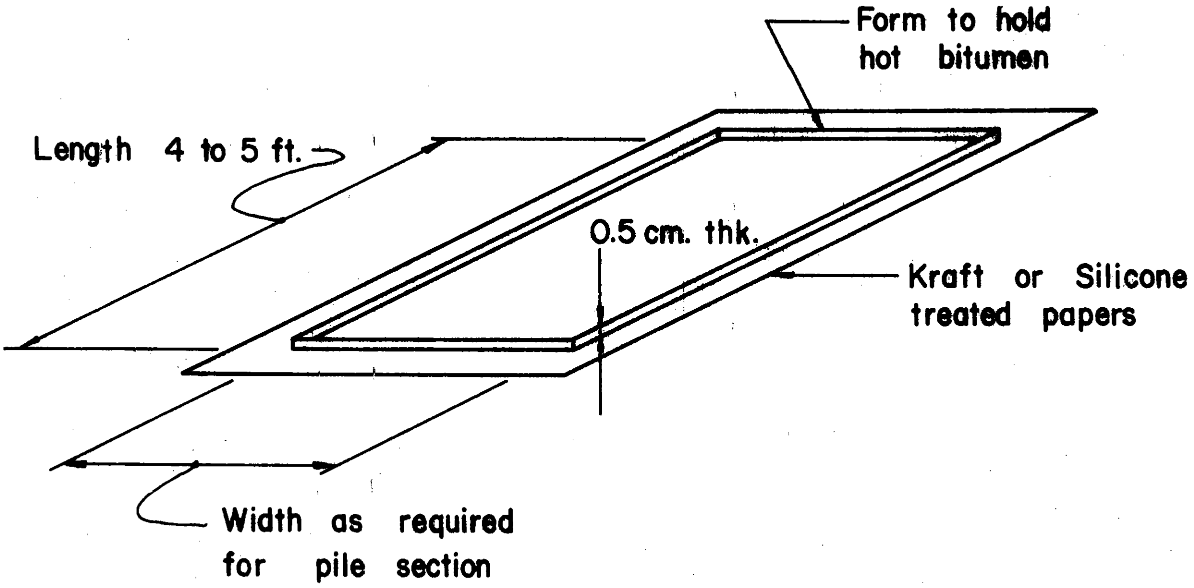
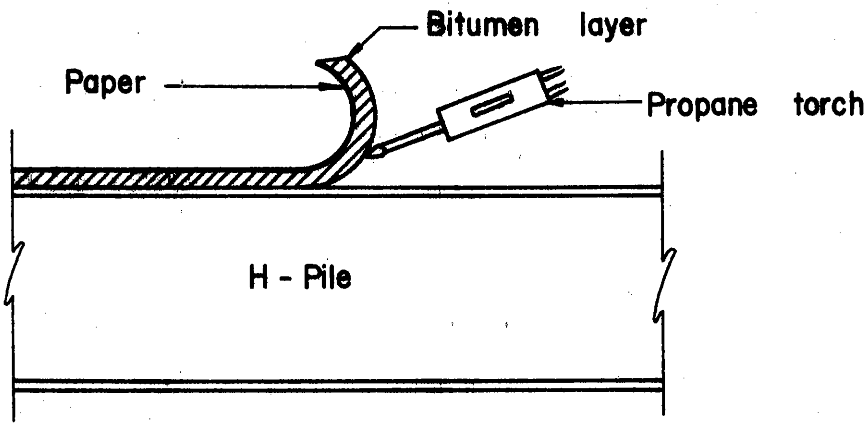

N
Total load cells
30'
20'
Pile
SI6-5
NORTHBOUND ROADWAY
889
888
887
886
SI6-6
SI6-4
SI6-3
30'±
Bitumen Coated Pile
Uncoated Pile
Piez. at
30'
45'
60'
below existing ground surface
SI5-5
SOUTHBOUND ROADWAY
893
892
891

FIGURE 11



CASTING BITUMEN LAYERS

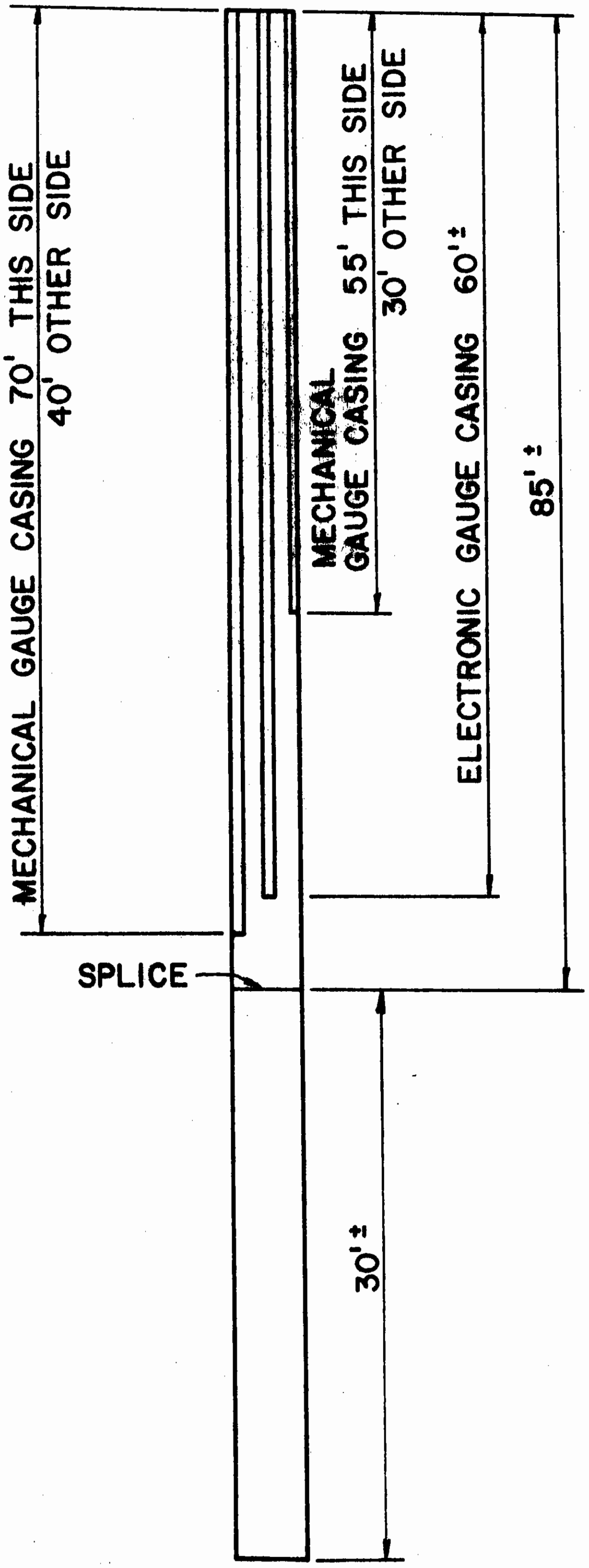
FIGURE 5



APPLYING BITUMEN LAYERS
TO PILE

FIGURE 6

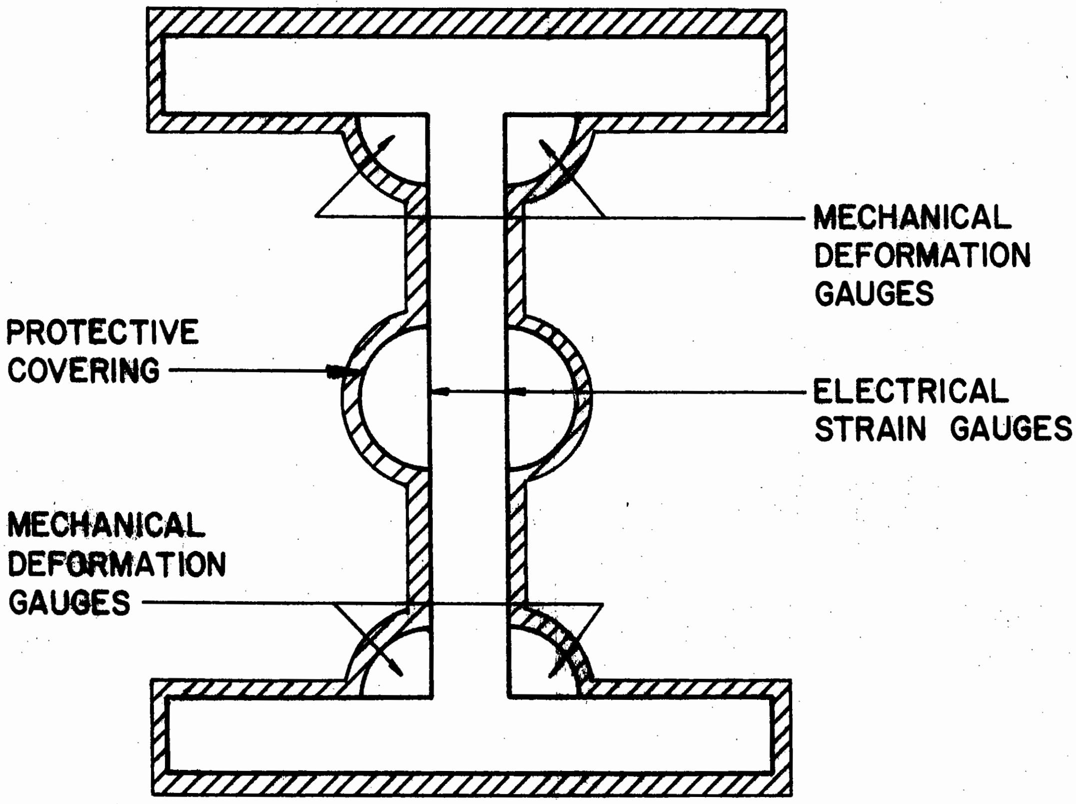
PILE INSTRUMENTATION



MECHANICAL GAUGES IN CASINGS ATTACHED IN CORNERS BETWEEN WEB AND FLANGES.

ELECTRONIC GAUGES IN CASING ALONG CENTER OF WEB BOTH SIDES.

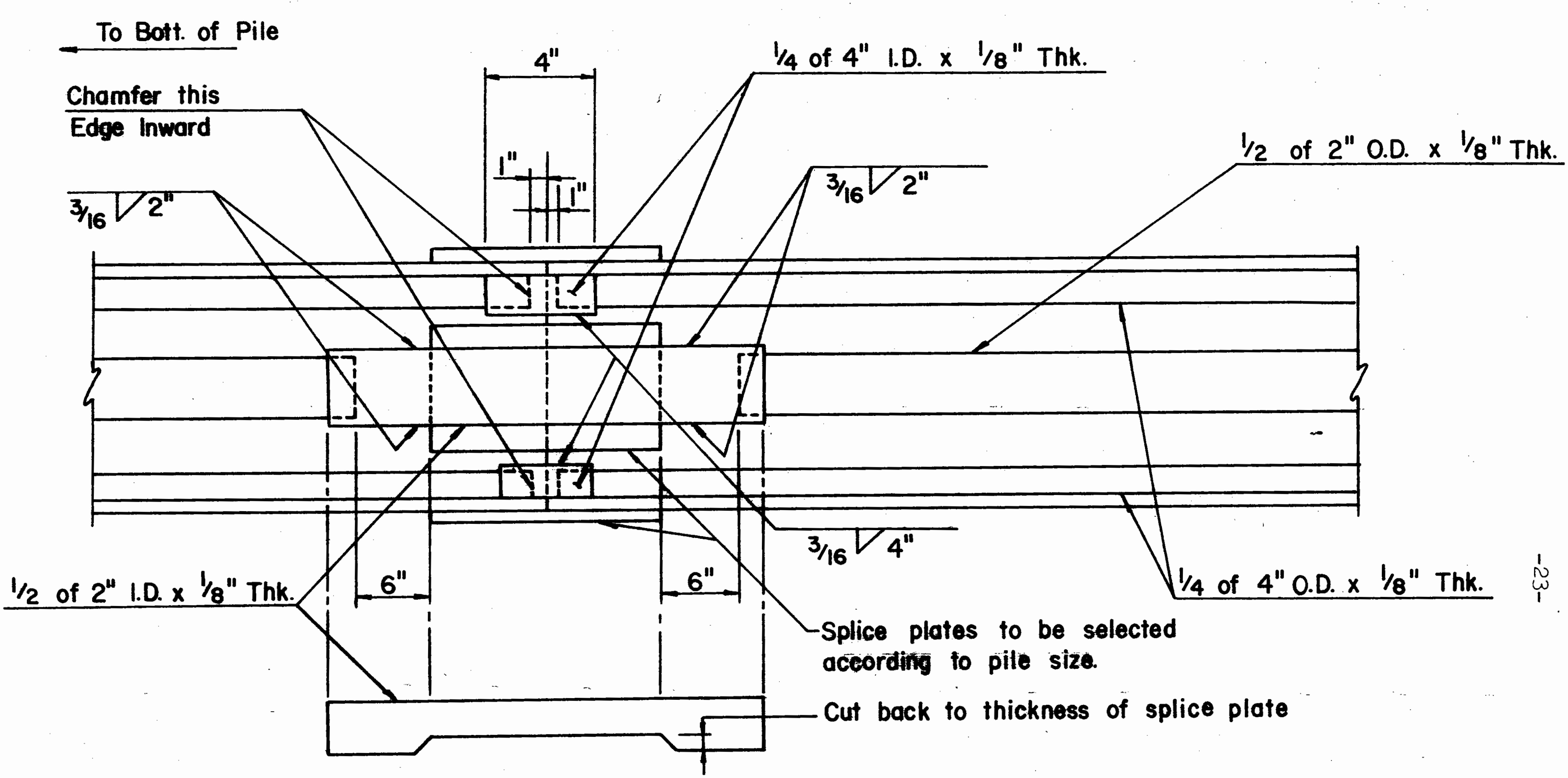
FIGURE 7



NOTE:
MECHANICAL AND ELECTRICAL GAUGES SAME FOR BOTH PILES.

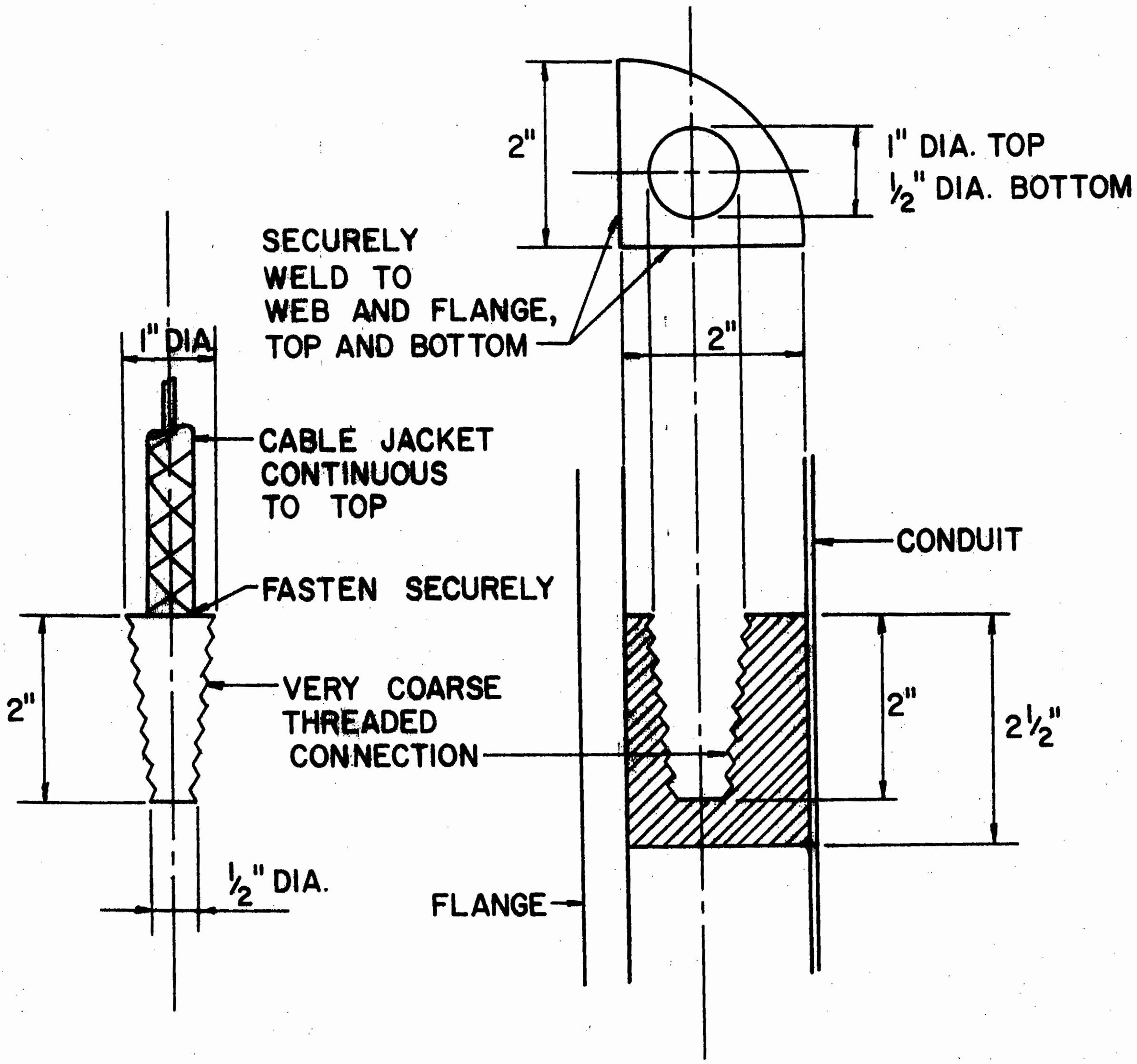
CROSS-SECTION THROUGH PILE SHOWING POSITIONING OF GAUGES

FIGURE 8



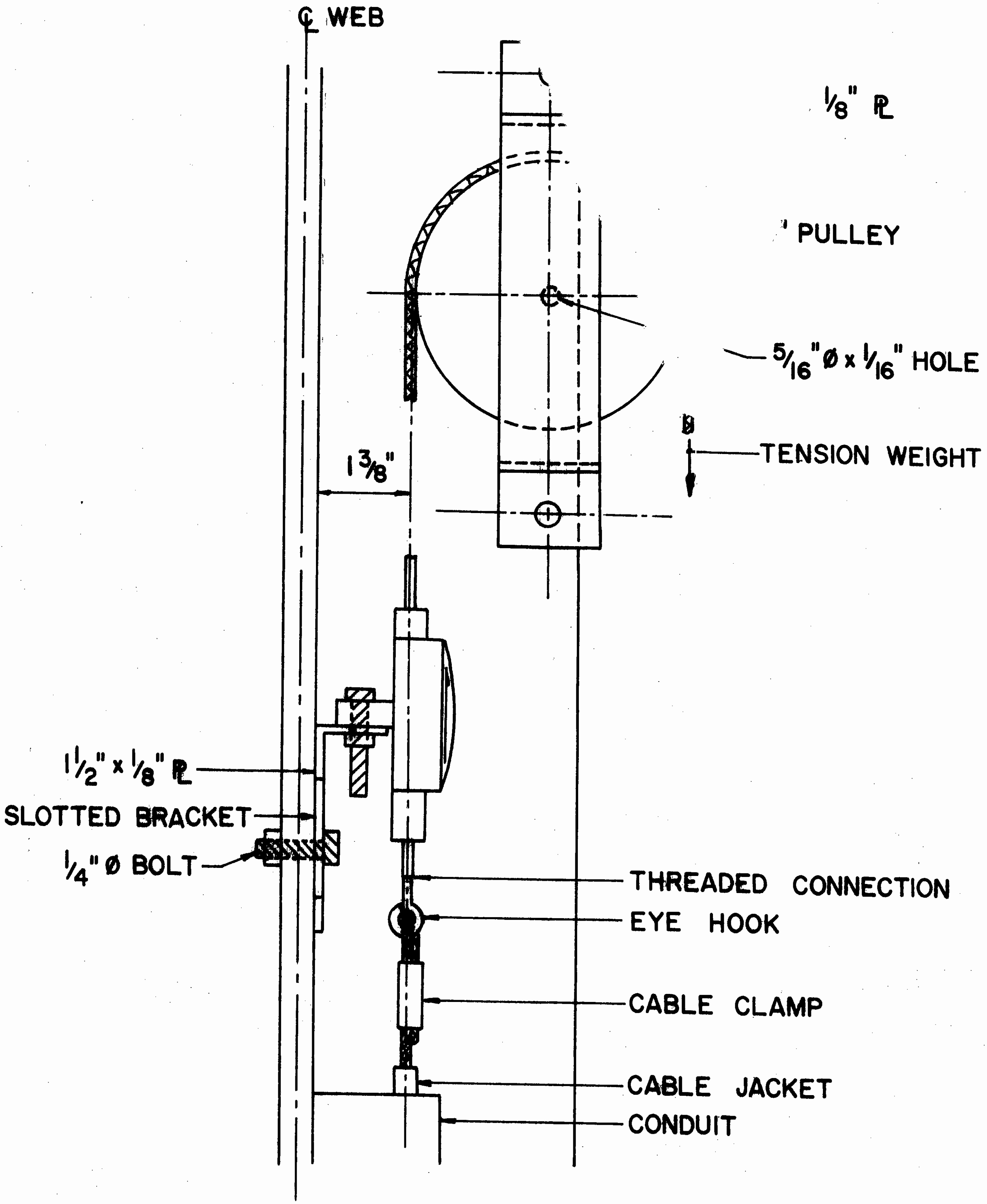
Connection for Strain Gauge Conduit
Across Pile Splice

FIGURE 10

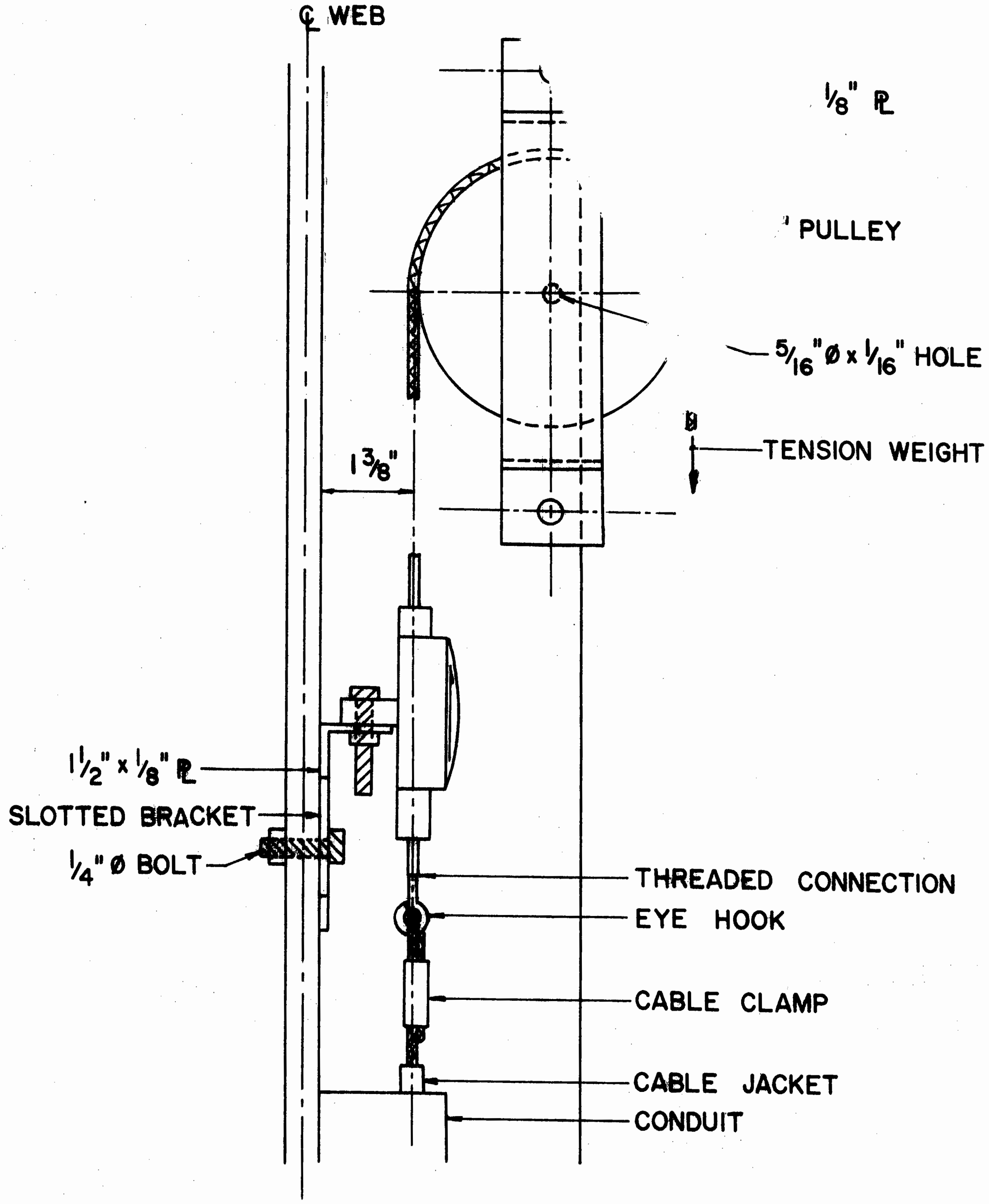


MECHANICAL STRAIN GAUGE ANCHORAGE

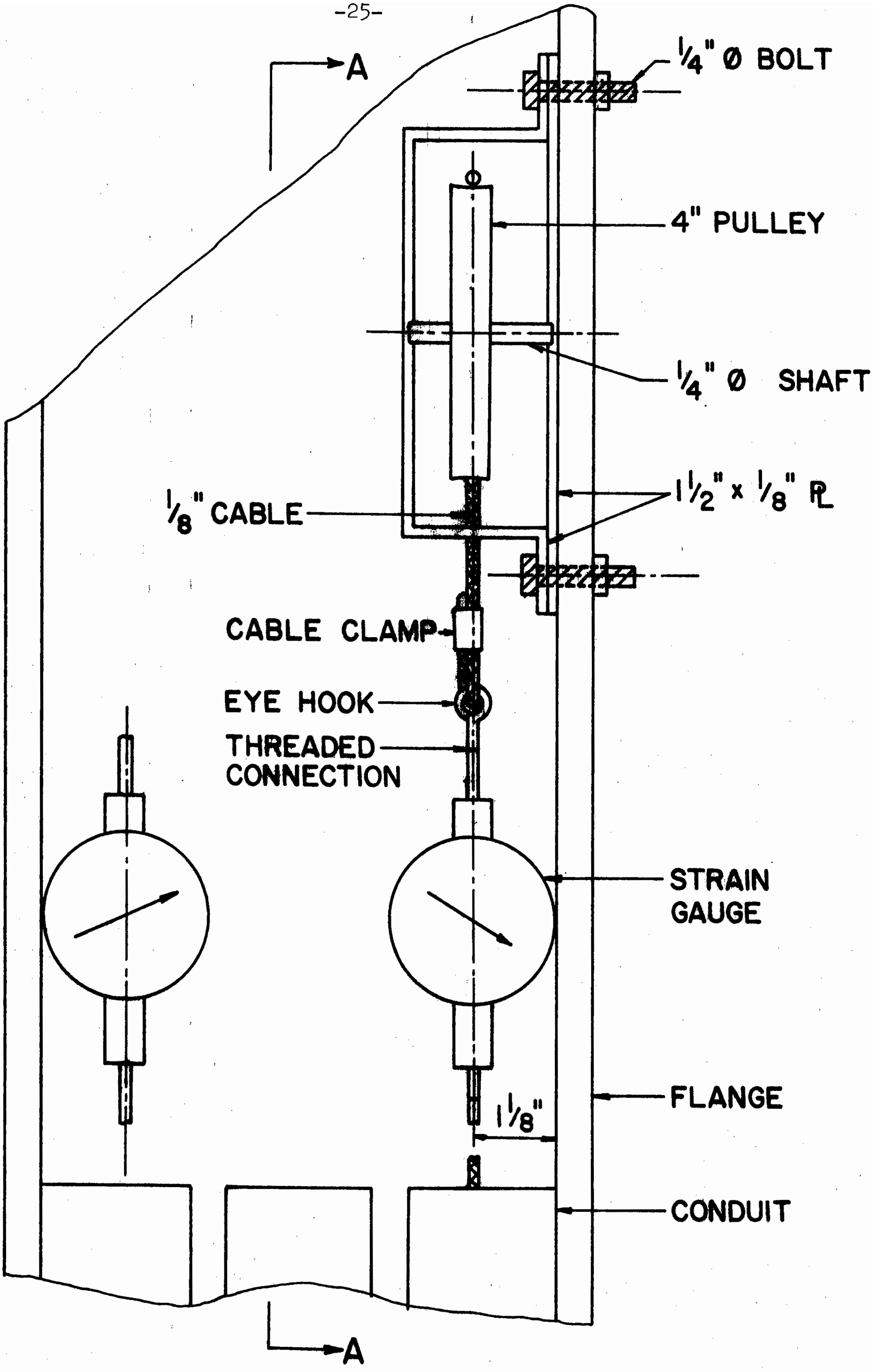
FIGURE 11



MECHANICAL STRAIN GAUGE
SECTION A-A
FIGURE 13



MECHANICAL STRAIN GAUGE
SECTION A-A
FIGURE 13



MECHANICAL STRAIN GAUGE LAYOUT

FIGURE 12