Techniques for Measuring Existing Long-Term Stresses in Prestressed Concrete Bridges, Vol. 2: Manual of Instruction

PUBLICATION NO. FHWA-RD-99-179

SEPTEMBER 1999

PB2000-100279

U.S. Department of Transportation
Federal Highway Administration

Research, Development, and Technology
Turner-Fairbank Highway Research Center
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FOREWORD

This report, *Techniques for Measuring Existing Long-Term Stresses in Prestressesed Concrete Bridges: Volume 11. Manual of Instruction*, presents the techniques studied by Construction Technology Laboratories under a contract with the Federal Highway Administration, Department of Transportation, Washington, DC.

Volume II is the second of a 3-part series. Volume I summarizes the analytical, laboratory, and field studies conducted to evaluate and improve flat-jack direct stress measurement techniques. Volume II presents a manual of instruction for using the equipment, while Volume III (previously published) summarizes the findings of the entire project.

This research was conducted to develop a technique for measuring the existing state of stress in prestressed concrete bridge members. This is needed to be able to evaluate the actual prestressing force and load capacity of prestressed concrete bridge members that may have been damaged. The evaluation included a state-of-the-art review of existing techniques and analytical studies of these techniques. Based on analytical results the flat-jack direct stress measurement technique was evaluated in laboratory and field tests. Based on these tests, Volume II was written to describe the equipment and procedures required to obtain reliable direct stress measurements.

Several strain relief methods, including boring and slitting techniques, were evaluated by performing analytical studies. The flat-jack slitting technique was determined to be the most promising. Laboratory tests were performed on unreinforced, reinforced, and prestressed concrete specimens. Additional variables included member thickness, magnitude of stress, and stress distribution. Various linear regression analyses were performed to determine the best relationship between flat-jack canceling pressure and internal concrete stress. Direct stress measurements taken on a 25-year-old prestressed concrete highway girder were similar to those determined from laboratory testing on companion girders.

Copies of this report are available from the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161.

T. Paul Teng, P.E.
Director
Office of Infrastructure
Research and Development

NOTICE

Technical Report Documentation Page

1. Report No. FHWA-RD- 99-179	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle
TECHNIQUES FOR MEASURING EXISTING LONG-TERM STRESSES IN PRESTRESSED CONCRETE BRIDGES
Vol. 2 Manual of Instruction

5. Report Date
September 1999

6. Performing Organization Code

7. Author(s) T. R. Overman, N. W. Hanson, B. G. Rabbat, B. J. Morgan, R. I. Zwiers, K. N. Shiu

8. Performing Organization Report No.
CR-4995-4321- 2

9. Performing Organization Name and Address
Construction Technology Laboratories
5420 Old Orchard Road
Skokie, Illinois 60077-4321

10. Work Unit No. (TRAIS)

11. Contract or Grant No.
DOT-FH-61-82-C-00020

12. Sponsoring Agency Name and Address
Offices of Research and Development
Federal Highway Administration
U. S. Department of Transportation
Washington, D. C. 20590

13. Type of Report and Period Covered
Final
July 1982 - December 1985

14. Sponsoring Agency Code

15. Supplementary Notes

FHWA Contract Manager: C. A. Ballinger (HNR-10)

16. Abstract

Various stress measurement techniques were evaluated in this study. The evaluation included a state-of-the-art review of existing techniques and analytical studies of these techniques. Based on analytical results the flat-jack direct stress measurement technique was evaluated in laboratory and field tests. Based on these tests a manual of instruction was written to describe the equipment and procedures required to obtain reliable direct stress measurements.

This manual of instruction outlines the equipment and techniques used in taking stress measurement readings. In addition, techniques for data analysis are explained. There are three reports in the series:

Vol. No.	FHWA No.	Short Title
-	FHWA-RD-85-	Executive Summary Report
1	FHWA-RD- 99-178	Analytical, Laboratory, and Field Studies
2	FHWA-RD- 99-179	Manual of Instruction

17. Key Words
Nondestructive tests, normal stress, strain, residual stress, reinforced concrete, prestressed concrete, field tests, determination of stress, instruction manual

18. Distribution Statement
No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	32	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

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1.0 INTRODUCTION

In a prestressed concrete member, the prestressing force decreases continuously with time at a decreasing rate. Decrease of prestressing force is primarily due to creep and shrinkage of the concrete and relaxation of the prestressing steel. Although there have been very few structural problems due to inaccuracies in estimating prestress losses, serviceability problems have occurred. The most common result of inaccurate estimates of losses is excessive camber or sag of prestressed girders, which can cause ride discomfort in bridges.

In segmental bridge construction, different prestressing systems may be utilized on one structure. Decks may be prestressed transversely. Webs may be prestressed in a vertical plane or diagonally across construction joints. Longitudinal prestressing is usually performed in stages as segments are erected. As a result, a complex state of stress exists in the bridge superstructure. Therefore, an accurate estimate of prestress forces and the resulting concrete stresses is very difficult in segmental bridge construction.

Several other factors affect the resultant prestressing force in tendons. In statically determinate bridge superstructures, temperature gradient across a cross section may cause minor changes in concrete and reinforcing steel stresses. If the bridge superstructure is statically indeterminate, temperature variation and differential settlement of supports will induce large stresses in the structure. In all cases, redistribution of stresses in the concrete will occur due to creep. As a result, the magnitude of concrete stresses will vary with time. Therefore, the exact state of stress can only be determined through measurements on the actual structure.

The flat-jack direct stress measurement technique can be used to determine internal stresses in existing structures. The technique was verified through analytical, laboratory, and field studies, detailed in Volume 1, under Federal Highway Administration Contract DTFH61-82-C-00020.

The stress measurement procedure begins with the selection of a particular location based on location of unknown stresses and locations of reinforcing and prestressing steel. Subsequently, a circular saw and reference points, used in measuring displacement, are installed. The distance between reference points is measured prior to cutting. An accurate cut is then made to a predetermined depth (figure 1). The saw blade is retracted. The appropriate flat jack and shims are installed (figure 2). The distance between reference points is measured. The flat jack is then pressurized in increments and displacement readings are taken after each increment. The pressure at which the slot displacement returns to its original position is the canceling pressure.

After displacement readings are taken for a given size flat jack, the flat-jack pressure is released and the jack is removed from the slot. Because the flat jack typically exceeds the required 4.0 mm (0.16 in) thickness after it has been used, it must be retracted somewhat. To perform this task, a press is used which returns the jack thickness to 4.0 mm (0.16 in).

After the flat jack has been removed, the saw blade is reinserted into the slot to make a deeper cut. This procedure continues with progressively deeper cuts. The results from all the cuts are averaged to obtain the stress. Multiple cuts are made to reduce experimental scatter and thus improve the accuracy of the method. Because temperature changes induce stresses in a restrained structure, it is recommended that stress measurements be taken at a time of day when temperature variations are minimal.

In this manual of instruction it is assumed that an engineer will oversee the construction and procurement of equipment, determine where cuts are to be made, supervise stress measurement operations, and reduce the raw data. It is also assumed that technicians will fabricate some equipment and fabricate points used in measuring displacement, make precision cuts, and take displacement readings.

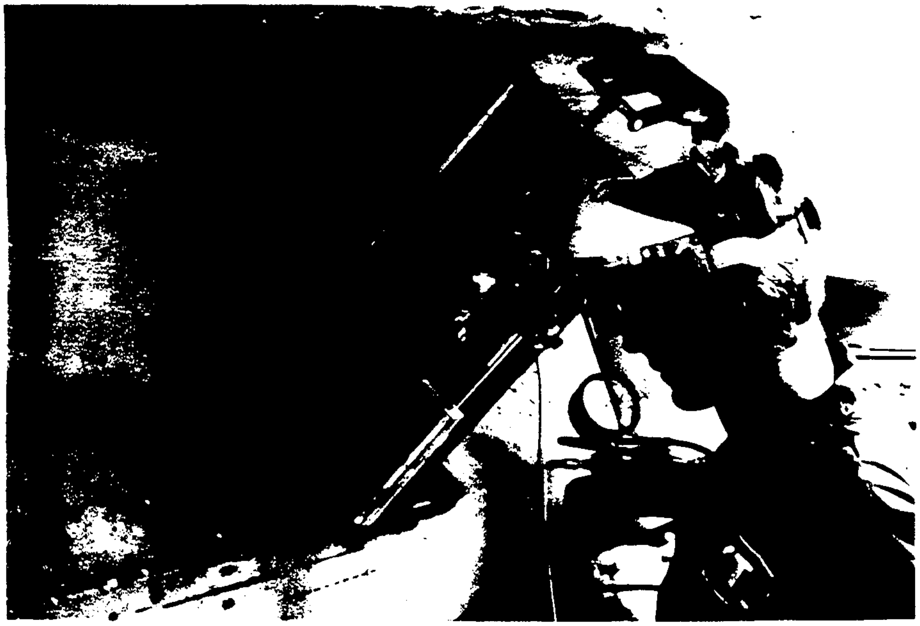

Figure 1. Use of precision saw.

Figure 2. Flat jack and pressure hose.

As a result of these assumptions, the technique is presented in three sections of this manual. Section 2.0 details the stress measurement equipment requirements; section 3.0 details fabrication of reference points, equipment requirements, and the stress measurement procedure; and section 4.0 outlines the engineering and data reduction requirements. The engineer should be familiar with all sections of this manual, while technicians should be concerned with all sections but 4.0.

2.0 EQUIPMENT REQUIREMENTS

The accuracy and reliability of stress measurements are dependent on the quality of the equipment. This section outlines cutting and measuring equipment requirements. These requirements were determined from the analytical, laboratory, and field studies.

2.1 Precision Saw

The precision saw used for stress measurement must cut smooth slots to precise depths; the blade must be 4.0 mm (0.16 in) thick, 300 mm (11.81 in) in diameter, and diamond tipped. The blade used in the laboratory and field studies had 21 teeth. The 150-mm (5.91-in) radius of the saw blade matches the radius of the flat jacks. The stress measurement procedure dictates that the saw assembly be swung away from the cut to make measurements. At all times the saw base must remain securely attached to the concrete surface. Prior to securely attaching the saw, movements of up to 1/4 in (6.35 mm) must be possible so the saw blade can be aligned properly. Slotted holes are often used for this purpose. Saws meeting these requirements are not currently available. Section 6.0, Appendix A, details the parts for a saw fabricated to meet these specifications.

2.2 Displacement Measuring Equipment

The equipment used to measure displacement must be capable of measuring displacements of 0.001 mm (39 millionths in) or less, consistently. The accuracy of manual readings is dependent on the technician. Therefore, the equipment should be compact and easy to handle. The use of a Pfender* mechanical gage, which was found to be the most suitable for this application, is assumed in this manual.

2.3 Flat Jacks and Peripheral Equipment

Pressure is applied against the sides of a slot by a flat jack inserted into the slot. The pressure at which the slot is returned to its initial, before cutting, position is the canceling pressure. To obtain valid canceling pressures, flat jacks must fit the slots snugly. To ensure that the jacks fit correctly, sheet metal shims (of various thicknesses and shaped like the flat jacks) are inserted into the slots along with the jacks. Flat jacks were procured from the French Government's "Laboratoire Central des Ponts et Chausses." Dimensions of the seven sizes of flat jacks are shown in figure 3. Use of the 20-mm jack is not recommended because of problems associated with surface cracking.

After a flat jack has been removed from a slot, it is typically thicker than the required 4.0 mm (0.16 in). To return it to the correct thickness, a press is used. The press is made from two 12-in (305-mm) by 4-in (102-mm) aluminum plates separated by 4.0-mm (0.16-in) spacers. Flat jacks are retracted by tightening four 1/2-in-diameter (12.7-mm) screws on the press.

2.4 Pressurization Equipment

Pressure is typically applied to the flat jacks by a hand pump and is monitored by a pressure transducer. The hand pump must be capable of applying small increments of pressure smoothly, that is, without sudden surges. The pressure transducer and peripheral equipment must be capable of measuring pressure to ± 5 psi (34 kPa). Pressurization equipment should be designed for pressures of at least 2000 psi (13.8 MPa).

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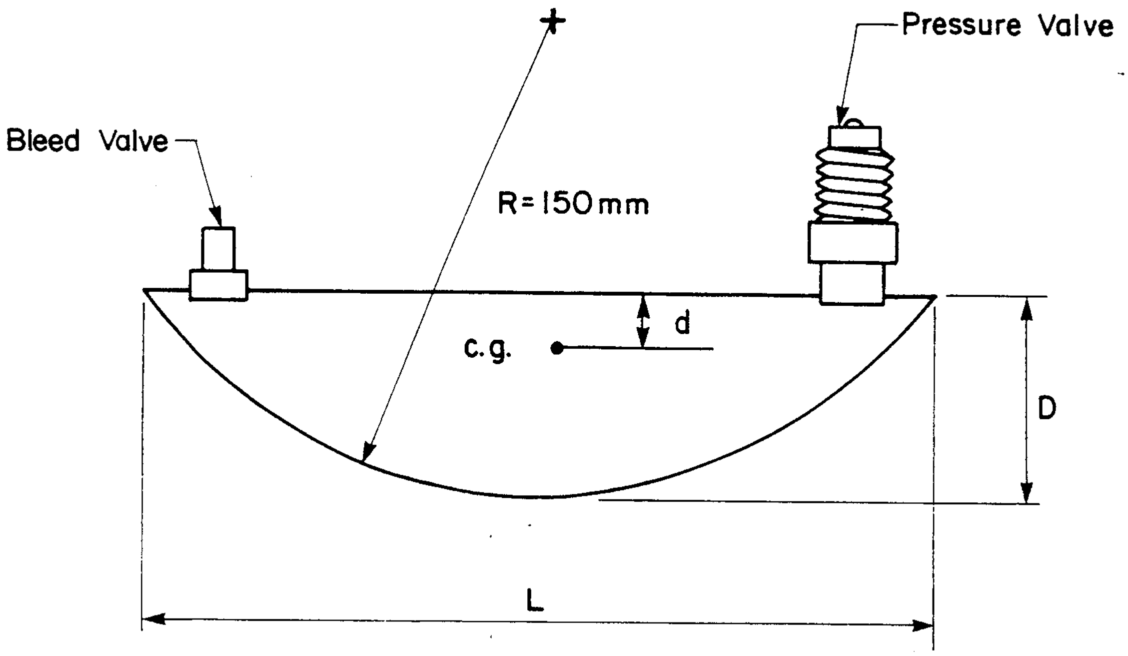
*The United States Government and the performing organization do not endorse products or manufacturers. Trade or manufacturer's names appear herein solely because they are considered essential for a complete description.



D	mm	20	30	40	50	60	70	80
	in	0.79	1.18	1.57	1.97	2.36	2.76	3.15
d	mm	8.3	12.0	16.0	20.4	24.6	28.6	32.9
	in	0.33	0.47	0.63	0.80	0.97	1.12	1.30
L	mm	150	180	204	224	240	254	265
	in	5.9	7.1	8.0	8.8	9.5	10.0	10.5

Thickness is 4.0 mm (0.16 in)

Metric Equivalent:
1 mm = 0.0394 in

Figure 3. Schematic of flat jacks.

3.0 TASKS PERFORMED BY TECHNICIANS

This section details the tasks that are typically performed by technicians in the stress measurement process. Their responsibilities include fabrication of reference points used in measuring displacement, using the Pfender gage, using the precision saw, and inserting and pressurizing the flat jacks.

The results of stress measurements are sensitive to the level of care and precision of the technicians. A word of caution is warranted at this time. The stress measurement equipment needed to make accurate cuts and to determine the internal stress of prestressed concrete members is precise and delicate, and must be treated accordingly.

3.1 Pressure and Displacement Measuring Equipment

The pressure and displacement measuring equipment includes a pressure transducer, a strain indicator to read the transducer, and a Pfender displacement measuring device. The pressure transducer and strain indicator must be portable, compact, and capable of measuring to ± 5 psi (34 kPa) pressure on the transducer. Pressure transducers and strain indicators are commercially available from various supplers. The Pfender gage, available from Fritz Staeger, Berlin, West Germany, with a gage length of 40 mm (1.6 in), is used to measure displacement.

A hand pump is used to pressurize the flat jack. The pump is commercially available from various vendors. Flat jacks were from the French Government's "Laboratoire Central des Ponts et Chausses." After a flat jack has been removed from a slot, it is typically thicker than the required 4.0 mm (0.16 in). To return it to the correct thickness, a press is required.

3.1.1 Fabrication of Reference Points

Assuming the Pfender gage is used to measure displacement, the reference points must be fabricated correctly to obtain accurate readings. Reference points consist of a steel ball embedded into a round steel "button." The Pfender gage was developed for use on structural steel, in which case, the steel balls were simply embedded into the steel to be measured. This is not possible with concrete, so "buttons" are needed to support the balls. A Pfender point fabrication kit, shown with the Pfender gage in figure 4, can be obtained from the gage manufacturer.

The fabrication process begins by cutting a 3/8-in-diameter (9.53-mm), 3/16-in-thick (4.76-mm) steel button from bar stock. A 1/32-in-diameter (0.79-mm) pilot hole is then punched in the center of the button. A photograph of bar stock and button is shown in figure 5.

Construction continues by enlarging the pilot hole and embedding a steel ball. Figure 6 shows the three tools used to:

1. Enlarge pilot hole.

2. Embed a steel ball into the hole.

3. Flatten the thin steel shoulders around the perimeter of the ball that are formed when the ball is embedded.

The third tool was not included in the construction kit but was fabricated from a steel punch. The hole in the end of the tool is slightly larger than the diameter of the steel ball.

Figure 7 shows the use of a fabrication tool. For best results, the reference points should be fabricated on a clean, smooth, hard surface.

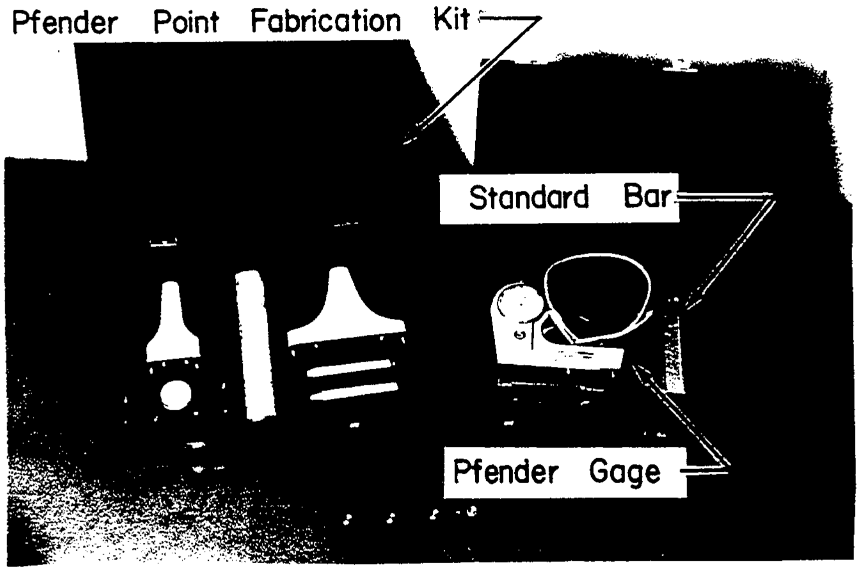
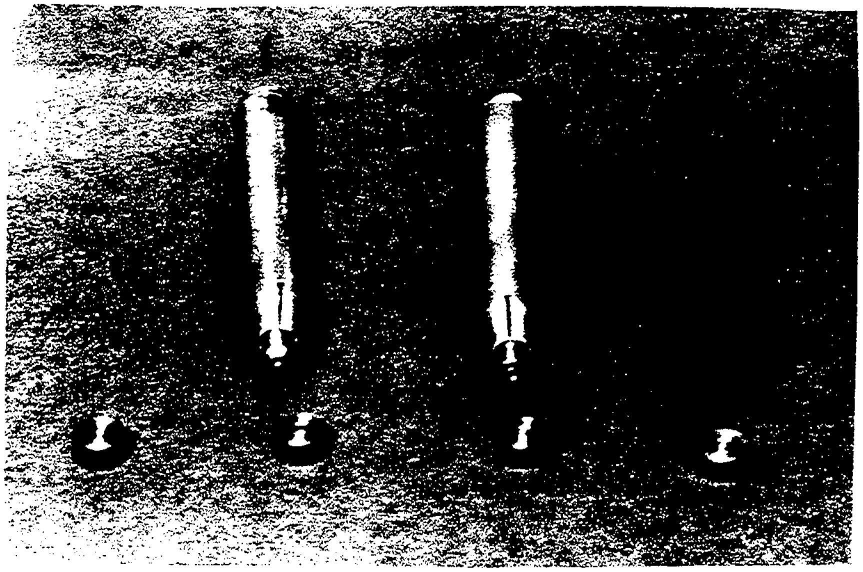


Figure 4. Pfender point fabrication kit and Pfender gage.

Figure 5. Pfender "button" cut from bar stock. A small pilot hole is punched in the center.



Tool 1. Used to enlarge pilot hole
Tool 2. Used to embed steel ball
Tool 3. Used to flatten steel shoulders around perimeter of ball

Figure 6. Various stages of Pfender instrumentation point construction and the accompanying tools.

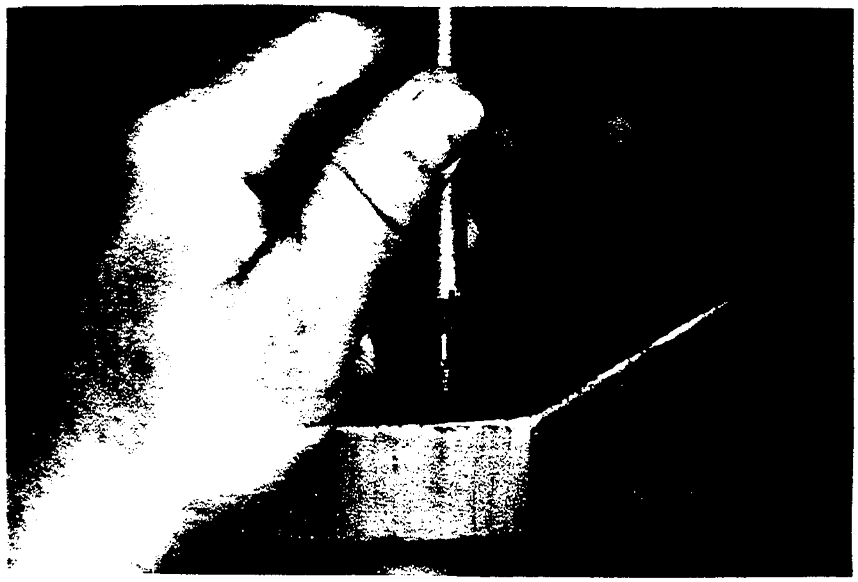


Figure 7. A deeper impression is made at the location of the punched hole with a Pfender tool.

Figure 8 shows various stages of point construction including a finished point. The construction process includes delicate work and can be time consuming.

3.1.2 Preparation

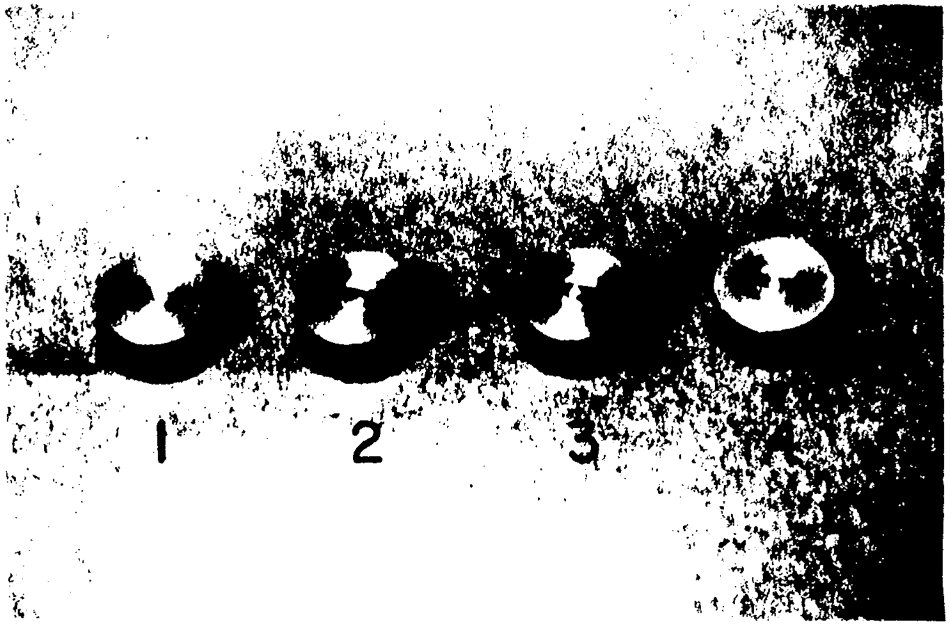
Before consistent, accurate readings can be obtained with the Pfender gage, some practice is required. It is recommended that several sets of Pfender points be applied to a convenient surface, such as a steel plate, and read until consistent readings can be obtained. Measurements should change by less than one Pfender division if the points are constructed properly and the technique is correct. The Pfender gage is a delicate piece of equipment and should be handled accordingly.

3.2 Sawing Equipment

The precision saw used for stress measurement must cut smooth slots to precise depths; the blade must be 4.0 mm (0.16 in) thick, 300 mm (11.8 in) in diameter, and diamond tipped. The blade used in the laboratory and field studies had 21 teeth. The 150-mm (5.91-in) radius of the saw blade matches the radius of the flat jacks. The stress measurement procedure dictates that the saw assembly be swung away from the cut to make measurements. At all times the saw base must remain securely attached to the concrete surface. Prior to securely attaching the saw, movements of up to 1/4 in (6.35 mm) must be possible so the saw blade can be aligned properly. Slotted holes are often used for this purpose. Saws meeting these requirements are not currently available. Appendix A details the parts for a saw fabricated to meet these specifications. Detailed drawings are shown for all machined parts. Sources for procured parts are also given. The entire saw assembly shown in figure 11 weighs 133 lbs (590 N).

3.3 Stress Measurement Procedure

Once the desired location for stress measurement has been determined, the following steps are performed.



1. A hole is punched into a 3/8-in-diameter (9.53-mm) steel disk.
2. An impression tool is used to widen the hole.
3. A 1/16-in-diameter (1.59-mm) ball is implanted into the hole.
4. The excess metal around the ball is flattened to complete the process.

Figure 8. Various stages of Pfender instrumentation point construction.

1. A pachometer or other device is used to precisely locate the primary reinforcing or prestressing steel. If secondary reinforcing steel cannot be avoided completely, it must be completely severed during cutting to obtain valid results.

2. The location of two rows (4 points) of Pfender reference points and holes for mounting the saw are laid out using a template. The template locates the Pfender points on either side of the saw cut and in pairs above and below the midheight of the cut. The spacing of Pfender points is shown in figure 9.

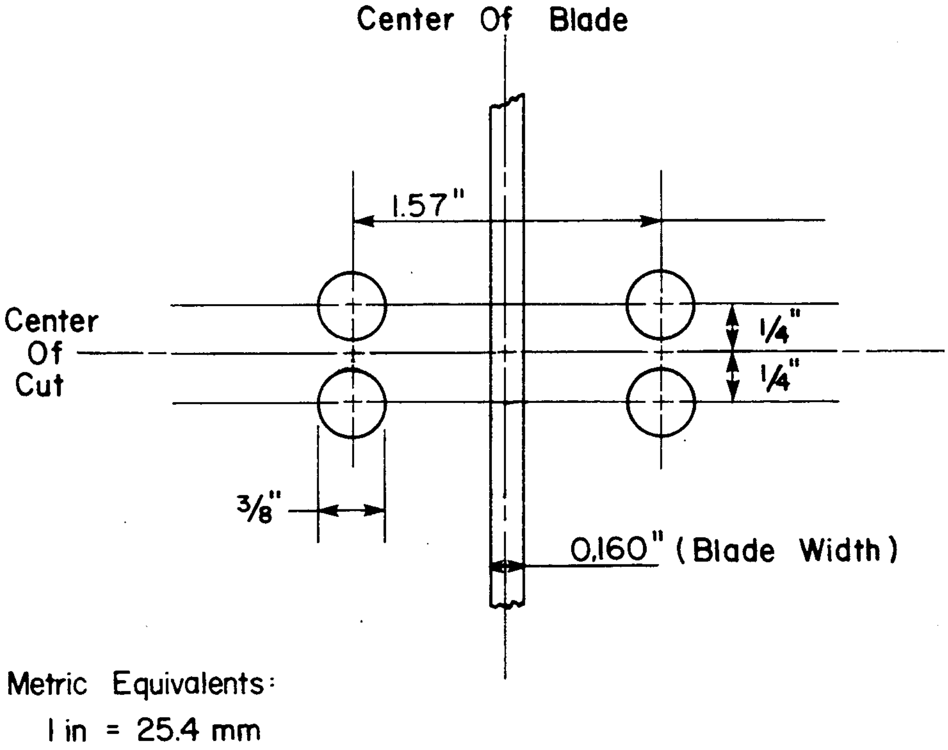


Figure 9. Pfender point spacing.

3. Holes are drilled for mounting the saw, and expansion anchors are inserted.

4. The base frame assembly (figure 12) is then snugly installed on the concrete surface by bolts to the expansion anchors. Readjustment will probably be required so the bolts only need to be snug.

5. Two sets of Pfender points (4 points) are glued to the specimen at the predetermined location. A quick-setting, waterproof epoxy is recommended. A small template is used to securely hold the spacing shown in figure 9 until the epoxy sets.

6. After the glue has hardened, the spacing between ball seats on the points is read with a Pfender gage to determine if readings are consistent (within plus or minus one Pfender unit) and near the center of the scale. Centering is necessary because displacements of up to 100 units or more are possible after cutting.

7. If points were improperly constructed or were glued incorrectly, repeat Steps 5 and 6.

8. The precision saw is then mounted on the base frame. The base frame is tightened securely once the blade is aligned properly at the centerline between the Pfender points.

9. The spacing between ball seats on the Pfender gage standard bar is read at least four times to obtain the initial standard reading. The bar's temperature is also recorded. The standard bar is shown with the Pfender gage in figure 4.

10. The two sets of Pfender points at the cut location are also read at least four times. The values are averaged to obtain the initial spacings.

11. The saw is swung into place and secured to the base frame with a lock bolt.

12. The blade is run down until it gently touches the surface to be sawed. A scale on the saw (Item 13, figure 19) to measure cut depth is subsequently zeroed.

13. A slot is then cut to the predetermined depth, D, shown in figure 3, using the scale as a guide. No supplementary cooling is provided, therefore, cutting should progress as quickly as possible to prevent heat build-up in the adjacent concrete.

14. After cutting, the blade is retracted while it is still turning.

15. The saw is switched off once the blade is free from the concrete.

16. The locking bolt is then removed and the saw is swung away from the cut.

17. A flat jack corresponding to the cut depth is inserted along with shims, shaped like the jack, so the flat jack fits snugly in the saw cut. Flat jack dimensions are shown in figure 3.

18. The pressure hose is attached at the quick-disconnect connection (figures 2 and 3).

19. The standard bar (figure 4) is read at least four times and recorded along with the bar temperature.

20. Pfender point spacing is measured at zero pressure. Again, the distances between both sets of points are read at least 4 times.

21. If the point spacings are greater than the initial spacings, the region under consideration is probably in tension. To prevent cracking of the concrete and questionable results, the flat-jack pressure must be limited to approximately 200 psi (1.38 MPa).

22. The flat jack is pressurized incrementally with at least four Pfender point readings taken for each set of points at each pressure. At least three pressure levels above zero are recommended, such as 200, 400, and 600 psi (1.38, 2.76, and 4.14 MPa).

23. The pressure is then released, and the flat jack and shims removed.

24. The flat jack, with the hydraulic hose attached, is then placed in a press to return it to the original thickness of 4.0 mm (0.16 in). After the jack has been retracted, the hydraulic hose is removed and the clamping force is released.

25. The saw is subsequently swung into place and secured to the base frame.

26. Steps 13 through 25 are then repeated for progressively deeper cuts.

27. Once the last measurements have been taken, the slot can be filled with dry-pack grout.

4.0 TASKS PERFORMED BY ENGINEER

This section details the tasks to be performed by the engineer in the stress measurement process. Responsibilities include determination of location for measurements, actual location selection, evaluation of displacement readings, and data reduction and analysis.

4.1 Location Selection

Prior to making any stress measurement cuts, the location must be selected with care. The engineer must consider location and orientation of stresses to be determined, design and as-built locations of reinforcing and prestressing steel, and accessibility.

The flat-jack technique measures the stress in the direction perpendicular to the slot. Where combined stresses exist, it may be necessary to make preliminary calculations to determine orientation of the principal stresses. If principal stresses are required, it is possible to make two cuts in orthogonal directions. In this case, the slots should be more than 1 ft (305 mm) apart. Care should be taken to avoid disturbing the strain field in the neighborhood of a slot prior to cutting the slot. When available, construction drawings can be helpful to determine general location and orientation of the slots. Exact location of cuts must be determined on location with the aid of a pachometer or other device, which indicates location of reinforcing and prestressing steel. Actual location of steel may be different from design location as a result of allowable tolerances, or construction changes. Laboratory tests indicated that stresses can be determined accurately when reinforcing steel is completely cut. Before the steel is severed, stress measurement readings were unreliable. Therefore, reinforcing steel must be either avoided or completely cut. Structural integrity and strength must also be considered before reinforcing steel is cut. In no case should primary reinforcement such as reinforcing steel or tensioned strands or cables, be cut.

Accessibility is important because technicians must be able to install the saw and make cuts. In addition, the technician taking readings must be in a comfortable position. The measurement equipment is delicate and the readings can be operator sensitive if sufficient care is not taken. Therefore, questionable readings can result when the selected slot locations are not easily accessible.

4.2 Evaluation of Displacement Readings

An engineer must be on site to evaluate displacement readings when they are taken. Generally a minimum of four readings are taken at each pressure, for two sets of reference points, for each slot depth. If the range of the four readings varies by more than one unit, additional readings are required until consistency is obtained. The technician's technique or precision of reference points should be checked if inconsistent readings persist. The chief advantage of taking measurements at more than one slot depth is to reduce experimental scatter and to increase accuracy.

Evaluation of displacement readings also involves averaging readings for each pressure for a given cut depth. Where more than four readings are taken, the last four consistent values only can be averaged. As an additional check, averaged readings and their corresponding pressures can be plotted. The line should be approximately linear. Pressure and displacement readings are taken at three or more pressures, including zero, for analysis purposes.

4.3 Data Reduction and Analysis

The averaged readings are used to determine canceling pressures and internal stresses. Displacement readings are a function of flat jack pressure, changes in the Pfender gage due to handling, and changes in the standard bar and concrete due to temperature. To reduce the effect of concrete temperature variation on stress measurements, readings should be taken at a time when temperature fluctuations are minimal. To determine the pressure induced displacement, Δ (in thousandths mm), the following equation is used:

$$\Delta = (Pr_j - Pr_o) + (S_j - S_o) + [(t_o - t_j)(0.17x10^{-6})40(\frac{1}{1000})]$$

Where:

Pr_j = averaged Pfender reading
Pr_o = averaged initial Pfender reading
S_j = the averaged standard reading that corresponds to Pfender reading Pr_j
S_o = the averaged initial standard reading
t_j = the standard bar temperature when S_j was taken, °F
t_o = the initial standard bar temperature, °F
$6.0x10^{-6}$ = the coefficient of thermal expansion of the steel standard bar included with the gage
40 = the recommended Pfender gage length, mm
$\frac{1}{1000}$ = factor because Pfender Units are one thousandth mm

The pressure versus displacement relationship is linear, but individual pressure induced displacements at discrete pressures reflect some sampling error, so the relationship for a set of readings is only approximately linear. To determine the "best" linear relationship a least squares analysis is performed. The least squares analysis minimizes the distance from the calculated line to individual points and is explained in detail in most basic statistical textbooks.

The statistical analysis should include calculation of the linear parameters a and b, as shown in figure 10, and a correlation coefficient. The parameter "a" is the y-intercept while "b" is the slope. For these measurements, the correlation coefficient which varies from +1, perfect positive correlation, to 0, no correlation, indicates the extent of sampling error. Generally, the correlation coefficient should be greater than +0.95. A linear relationship has a coefficient of +1.0. The y-intercept value, a, is the canceling pressure.

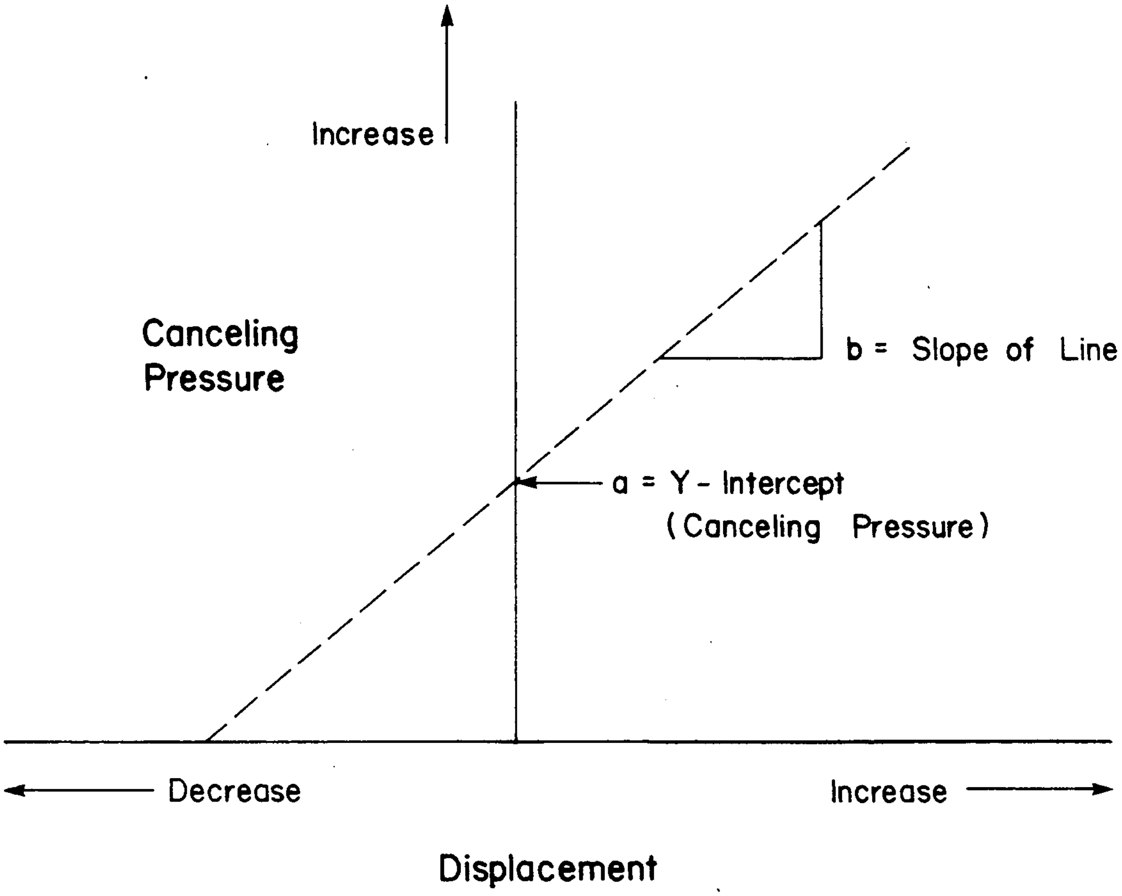


Figure 10. Y-intercept and slope of regression line.

The canceling pressures are not equal to the concrete stress. The following equation is recommended to calculate internal concrete stress:

Internal Concrete stress (psi) = 200 psi + 0.8 Canceling Pressure (psi)
Internal Concrete Stress (kPa) = 1378 kPa + 0.8 Canceling Pressure (kPa)

This equation was developed for applied stresses from zero to 1000 psi (0 to 6.895 MPa). The 90 percent confidence level corresponds to a stress of ± 125 psi (861 kPa) for individual canceling pressures. When the data from both sets of Pfender points and all seven cut depths are averaged, the 90 percent confidence level corresponds to a stress of ± 90 psi (620 kPa) and the 95 percent confidence level corresponds to ± 100 psi (689 kPa).

5.0 APPENDIX A - PARTS FOR SAW ASSEMBLY

Appendix A details the parts for a precision saw used to cut smooth slots in concrete. The machined parts are shown in table 1 and detailed in figures 11 through 19. The origins of the stock parts are shown in table 2.

Table 1. Machined parts.

Description	Number	Figure Number
Base Frame Assembly	1	12
Support Frame	1	13
Bearing Post	2	14
Central Box	1	15
Cross Angle	1	16
Cross Bar	1	17
5/8-in Threaded Crank Shaft	1	18
Shaft Collar	1	18
14x5x1-1/4-in Sheet Metal Belt Shield	1	To Suit
5/8-in Hinge Shaft	1	To Suit
Blade Guard	1	To Suit

Metric Equivalent:
1 in = 25.4 mm

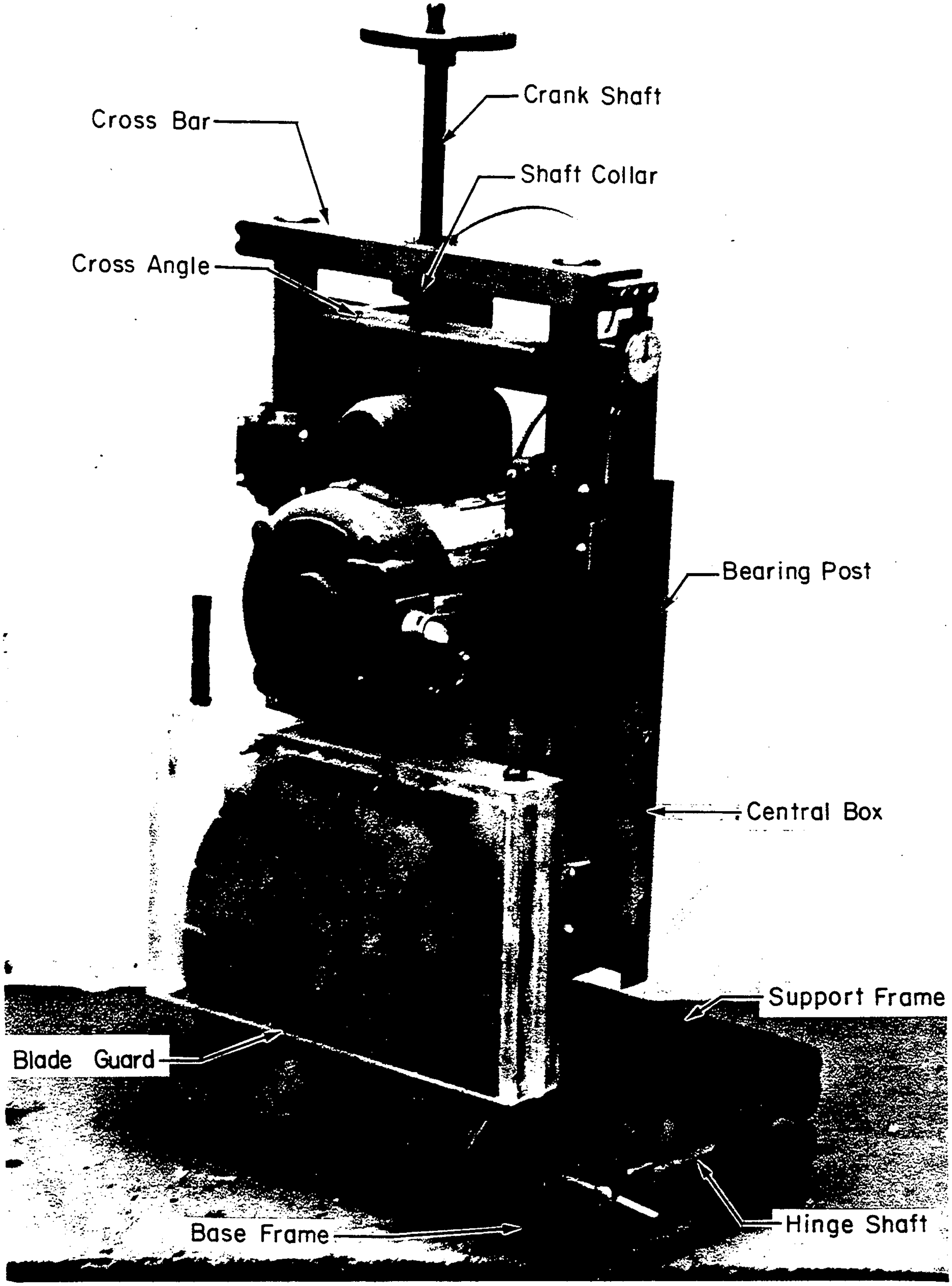
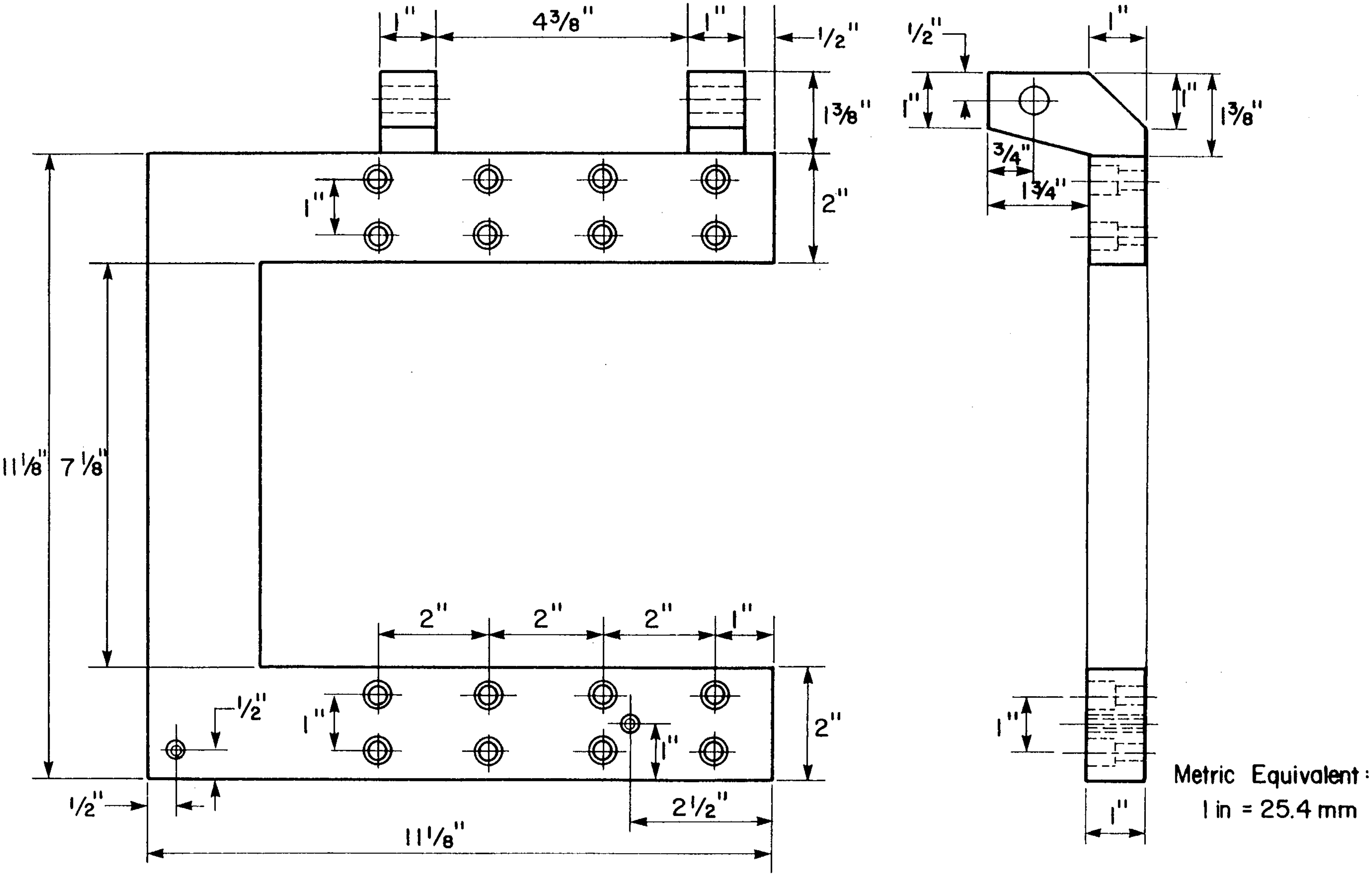
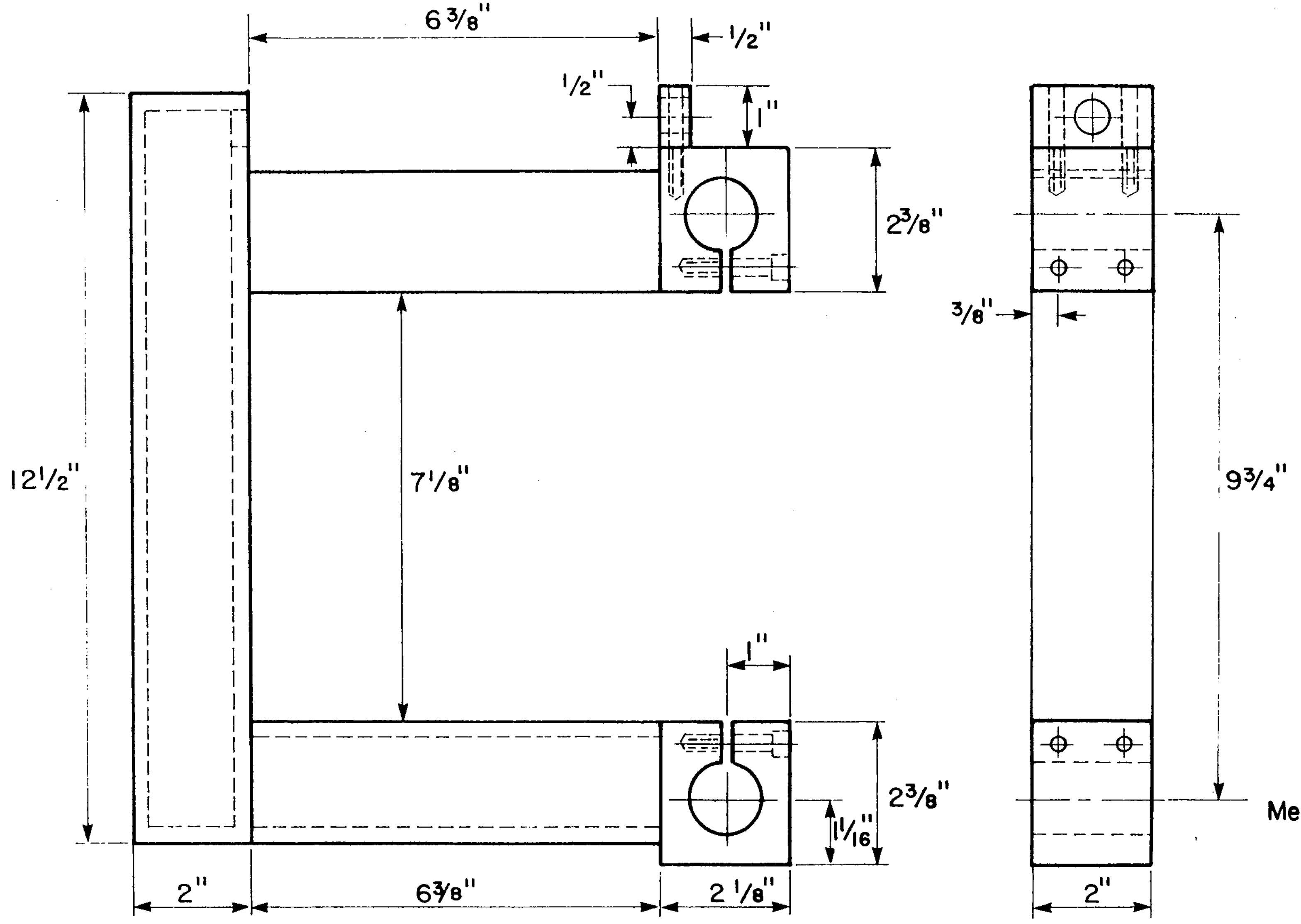


Figure 11. Precision saw, blade retracted. (Machined parts.)



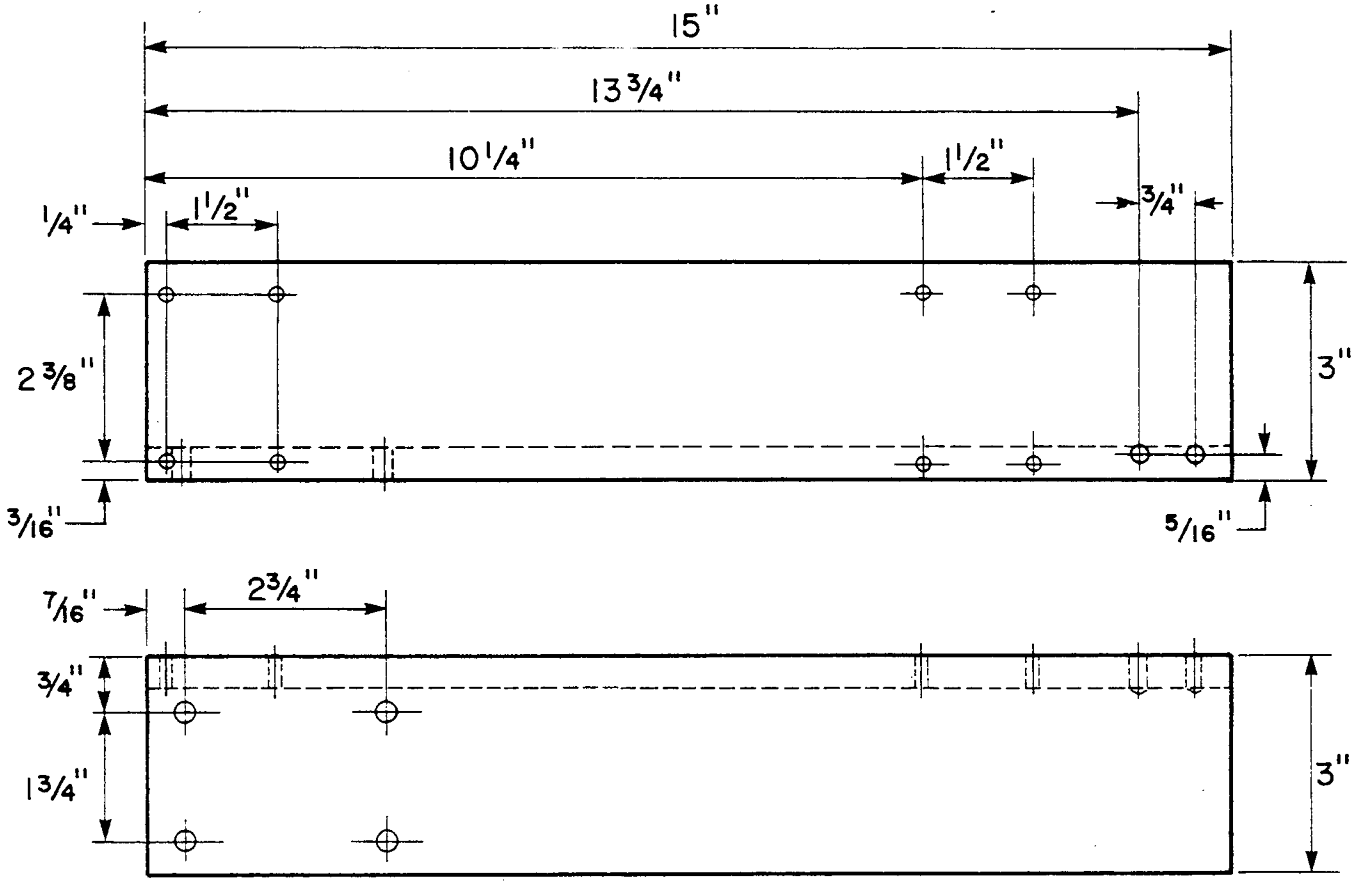
Metric Equivalent:
1 in = 25.4 mm

Figure 12. Base frame assembly.



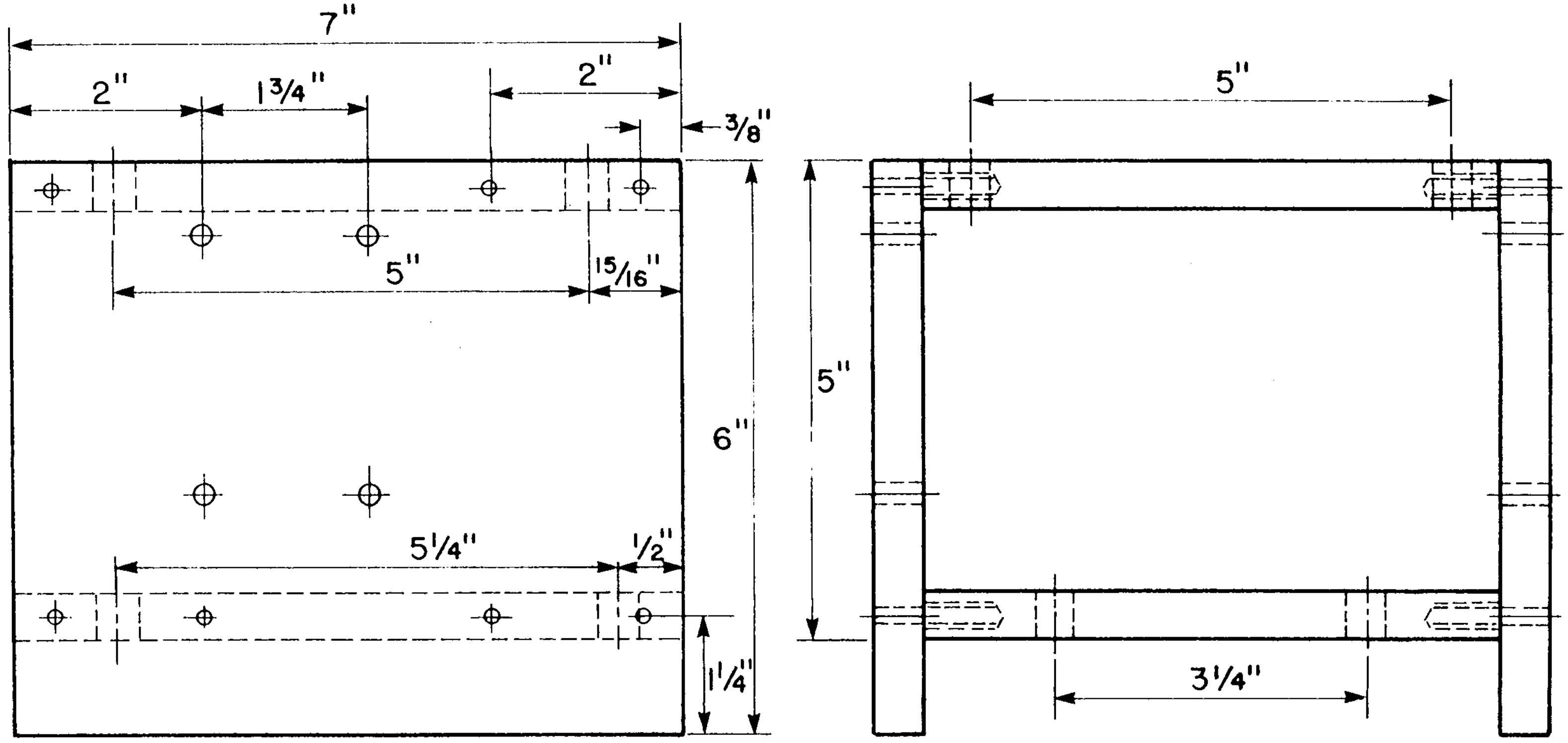
Metric Equivalent:
1 in = 25.4 mm

Figure 13. Support frame.



Metric Equivalent:
1 in = 25.4 mm

Figure 14. Bearing post.



Metric Equivalent:
1 in = 25.4 mm

Figure 15. Central box.

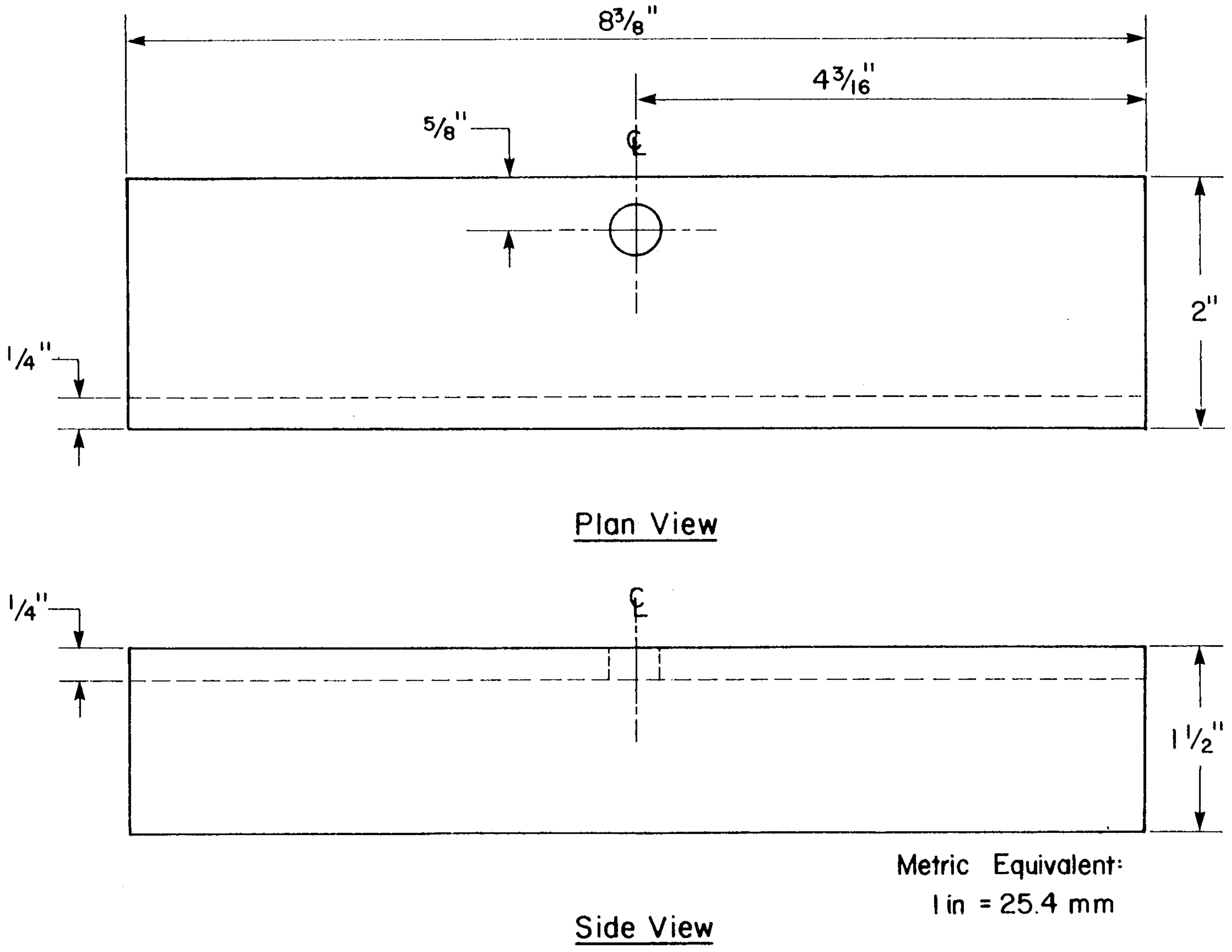
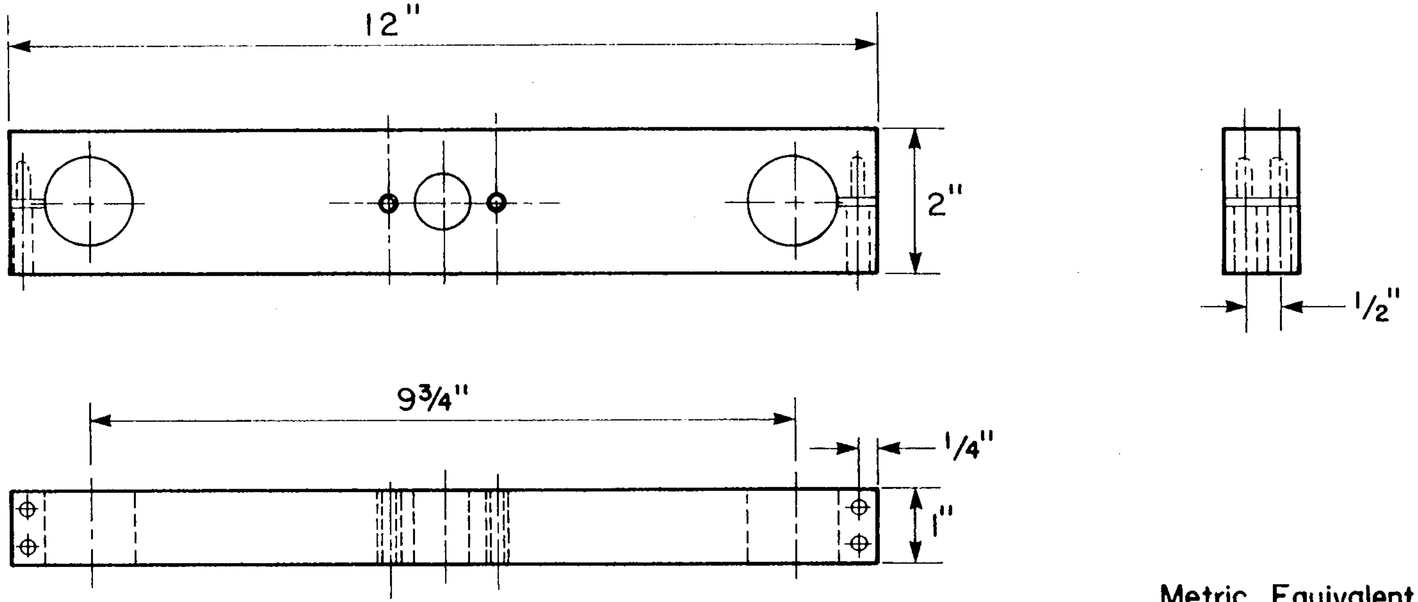


Figure 16. Cross angle.



Metric Equivalent:
1 in = 25.4 mm

Figure 17. Cross bar.

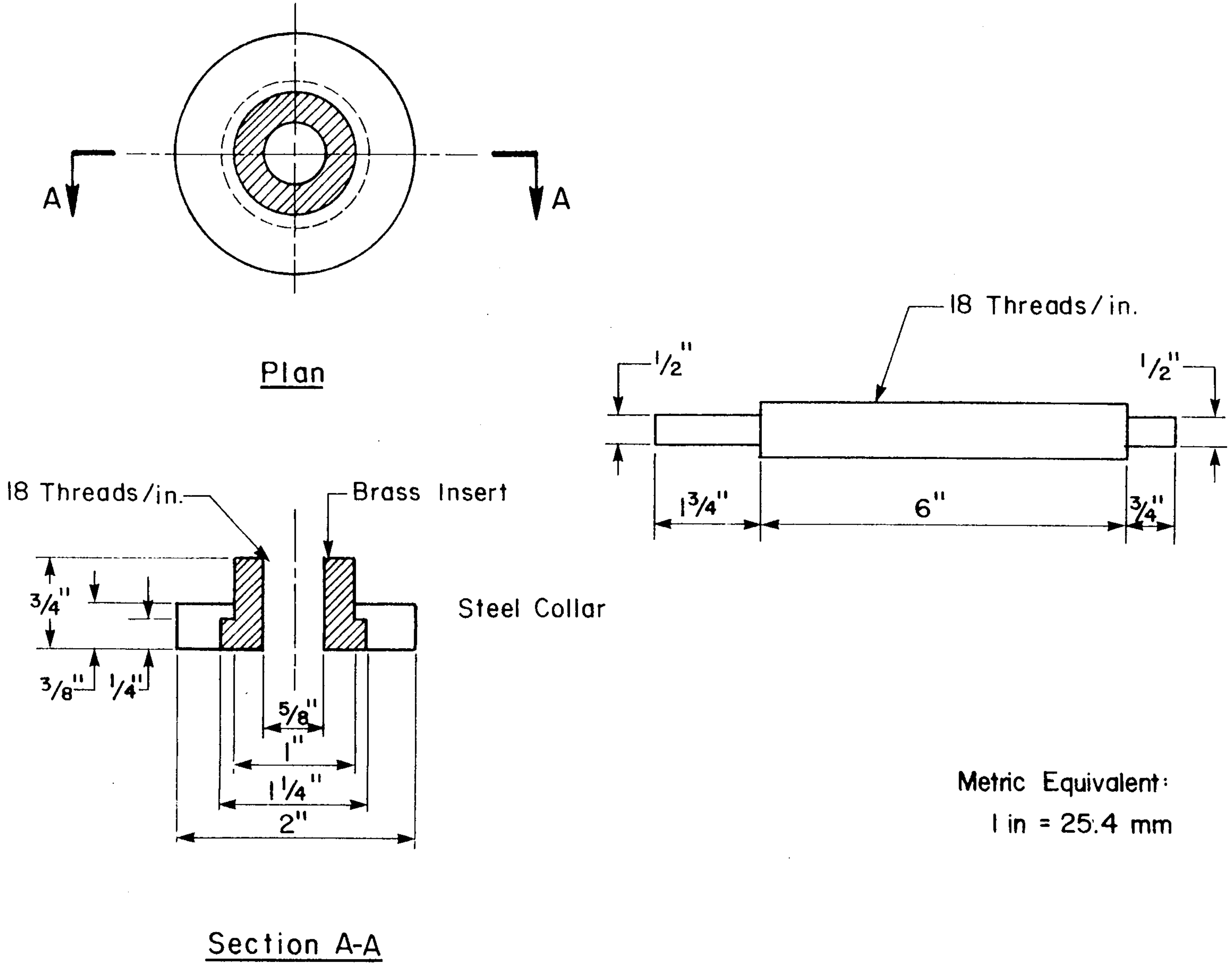


Figure 18. Shaft collar and threaded crank shaft.

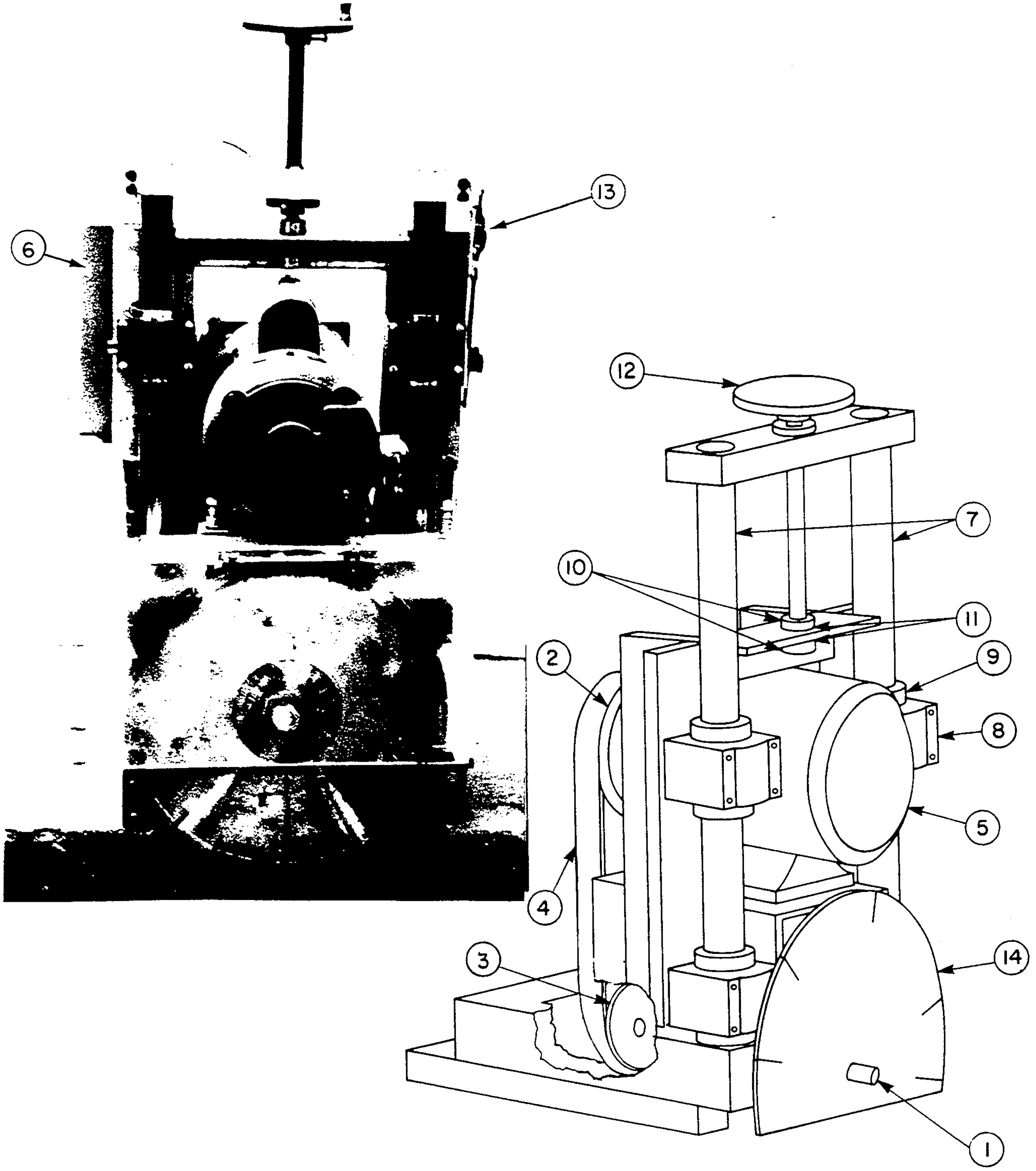


Figure 19. Precision saw, blade extended. (Procured parts.)

Table 2. Procured parts.

Part Designation	Description	Number	Stock Number
1	Belt-to-Blade Mandrel	1	(1)* 2x625
2	3.75-in O.D. Belt Sheave	1	(1) 3x887
3	4.45-in O.D. Belt Sheave	1	(1) 3x782
4	1/2-in Top Width x 9/32-in-Thick x 32-in-Length V-Belt	1	(1) 4L320
5	1-1/2 HP 1725 RPM, 115V Electric Motor with Ball Bearing and 56H NEMA Frame	1	(1) 5K923
6	Motor Control Unit	1	To Suit
7	1-1/4-in-Diameter x 21-3/4-in Hardened Steel Shaft	2	(2) LMS-20-21-3/4
8	1-1/4-in Ball Bearing Mounting Bracket	4	(2) LME-6
9	Linear Recirculating Ball Bearing	4	(2) LMB-6-W
10	1/2-in Set Screw Collar	2	(2) CS-39
11	Teflon Thrust Washer	2	(2) CD8-5
12	4-in-Diagonal Knurled Hand Crank	1	(2) CN2-18
13	130-mm Plastic Dial Caliper	1	(3) 8588A11
14	300-mm-Diameter x 4.00-mm-Thick Diamond-Tipped Saw Blade with 21 Teeth	1	Made to Specifications

*(1) Grainger's Wholesale Net Price Motorbook, No. 365, Spring 1984
(2) Winfred M. Berg, Inc., Manual B, 1979
(3) McMaster-Carr Supply Company, Catalog 91

Metric Equivalent:
1 in = 25.4 mm
1 mm = 0.0394 in
1 HP = 745.7 N.m/s