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Borehole Shear Tester: Equipment and Technique

By Khamis Y. Haramy

UNITED STATES DEPARTMENT OF THE INTERIOR

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UNITED STATES DEPARTMENT OF THE INTERIOR
James G. Watt, Secretary

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As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. administration.

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BOREHOLE SHEAR TESTER: EQUIPMENT AND TECHNIQUE

By Khamis Y. Haramy[1]

ABSTRACT

This Bureau of Mines paper describes the use of the borehole shear tester (BST) in mines. Assembly and procedure sections explain how the equipment is assembled and used properly. Schematics of the BST, limitations, test hole specifications, data recording, and calculations are all explained briefly, and an example of the data collecting and calculations is given to assist understanding.

INTRODUCTION

The borehole shear tester (BST) was developed by Dr. Richard L. Handy of Iowa State University in 1976 under Bureau of Mines Contract G0144021. The purpose of the work was to obtain a device for rapid, in situ measurement of rock shearing strength as a function of the normal stress acting on the plane of failure. The device is light in weight, mechanically simple, and easily transported. It is sufficiently durable to withstand repeated use in adverse environmental conditions and can be used in the rib, roof, or floor of the mine. It requires an NX-size borehole.

The data obtained from BST tests support well-known theories such as Mohr's theory of failure. This theory is based on a relationship between shearing stresses and normal stress at every point within the specimen body. The Coloumb theory, which is considered to be a special case of Mohr's theory, and the 1921 Griffith theory, which deals with material failure on a microscopic basis, are also supported by the BST results.

Owing to the difficulty in obtaining large samples of coal and rock for laboratory testing and the bias that is introduced in large samples, the borehole shear tester promises to be of significant value to the mining engineer and researcher in determining physical properties of in situ rock formations.

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USING THE BOREHOLE SHEAR TESTER

The BST is a device for making in situ tests to determine the shear strength of coal and rock using a 76-mm-diameter borehole (NX-size) up to 12 m long determines the shear strength as a function of the normal stress acting on a plane of failure.

LIMITATIONS

1. Do not use the BST in unsupported roof rock or within 1 foot of the borehole collar because it may cause spalling and buckling.

2. Do not exceed a shearing stress of 6,500 psig.

3. Do not fully extend the shear plates unless the BST body is in place inside the borehole.

4. Use the right type of shear plates depending on the type of rock tested, as described in table 1.

TABLE 1.—Types of shear plates available for various rock types

Type designation	Configuration	Tooth spacing, inch	Number of teeth	Tooth depth, inch	Shear area per plate, sq in	Remarks
Steel...	Flat full wedge.	0.4	3	0.040	0.8	Used for softer rocks only.
Carbide insert.	.. do ..	.8	2	.040	.7	Used for coal and all other rocks.[1]

[1]The upper limit of rock strength has not been decided. However, the device has been used in hard rock such as granite.

TEST HOLE SPECIFICATIONS

1. Diameter of test hole should be 76 mm (NX-size).

2. Length of test hole should not be less than 1 meter.

3. Hole should be dry to prevent rock dust penetrating behind the shear plates and thus preventing their free rotation. If water exists, the shear head swivel should be covered with a heavy grease.

4. Hole must be freshly drilled and clear of dust and cuttings, especially in rapidly deteriorating material such as coal and shale.

5. Drilling may be done by diamond bit, pneumatic percussion drill, or others, provided the borehole is smooth, straight, and free of ridges.

BST COMPONENTS

The unassembled BST components are shown in figure 1.

Shear Head (fig. 2)

1. Two shear plates, each with two or three teeth which penetrate into the rock when normal pressure is applied, are mounted at the end of a double-acting hydraulic cylinder. The plates are fixed in place and linked to individual push plates, which apply the normal force. Two types of shear plates are available for use with different ranges of rock strength (table 1). The steel plates are adequate for coal and softer rocks. If the teeth chip or wear, the carbide insert shoes should be used.

2. The two push plates are connected to a locking mechanism and stay parallel during initial shear head expansion.

3. Two short hydraulic hoses of different lengths are provided, which connect onto the BST body. One is used for shear plates expansion, the other for retraction.

Pulling Assembly (fig. 3)

1. A 12-ton center hole, hydraulic jack fits over the threaded pull rod for pulling.

2. An adjustable tripod is used to assure axial alinement of jack and threaded rod.

3. Jack base plate.

4. A lock grip half-nut clamp provides a quick-acting stop nut on the threaded rod.

5. A dial gage reads displacement of BST in the hole, if required.

Console (fig. 4)

1. Hand pump.

2. Lever-type pump valve for "open-close" operating modes.

3. Normal pressure valve and gage to read the applied pressure for normal forces against the shear plates.

4. Shear pressure valve and gage to read the applied pressure for shearing forces between the shear plates and the rock.

5. Manifold valve (expand-neutral-retract) used for the expansion and retraction of the shear plates.

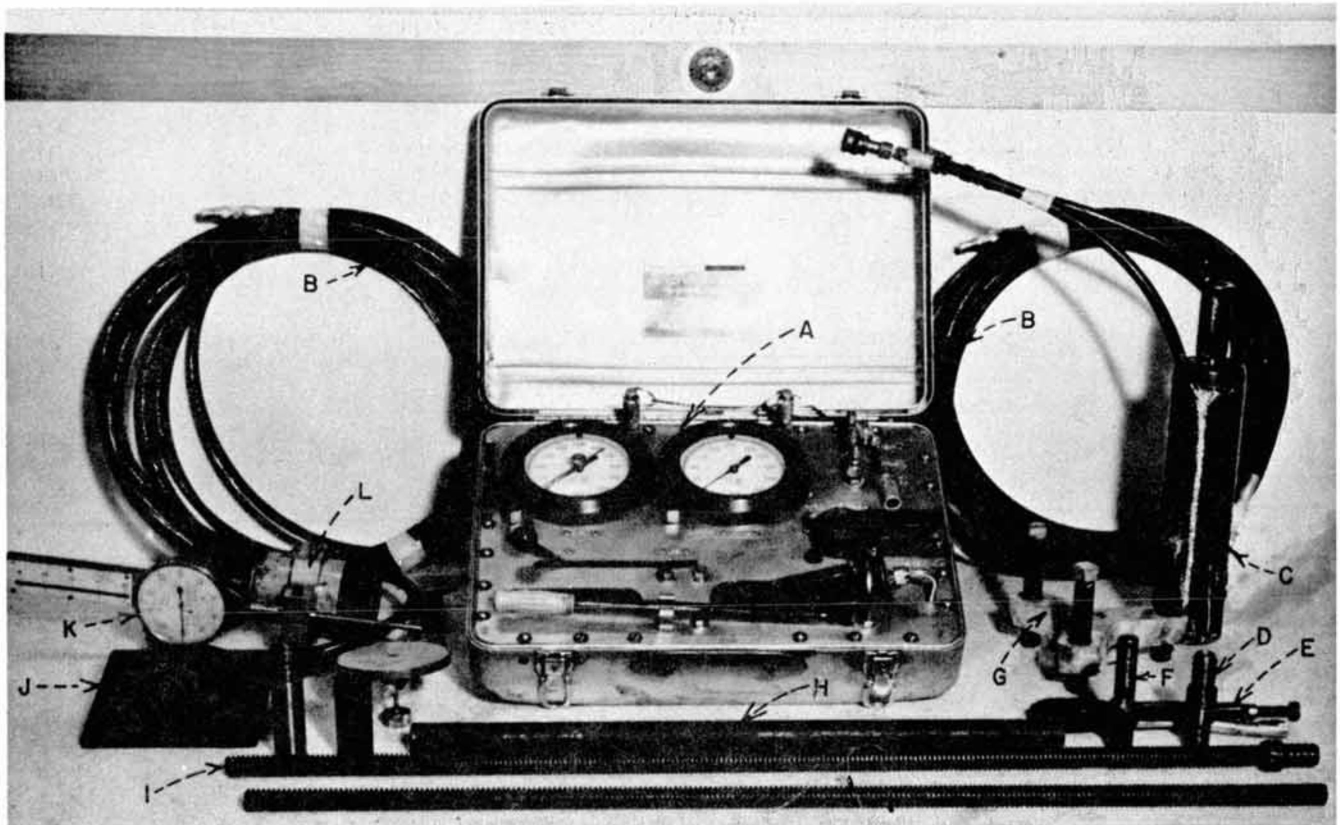
6. Three hydraulic ports (shear, retract, and normal) onto which the hydraulic hoses connect.

7. Two unmarked terminals for possible addition of shear and normal pressure transducers. (Otherwise these are left capped.)

8. An aluminum case to protect the console.

Miscellaneous

Other BST assembly components include hydraulic extension lines, threaded rods, RW adapters, and RW-size rods in 5-foot sections. Figure 5 shows a schematic of the BST and the way it should appear when placed in the hole.



A. Console
B. Hydraulic hoses
C. Shear head (BST body)
D. RW rod connector
E. Half-nut clamp
F. RW rod adapters
G. Adjustable tripod
H. RW rod
I. Threaded rod
J. Jack base plate
K. Dial gage
L. Hollow jack

FIGURE 1.—Borehole shear tester components.

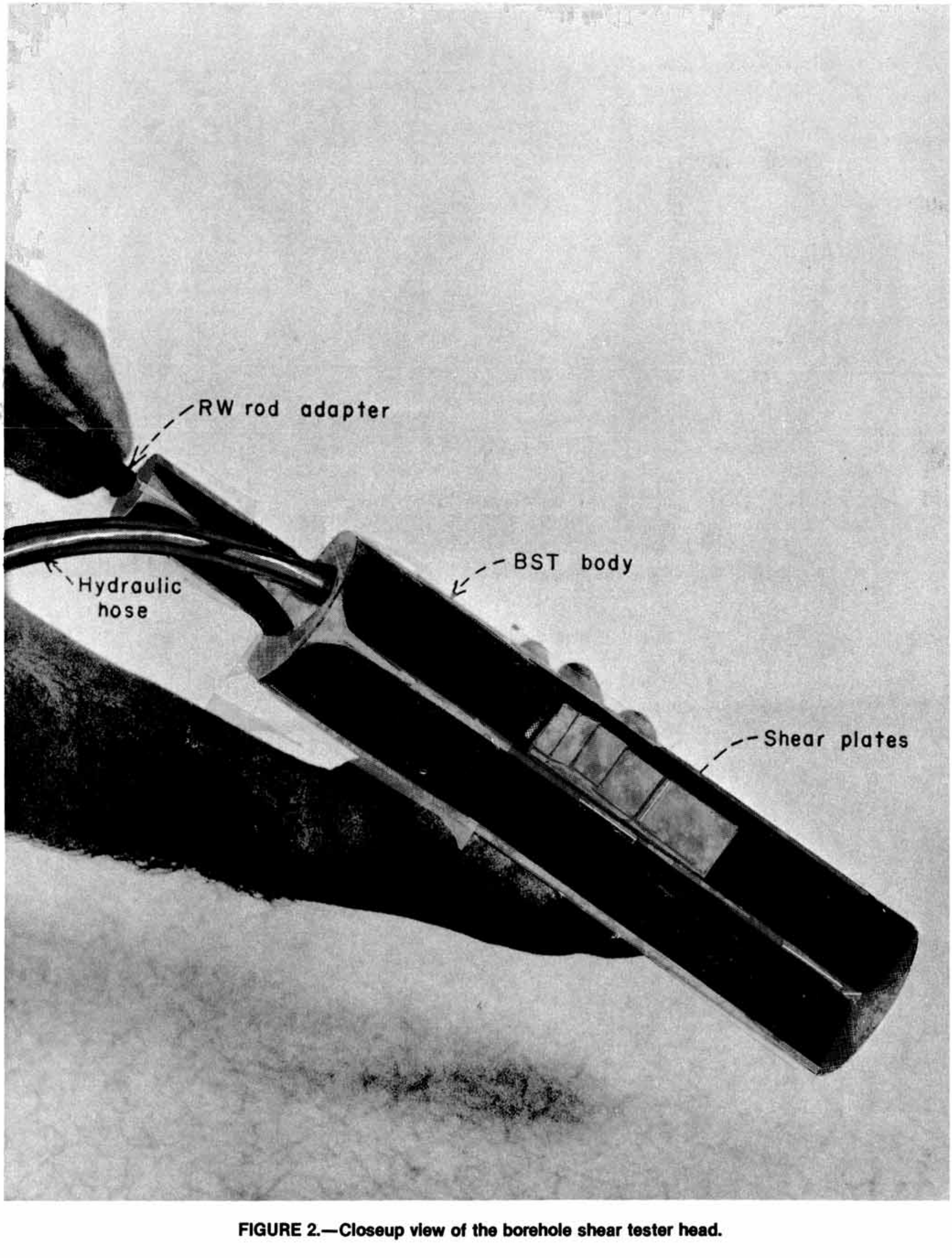


FIGURE 2.—Closeup view of the borehole shear tester head.

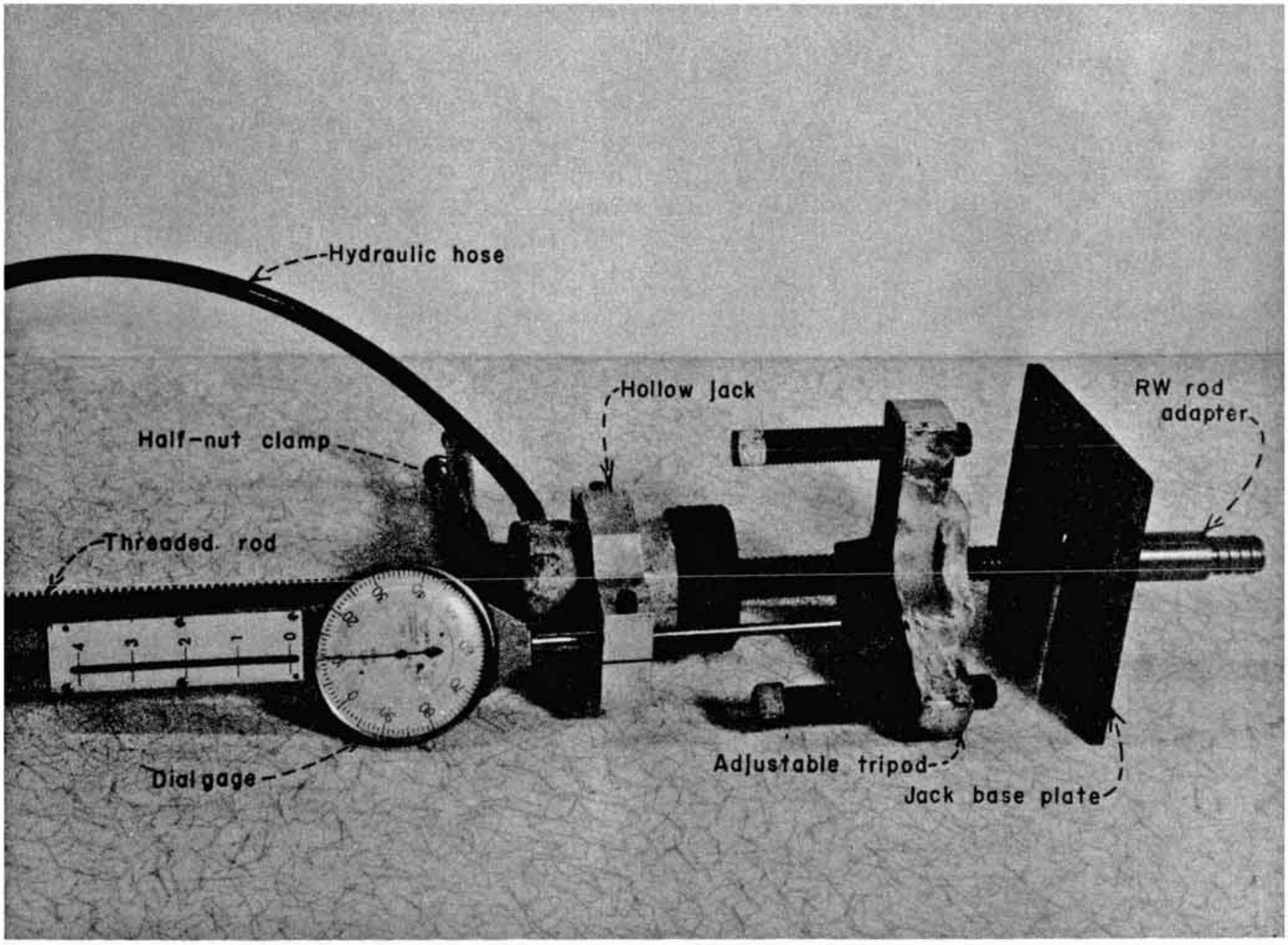


FIGURE 3.—Pulling assembly including hollow jack, half-nut, clamp and dial gage.

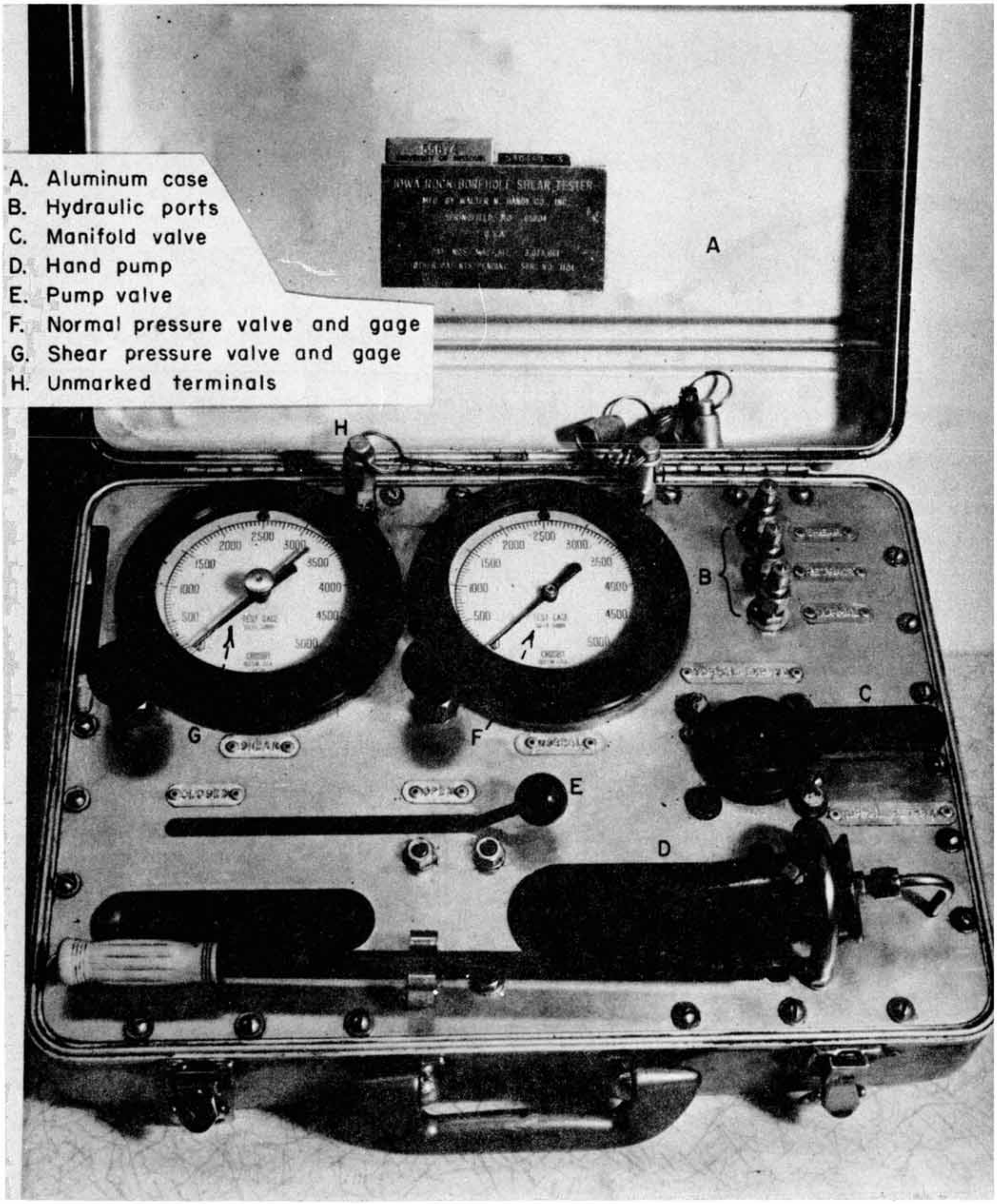


FIGURE 4.—Closeup view of the console.

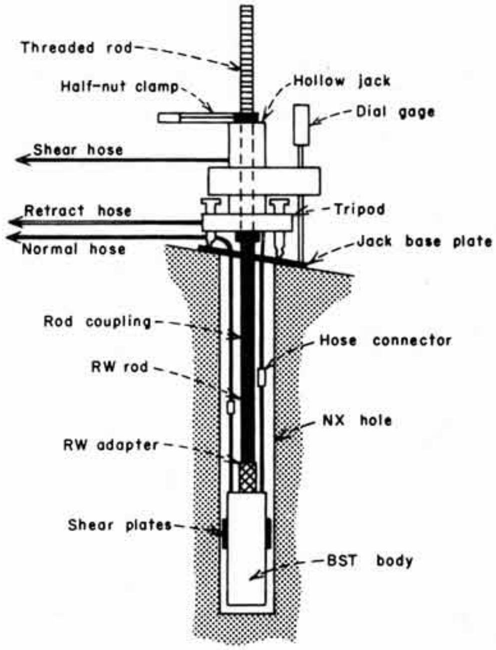


FIGURE 5.—Schematic of the BST in the hole.

BST ASSEMBLY

In assembling the borehole shear tester, refer to the sequence of photographs 6 through 17 to help understand each step in the process. At least a 12-inch pipe wrench, several screwdrivers, an 8-inch crescent wrench, shear plates, and hydraulic fluid are tools needed for the BST setup.

1. Screw the RW rod adapter into the end of the BST body. This adapter adapts the thread in the BST body to the RW rod thread (fig. 6).

2. Couple the hydraulic extension hoses to the hoses attached to the BST body (fig. 7).

3. Mark the extension hose that is connected to the shorter hose from the BST body (fig. 8). (The BST has a long hose section and a short hose section attached to it.)

4. Attach the RW rods in 5-foot sections to the rod adapter (fig. 8).

5. Place the BST body in the hole with the shear plates at a known orientation, such as N-S or E-W, and a known depth (fig. 9). Record both orientation and depth on the data sheet.

6. When the BST body is at the required depth, attach another RW adapter, to the RW rod (fig. 9). The reason RW rods are used is that they are much stiffer than threaded rods, which eliminates bending or stretching while the BST is under shearing load.

7. Screw in a 3-foot threaded bar to the RW adapter attached to the end of the RW drill rod (fig. 10).

8. Mount the pulling assembly at the hole collar as follows:

a. Place the jack base plate over the threaded bar and the hoses at the collar of the hole. Allow the hoses and the threaded bar to pass through the slot in the plate (fig. 11).

b. Place the tripod with the adjustable screws against the jack base plate (fig. 12). These screws are used to aline the jack along the centerline of the hole.

c. Slide the hollow jack over the threaded bar and against the tripod (fig. 13). Hold it in place, and after pushing everything tight together, secure the visegrip-type, half-nut clamp on the threaded bar tight behind the jack (fig. 14). The pulling assembly should look like figure 15 before testing begins. The dial gage, shown in figures 13–16, is included in the assembly only if axial displacements of the BST are to be measured, see "Procedure" section.

Caution:—If the testing is in a vertical hole, the BST pulling rods and tripod assembly should be held in the center of the hole at the collar at all times until the normal seating pressure is applied. It is recommended that, for safety purposes, a safety chain and rod hook be used to hold the assembly in the vertical hole (fig. 16).

9. Connect the hydraulic hoses to connectors, which are in the upper right-hand corner of the console (fig. 17), as follows:

a. The marked hose (from step 3 of this section) to the port on console marked Normal.

b. The other hose from the BST body to the port on console marked Retract.

c. The hose from the jack to the port on console marked Shear.

PROCEDURE

The following procedure is for the BST in a vertical upward hole. In a downward vertical hole, the procedure is similar, except that when placing the BST body in the borehole, one should restrain it or it may be lost in the hole. Remember to record the orientation and depth of the shear plates before every test.

1. Assemble the BST body, snap hoses on, connect rods, and place it in the hole as mentioned in the previous section, steps 1 through 7 and steps 9a and 9b.

2. Place the pump valve and the valve labeled "shear" on CLOSE.

3. Open the *normal* valve, and place the *manifold* valve on NORMAL EXPAND.

4. Pump up normal gage pressure to a certain level which depends on rock type as follows:

400 psig... Soft rock.
1,600 psig... Medium rock.
3,200 psig... Hard rock.

Enough seating pressure must be exerted to achieve full penetration of the teeth into the rock or coal prior to the test, to insure that the teeth will shear off a coupon of rock or coal and not simply scrape the surface. Excessive displacement during the test or low apparent shear strength may indicate the need to apply a higher seating pressure. The seating pressures given above are typical and may be used as a guide. The appendix gives more details on seating pressure calculations.

5. CLOSE *normal* valve.

6. Wait 5 minutes for the teeth on the shear head to penetrate into the rock. Remember to keep holding the BST in the hole until normal pressure is applied.

7. Mount pulling assembly at the borehole collar as explained in steps 8a through 8c in the previous section.

8. Snap on the jack hose according to step 9c.

9. Adjust the dial gage for a zero reading and record it on the data sheet if BST axial displacements are to be made.

10. OPEN *normal* valve.

11. Readjust normal pressure to the chosen setting pressure (if any change in pressure has occurred) by either pumping (to increase pressure) or opening *pump* valve slowly (to reduce pressure).

12. CLOSE *normal* valve.

13. OPEN *shear* valve.

14. Pump at a slow rate until shear gage reads 100 psig, then record the following data on the data sheet (see example in appendix):

Normal pressure .. From normal gage on console.
Shear pressure ... From shear gage on console.
Displacement .... From dial gage if desired.

15. Pump the shear pressure in steps to 200 psig, 400 psig, 600 psig, and so on until the peak shear has been determined. Record shear pressure and displacement for each pressure. If the pulling rod bends as the shear pressure is increased, the load should be released and the tripod adjusted so that the pulling action is parallel to the axis of the hole; otherwise the displacement measurements will be meaningless and the pulling rods may be damaged.

16. Continue to pump until shearing pressure changes are relatively slow or a predetermined maximum displacement is reached.

17. Upon each completion of each test, OPEN *pump* valve, CLOSE *shear* valve, OPEN *normal* valve, and switch *manifold* valve to retract.

18. Before removing BST from hole, CLOSE *pump* valve, CLOSE *shear* valve, keep *normal* valve OPEN, and pump until the shear plates retract and the BST head apparatus pulls loose from the hole.

19. For the next sequential test, reinsert the device in the hole either rotated 45° at the same depth, or at a different depth. Repeat all above procedures.

Note.—When the BST is used in harder rocks, the shear plate teeth may wear enough during a series of tests to begin to affect the results. The effect of this wear should be distributed over the length of a test hole by randomizing the depths and orientations of the shear tests.

CLEANING THE BST

After every test, clean off shear plates and make sure they swivel freely. After the completion of all testing, clean the BST body very well and lubricate it by using a WD-40 lubricant spray (or equivalent) to prevent rusting.

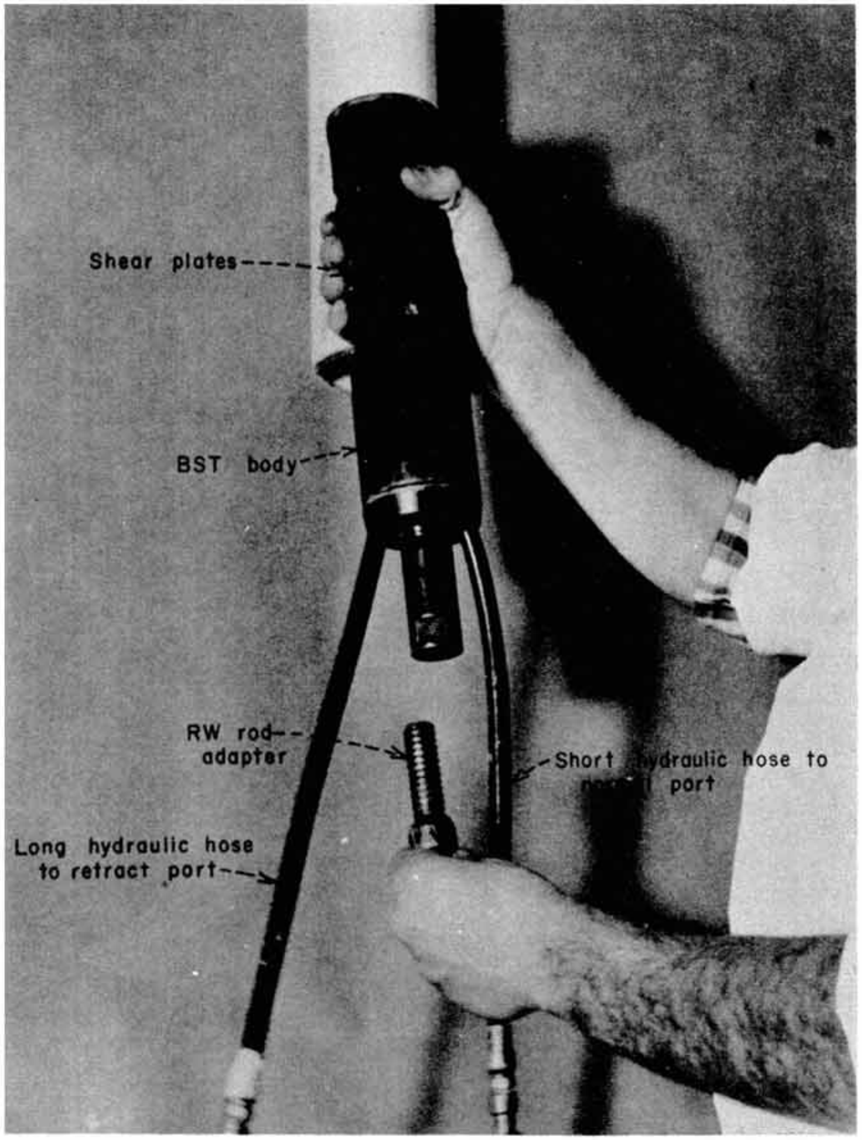


FIGURE 6.—BST assembly, step 1.

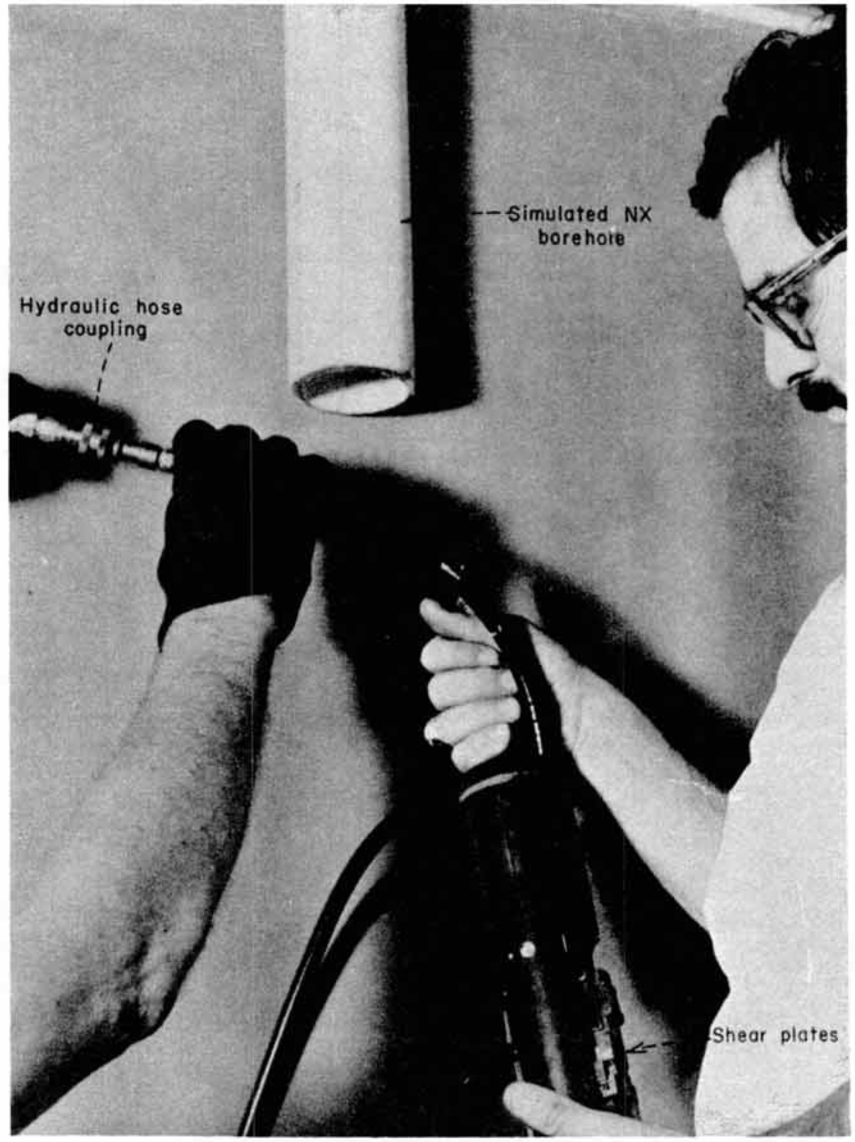


FIGURE 7.—BST assembly, step 2.

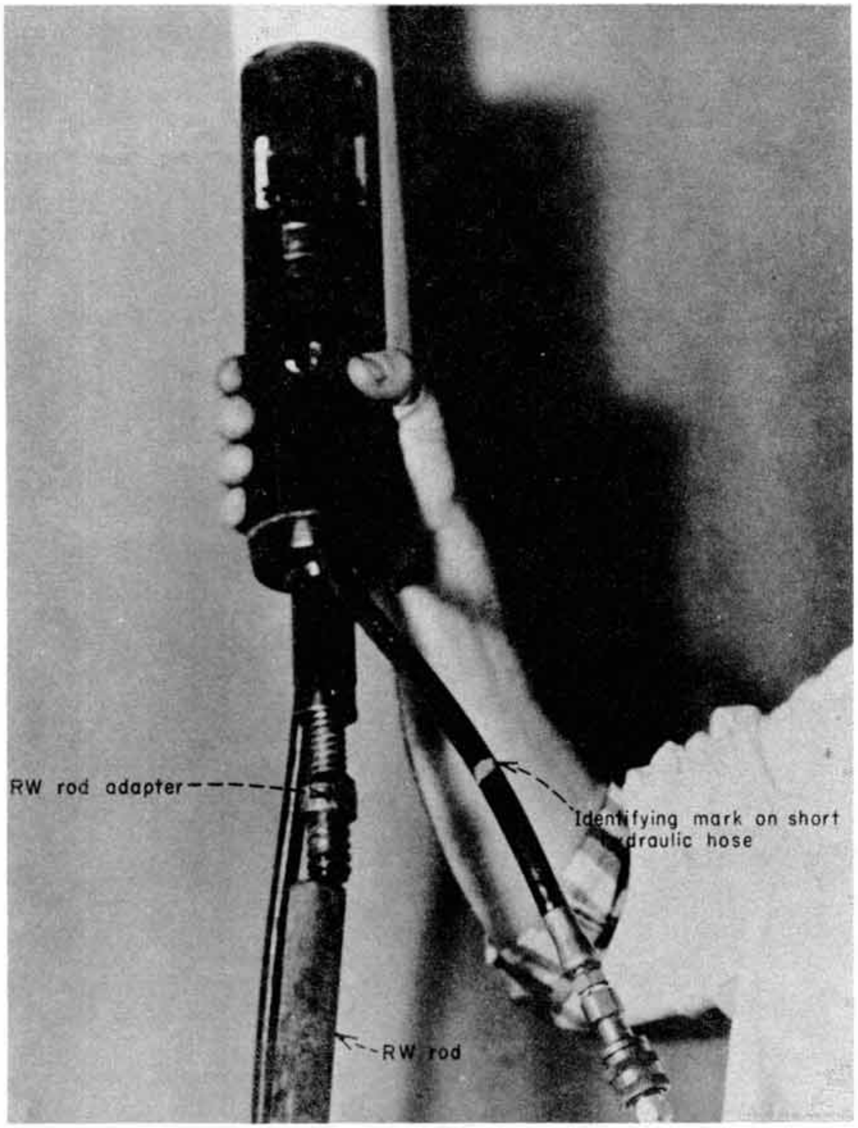


FIGURE 8.—BST assembly, steps 3 and 4.

FIGURE 9.—BST assembly, steps 5 and 6.

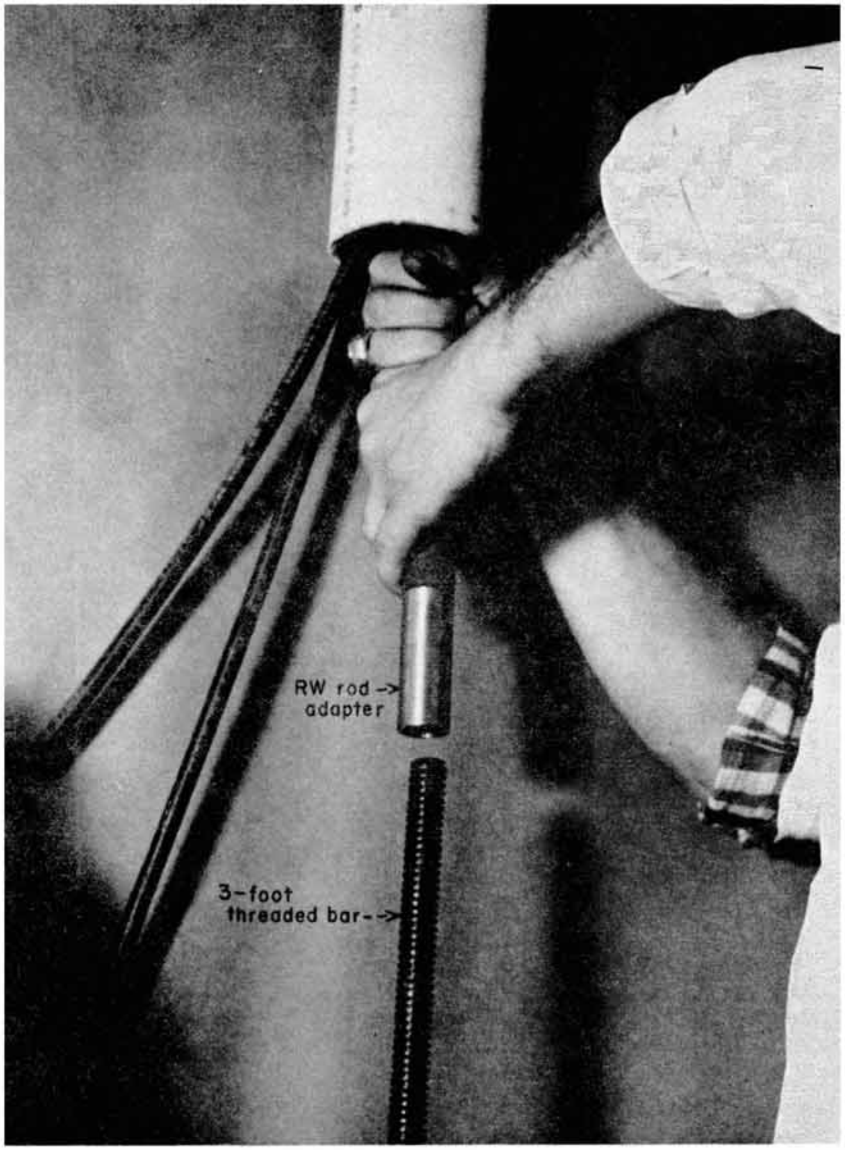


FIGURE 10.—BST assembly, step 7.

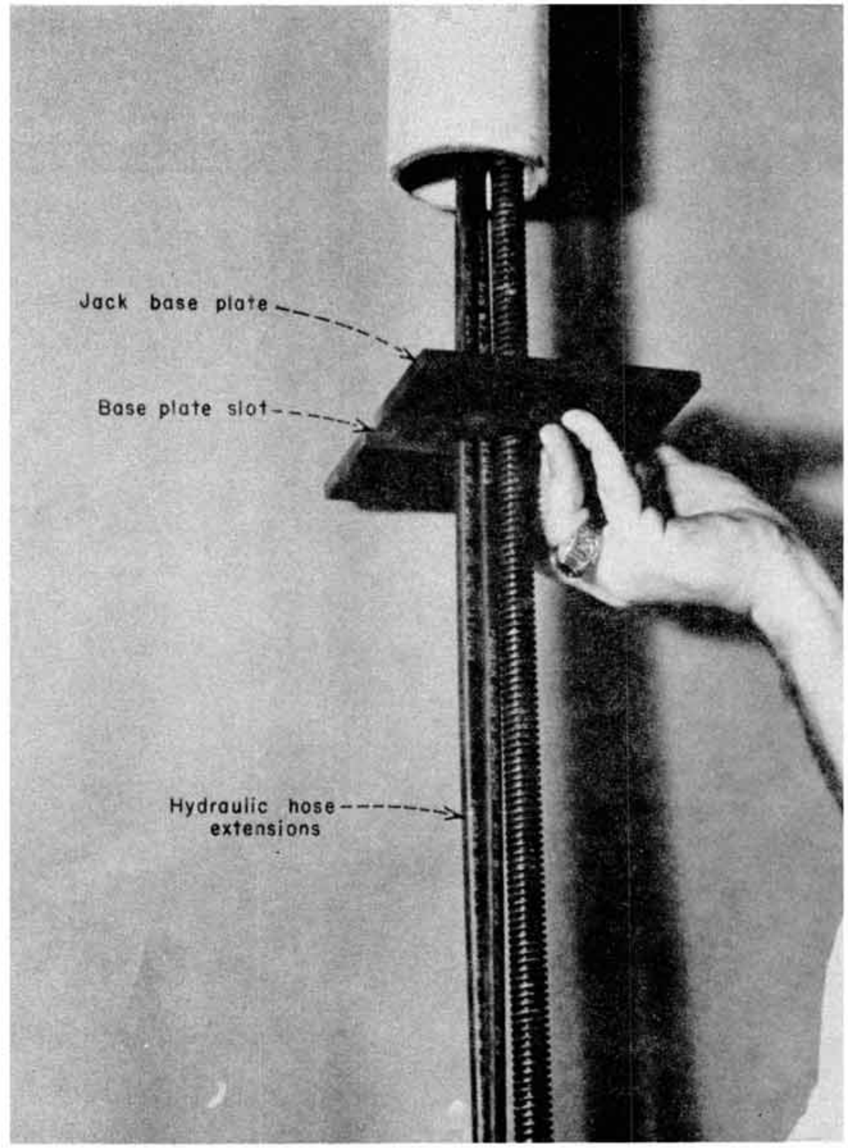


FIGURE 11.—BST assembly, step 8a.

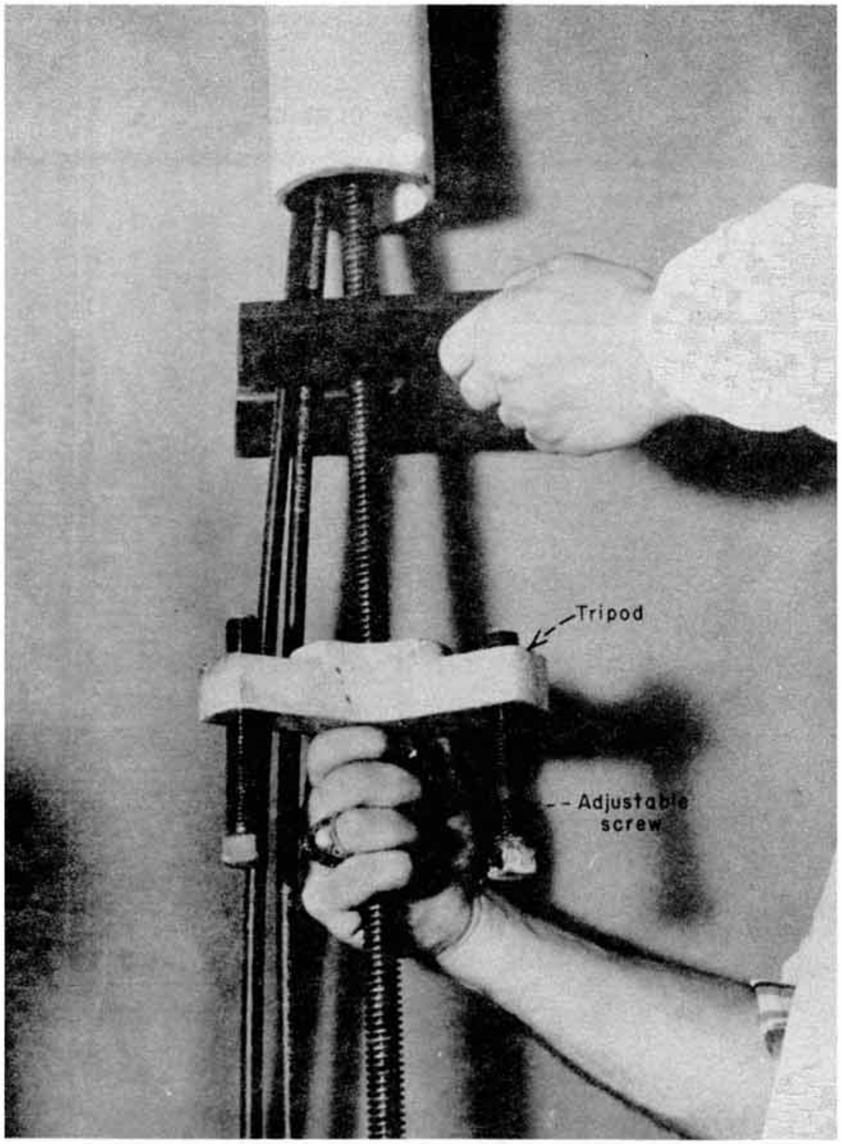


FIGURE 12.—BST assembly, step 8b.

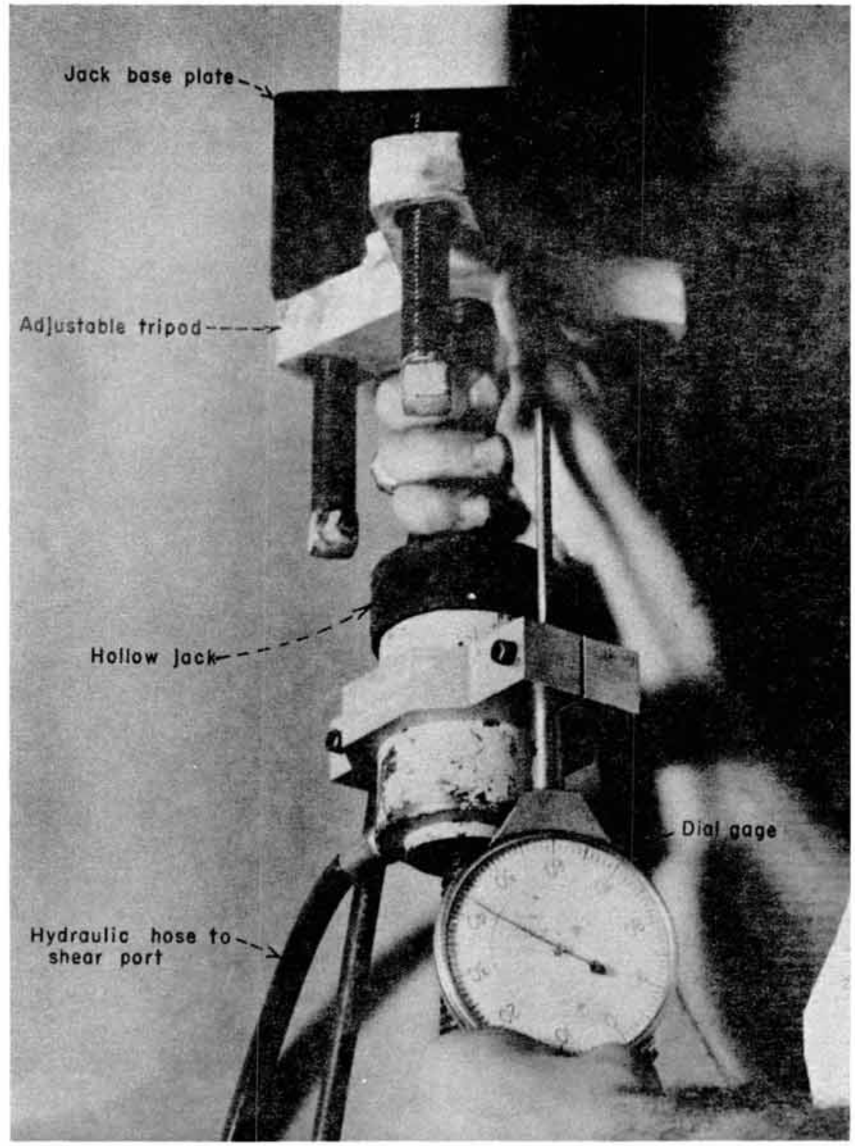


FIGURE 13.—BST assembly, step 8c-1.

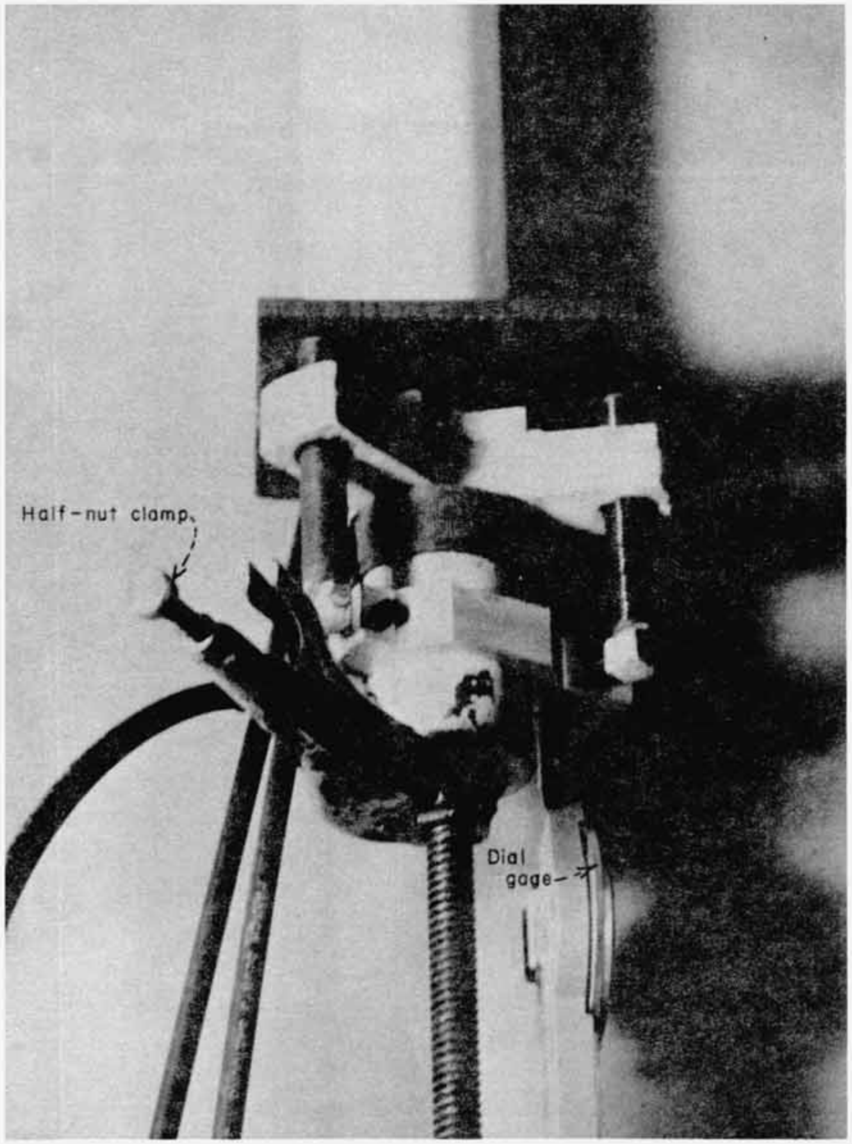


FIGURE 14.—BST assembly, step 8c-2.

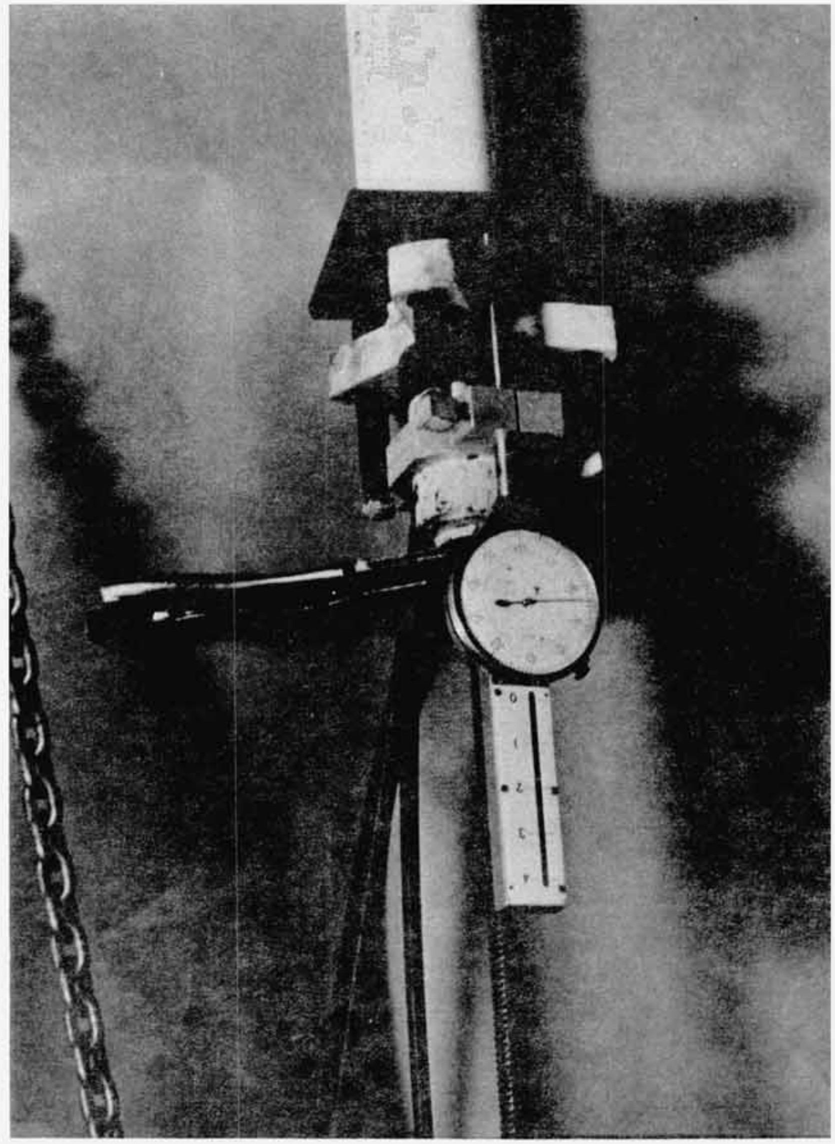


FIGURE 15.—BST assembly, step 8c-3.

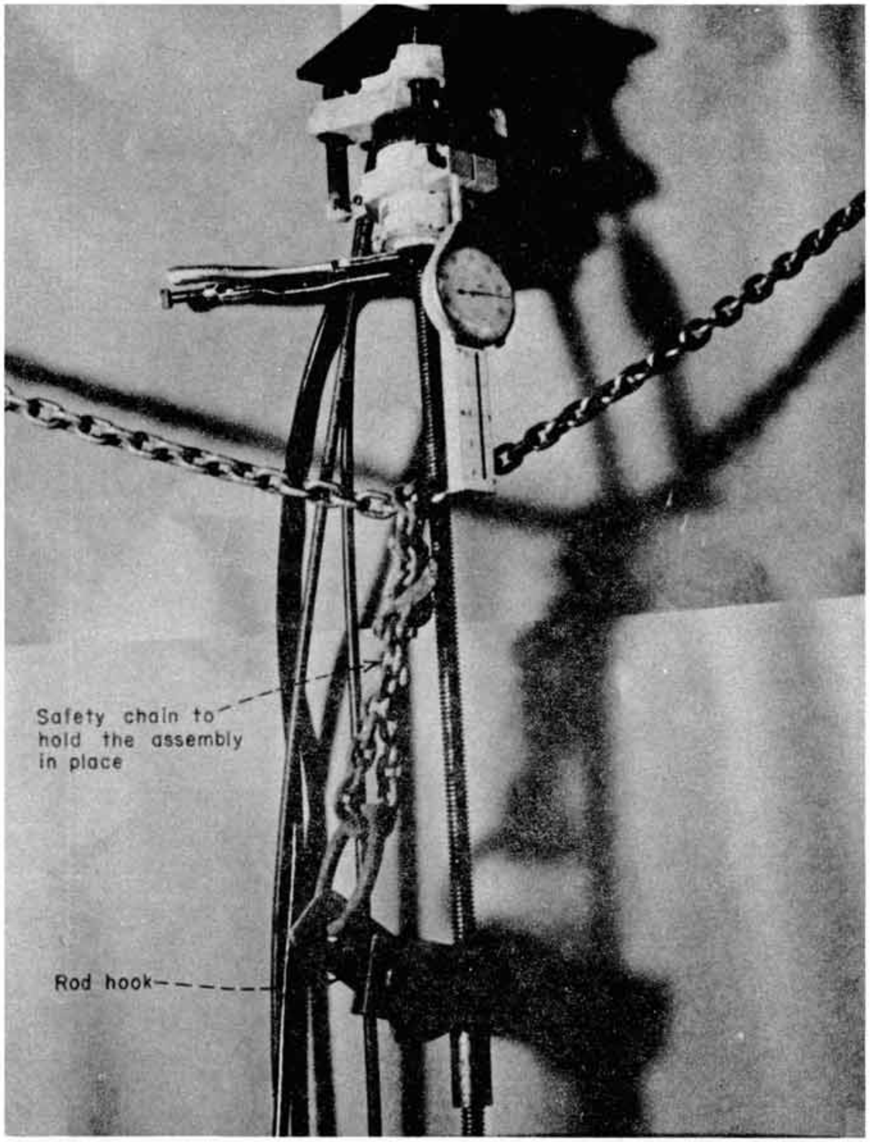


FIGURE 16.—BST assembly, step 8c-4.

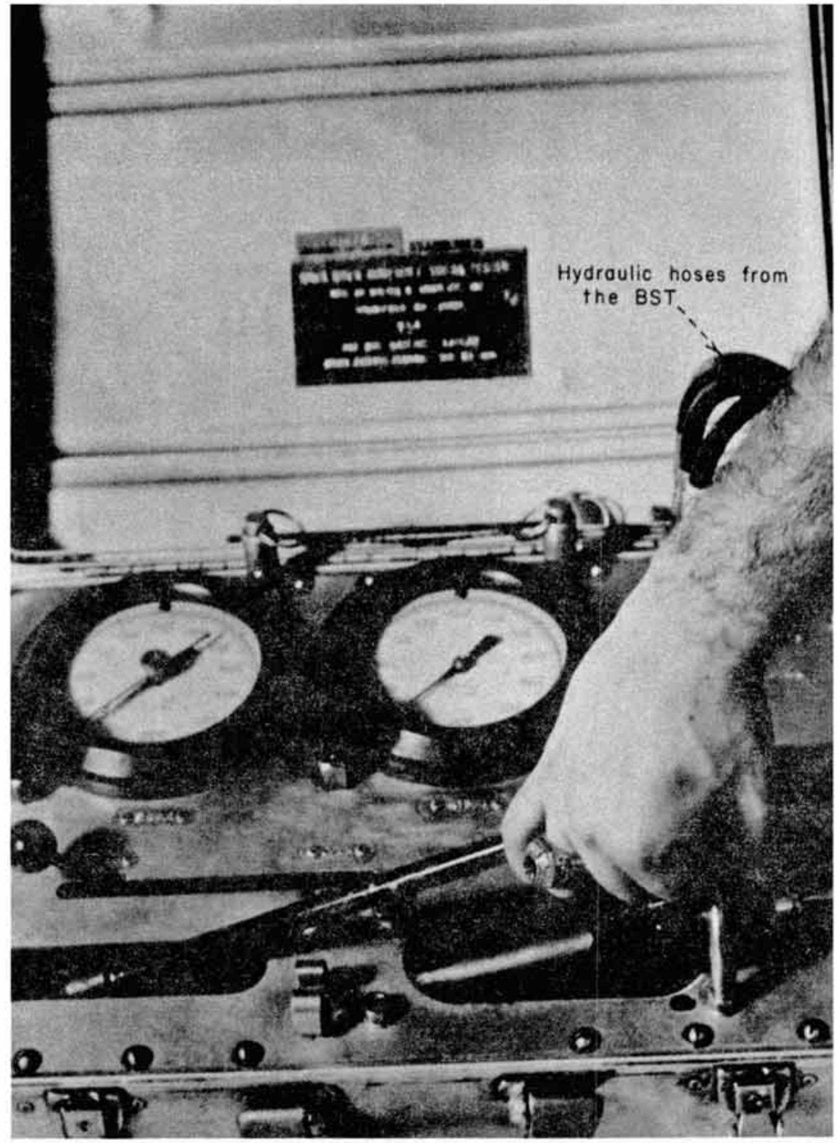


FIGURE 17.—BST assembly, step 9.

DATA AND CALCULATION

A blank data sheet for the borehole shear tester data appears as table 2; each sheet should be filled in completely as shown in table 3, including the name and location of the mine, the type of rock tested, the hole specifications, the date of testing, and the name of the person(s) doing the testing.

Every BST has two calibration curves, similar to the ones shown in figures 18 and 19. One is a normal stress calibration curve; the other is a shear stress calibration curve. The normal gage pressure P_n and the shear gage pressure P_s (in psig) are read from the normal and shear gages respectively on the console. The normal stress σ_n and the shear stress T_s (in psi) are calculated from formulas such as the following:

$$\text{Normal stress } (\sigma_n) = 2.604\ P_n - 85.135 \quad (1)$$

$$\text{Shear stress } (T_s) = 1.744\ P_n - 81.035 \quad (2)$$

Formulas 1 and 2 were obtained from the calibration curves. Both curves have a small negative intercept. (One may also use the curves in figures 18 and 19 to obtain σ_n and T_s).

The calculated normal stress σ_n is plotted on the X-axis versus the calculated shear stress T_s on the Y-axis on linear-linear graph paper. The best-fitting straight line is drawn through the plotted points. The cohesion (in psi) for a particular rock is indicated by the intercept of this fitted line with the Y-axis. Provided that the scales are the same, the angle of internal friction ϕ is the angle between the X-axis and the plotted line as shown in figure 20. The angle of internal friction can also be calculated as the arc tangent of the slope of the plotted line.

$$\phi = \text{arc tan } \mu$$

where μ = the slope of the line (coefficient of friction).

The calculation of the BST tests made in a Utah coal mine given in table 3 should help clarify the calculations.

A Bureau of Mines computer program can be used to analyze the BST data; a copy may be obtained from the author of this paper at the Bureau of Mines, Denver, Colo.

In calculating the shear stress, the weight of the BST assembly (see table 4) should be taken into consideration as follows:

1. In an uphole, the shear stress caused by the weight of the BST body and the hoses used in the hole. The weights of the RW-size drill rods, threaded rods, plates and tripod, and hollow jack should all be added to the maximum shearing force required. If a dial gage is used, its weight should be added.

2. In a downhole, the shear stress caused by the weight of the BST body, hoses used in the hole, and RW rods should be subtracted from the maximum shearing force required.

3. In a horizontal hole, the shear stress caused by the weight of the BST assembly has a very small effect. Therefore it does not have to be included in the shearing force calculations, and no adjustments are required.

TABLE 2.—Sample BST data sheet

DATA SHEET FOR BOREHOLE SHEAR TESTER

Mine ______________________ Date ______________________

Type of rock __________ Roof __________ Tested by ______________________

Hole No. _____ Hole location __________ Floor ______________________

Hole depth ______________________

Test	Normal		Shear		Orientation of teeth	Depth into hole	Displacement
	P_o	σ_n	P_s	T_s			

P_n = Normal gage pressure (psig).
σ_n = Normal stress (psi) (calculated).
P_n = Maximum shearing gage pressure.
T_s = Shearing stress (psi) (calculated).

TABLE 3.—Completed BST data sheet

DATA SHEET FOR BOREHOLE SHEAR TESTER

Date: OCTOBER 1, 1980

Mine: COAL MINE "X", UTAH

Tested by: HARAMY AND DeWAELE

Type of rock: COAL Roof: SANDSTONE

Floor:

Hole No.: W-25 Hole location: HOLE IN ROOF, CROSSCUT #25, 3d Rt.

Hole depth: 30'(NX-HOLE)

Test	Normal		Shear		Orientation of teeth	Depth* into hole	Displacement	
	P_n	σ_n	P_s	T_s				
1	1000	2392	1350	1841	NS	12'5" + H**	—	—
2	1250	2990	1700	2318	NS	10'7.5" + H	—	—
			250		ZERO READING ON DIAL GAGE = 6.0		5.95	0.05
			500				5.61	0.39
			750				5.25	0.75
			1000				4.85	1.15
			1250				4.20	1.80
			1500				3.56	2.44
			1700		PEAK		2.43	3.57
3	1500	3588	1760	2400	NS	8'4.5" + H	—	—
			250				5.00	0.00
			500				4.90	0.10
			750		ZERO DISPL. = 5.0		4.79	0.21
			1000				4.44	0.56
			1250				2.77	2.23
			1500				.16	4.84
			1760		PEAK		—	—
4	1750	4186	2200	3000	EW	8'11" + H	—	—
			250				5.80	0.20
			500		ZERO DISP = 6.0		5.27	0.73
			750				5.09	0.91
			1000				4.84	1.16
			1250				4.60	1.40
			1500				4.21	1.79
			1750				3.68	2.32
			2000				2.88	3.12
			2200		PEAK		1.30	4.70
5	2000	4784	2350	3205	EW	11'0" + H	—	—
			500				6.55	0.45
			750		ZERO DISPL. = 7.0		6.14	0.86
			1000				5.72	1.23
			1250				5.40	1.60
			1500				5.09	1.91
			1750				4.70	2.30
5			2000				3.50	3.50
			2250				2.00	5.00
			2350				1.92	4.08
6	2250	5380	3010	4106		12'6" + H	—	—
			500				7.09	0.91
			1000				6.05	1.95
			1500				5.49	2.51
			2000				4.90	3.10
			2500				3.92	4.08
			3000				2.15	
			3010				—	—

*Distance from collar of borehole to the center of loading plates

**H = Length of BST head 1.5'

P_n = Normal gage pressure (psig)

σ_n = Normal stress (psi) (calculated)

P_s = Maximum shearing gage pressure

T_s = Shearing stress (psi) (calculated)

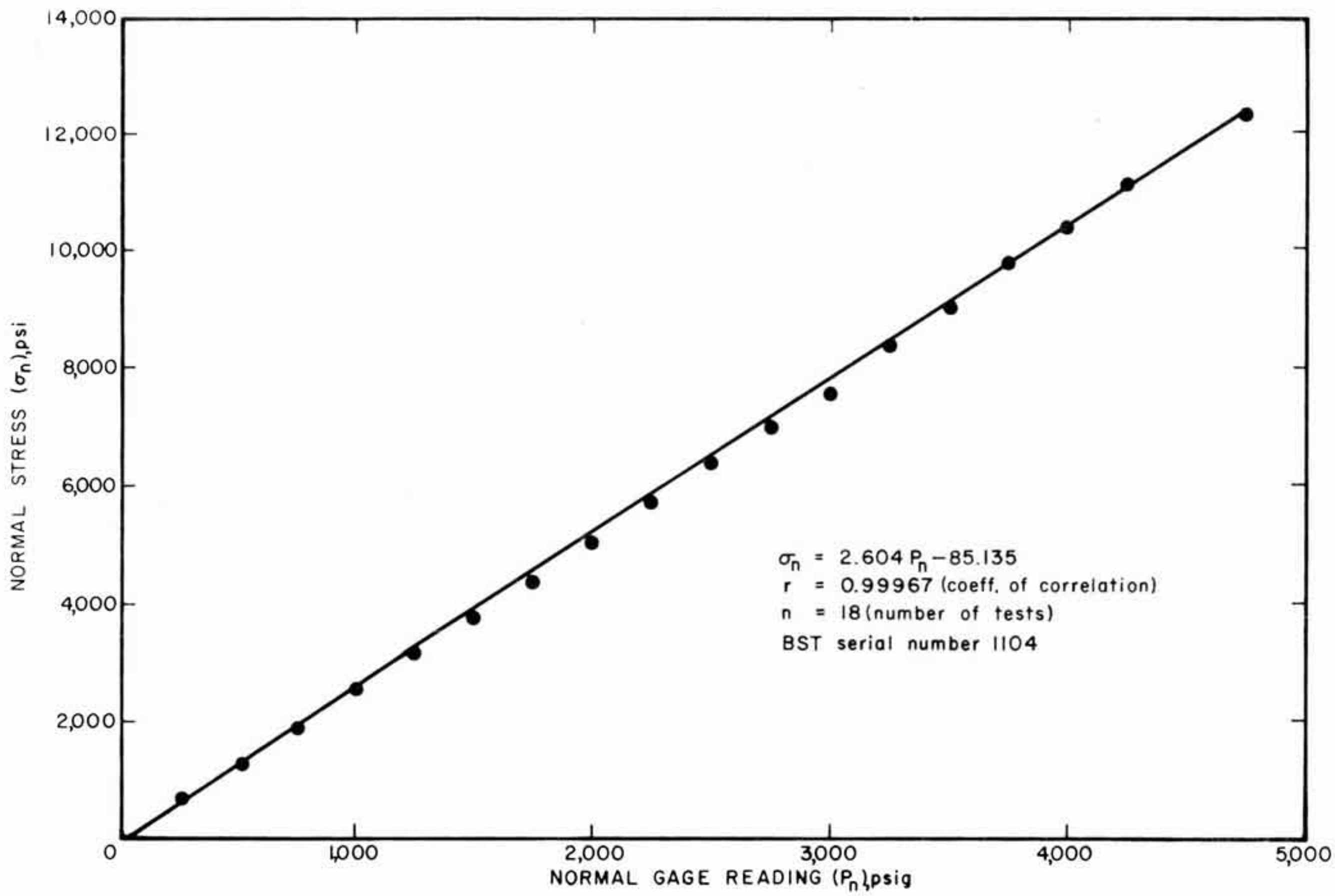


FIGURE 18.—Normal stress calibration curve.

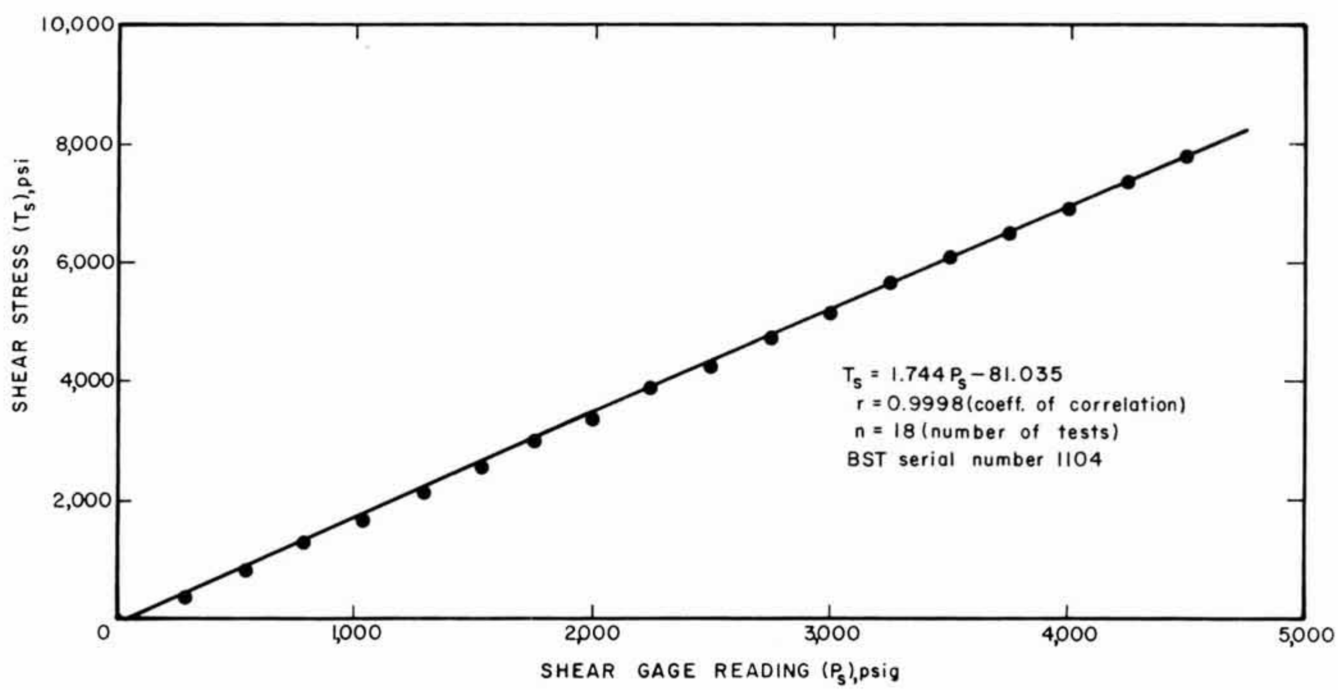


FIGURE 19.—Shear stress calibration curve.

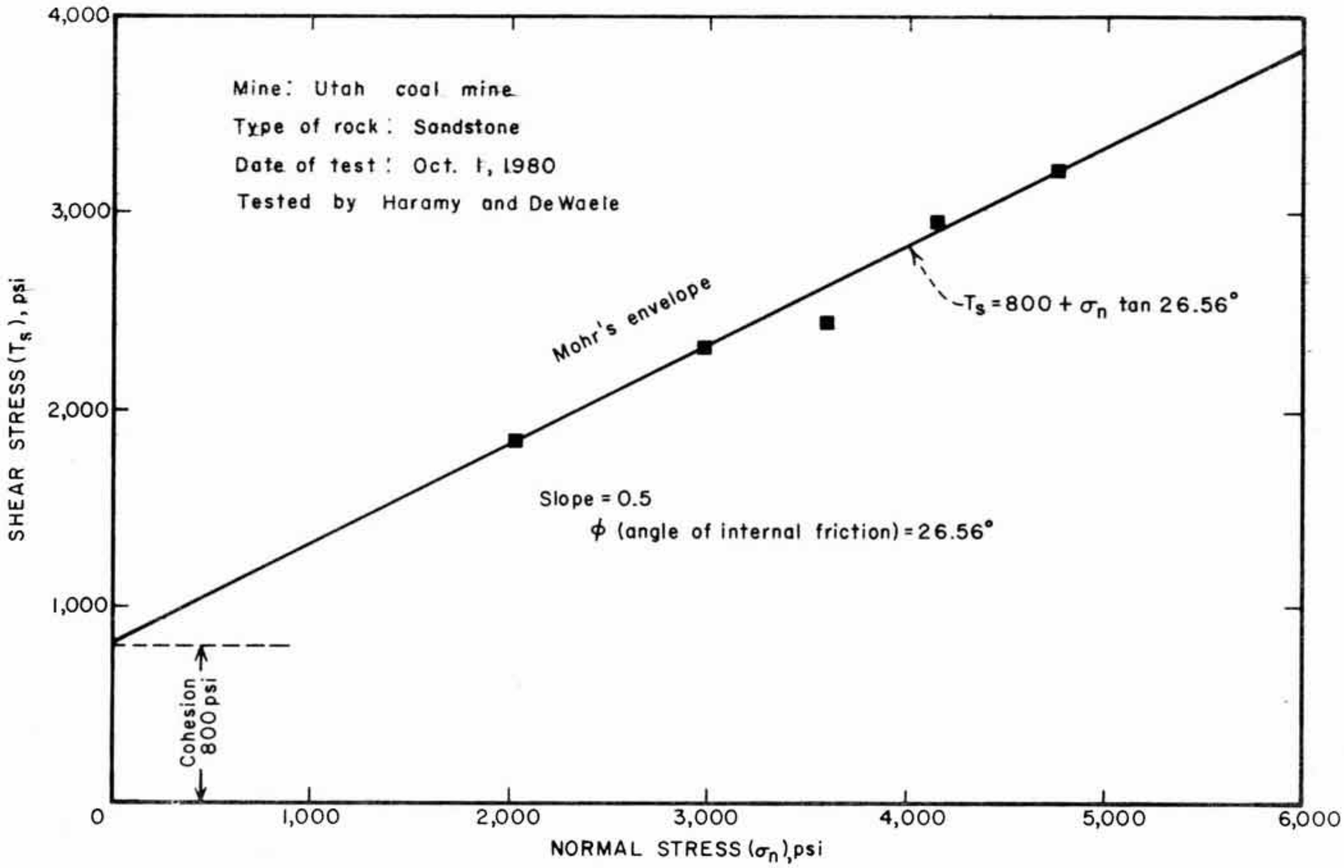


FIGURE 20.—Example of BST plot.

TABLE 4.—Weights of BST components

Component	Weight	Stress[1]
RW rod	1.8 lb_f/ft	0.45 psi/ft
BST body and 2 attached short hoses	9.5 lb_f	2.375 psi
Hydraulic hoses and fluid	0.1 lb/ft	0.025 psi/ft
Tripod and base plate	7.0 lb	1.750 psi
Dial gage	1.0 lb	0.250 psi
Threaded rods	1.5 lb/ft	0.375 psi/ft
Hollow jack	11.0 lb	2.750 psi/ft
Half-nut clamp	.8 lb	0.200 psi

[1]Stress = $\frac{\text{weight}}{2\text{ (cross-sectional area of plates)}}$

NOTE.—This table also allows the operator to decide whether a winch is needed to hold the BST assembly as opposed to the operator handling the weight.

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APPENDIX—SEATING PRESSURE CALCULATIONS FOR COAL

The coefficient of sliding friction can be calculated as follows:

$$\mu = \tan \beta$$

where μ = coefficient of friction

and β = angle of friction between the shear plates and the material being tested.

In laboratory testing by the Bureau, the coefficient of friction between coal and steel was found to be 0.3 ± 0.04. From equation 1

$$\beta = \text{arc tan } (0.3) = 16.7°.$$

The minimum normal stress to cause material failure can be calculated using the following formula:

$$\frac{C_o}{\sigma_n} < \tan (\theta + \beta) - \tan \phi$$

where C_o = materials cohesion,
σ_n = normal stress,
θ = angle of plate inclination shown in figure A-1,
β = angle of friction between steel plates and rock tested,

and ϕ = angle of internal friction of the material.

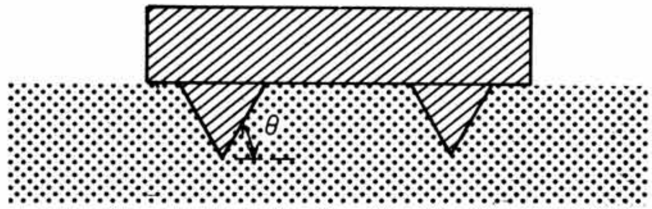

FIGURE A-1.—Angle of plate inclination.

Substituting in equation 2

$\theta = 60°$ .... Fixed,
$\phi = 60°$ .... Highest for coal,
and $\beta = 16.7°$ .... from equation 1

Thus, for coal with $C_o = 1{,}000$ psi, the minimum σ_n to cause material failure rather than slippage is

$$\frac{C_o}{\sigma_n} < 2.5$$

$$\sigma_n > \frac{1{,}000}{2.5} > 400 \text{ psi.}$$

The normal stress will vary depending on C_o and μ of coal. This method of estimating σ_n is a good approximation and may be used for any type of rock.

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