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A PORTABLE VACUUM HAMMER SEISMIC SOURCE FOR USE IN TUNNEL ENVIRONMENTS

By

R.D. Carroll and J.E. Magner

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ABSTRACT

Concern for the measurement of seismic refraction velocities in tunnel areas where cables, construction features, and other sensitive structures render the use of dynamite sources unwise, resulted in the design of a vacuum-driven impact system utilizing a 43-kg (94-lb) weight in a 2-m (6.5-ft) tube. The system is portable, quickly assembled and disassembled, and requires only standard electrical power, an air pressure supply, and a laboratory vacuum pump to operate. The maximum weight of any component is 84 kg (185 lb), the remaining components being significantly lighter.

Tests in volcanic rock tunnels in Rainier Mesa at the Nevada Test Site indicate maximum energy generated by the system is in the SV wave. When the system was employed at angles other than vertical, a polarized SH mode was also observed. The hammer was used to obtain velocities in an in-hole survey in a 138-m horizontal hole drilled behind the flat face of the Red Hot chamber after the Red Hot nuclear detonation. A large decrease was observed in compressional velocity compared with pre-event values. Because 20 years have elapsed since the explosion, one cannot separate the effect of ground shock on lowering the velocity from possible effects of destressing around adjacent underground openings over this period.

INTRODUCTION

Hammer impact sources are routinely used in shallow seismic refraction and reflection investigations. Although impact sources are inherently unable to generate large compressional-wave energy, they have the advantages, where applicable, of ease of use, rapid source generation, and elimination of the need for drill holes and associated logistics when compared with dynamite sources. In the tunnel environment of Rainier Mesa at the Nevada Test Site (NTS), locations exist where the use of dynamite in seismic investigations is of concern because of restricted working spaces and proximity of construction features and cables. The need for additional safety precautions when using dynamite sources, such as complete power outage in the vicinity of the seismic lines, is also expensive and time consuming. Sledge hammers are inadequate energy sources for propagation over the 200-m array lengths routinely involved in refraction surveys in these tunnels. Although pressure-driven hammers are commercially available, they lack portability. More importantly, the use of gasoline engines to provide energy to drive some systems is prohibited underground from a safety standpoint.[1] Lack of overhead clearance at some underground locations is an additional design consideration.

As a consequence, an impact source was constructed to obtain seismic information in the Rainier Mesa tunnel environment. The system design was based on simplicity, portability, quick assembly and disassembly, and the use of a standard electric power source.

Acknowledgments

This work was funded by the Defense Nuclear Agency, TDNV, who also provided logistical support for these studies. The underground support of the Reynolds Electrical and Engineering Co., Inc., is greatly appreciated. The efforts of Dale Elliot, USGS, who provided machine shop expertise and advice in system construction, and Ray Sabala, USGS, who provided the engineering drawings of the system, merit special mention.

SYSTEM DESCRIPTION AND OPERATION

Figures 1 and 2 depict major features of the assembled system. The basic operation consists of driving a 43-kg piston within a cylinder under vacuum onto an anvil-base plate coupled to the earth. The vacuum is drawn by a standard laboratory Welch "Duo-Seal" 1/3-HP vacuum pump. A control box allows connection of a compressed air source to raise the weight to the top of the cylinder, where it is manually latched while a vacuum is drawn for the next impact. Vacuum and positive pressure in the system are monitored at the control box. The air compressor is a 1-HP, Sears paint sprayer with a 12 gal tank rated at 100 psi. In lieu of an air compressor, a regulator may be used in conjunction with either a pressure bottle or pressure taken directly from the tunnel air line. In order to maintain portability and allow for easy accessibility of the system for repair, all components shown on figure 1 may be rapidly assembled and disassembled.

Diagrams and photographs of the pertinent system components (those to the left of the vacuum pump in fig. 1), in addition to comments regarding specific facets of the design, are given in the appendix. The vacuum pump, compressor, and control box were assembled from equipment and materials on hand. The system as described is a working prototype, and no additional improvements

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[1] EG&G Geometrics manufactures a trailer-mounted, gasoline-powered vacuum hammer consisting of a 17.5-cm-diameter, 39-kg weight with a drop height of 1.8 meters. Total system height is 2.75 meters. The total system weight is 544 kg.

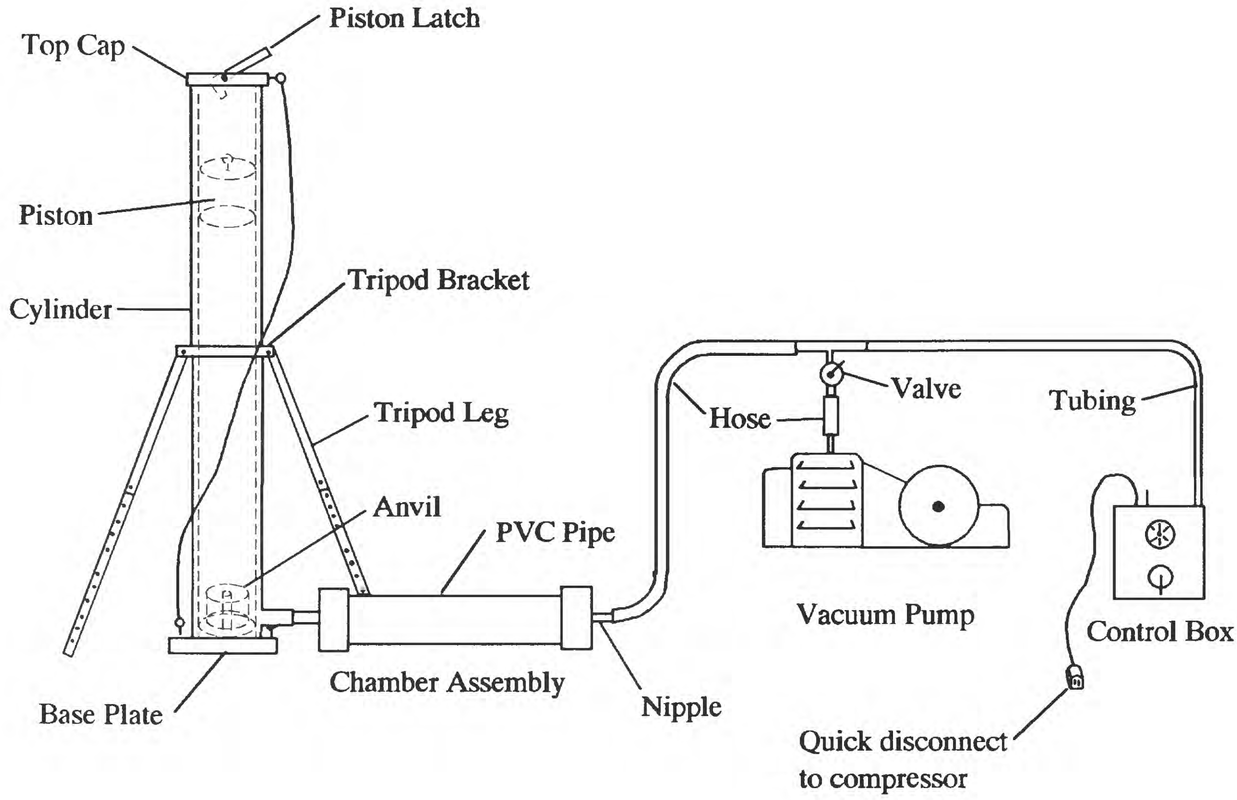

Figure 1.--Schematic of vacuum hammer setup.

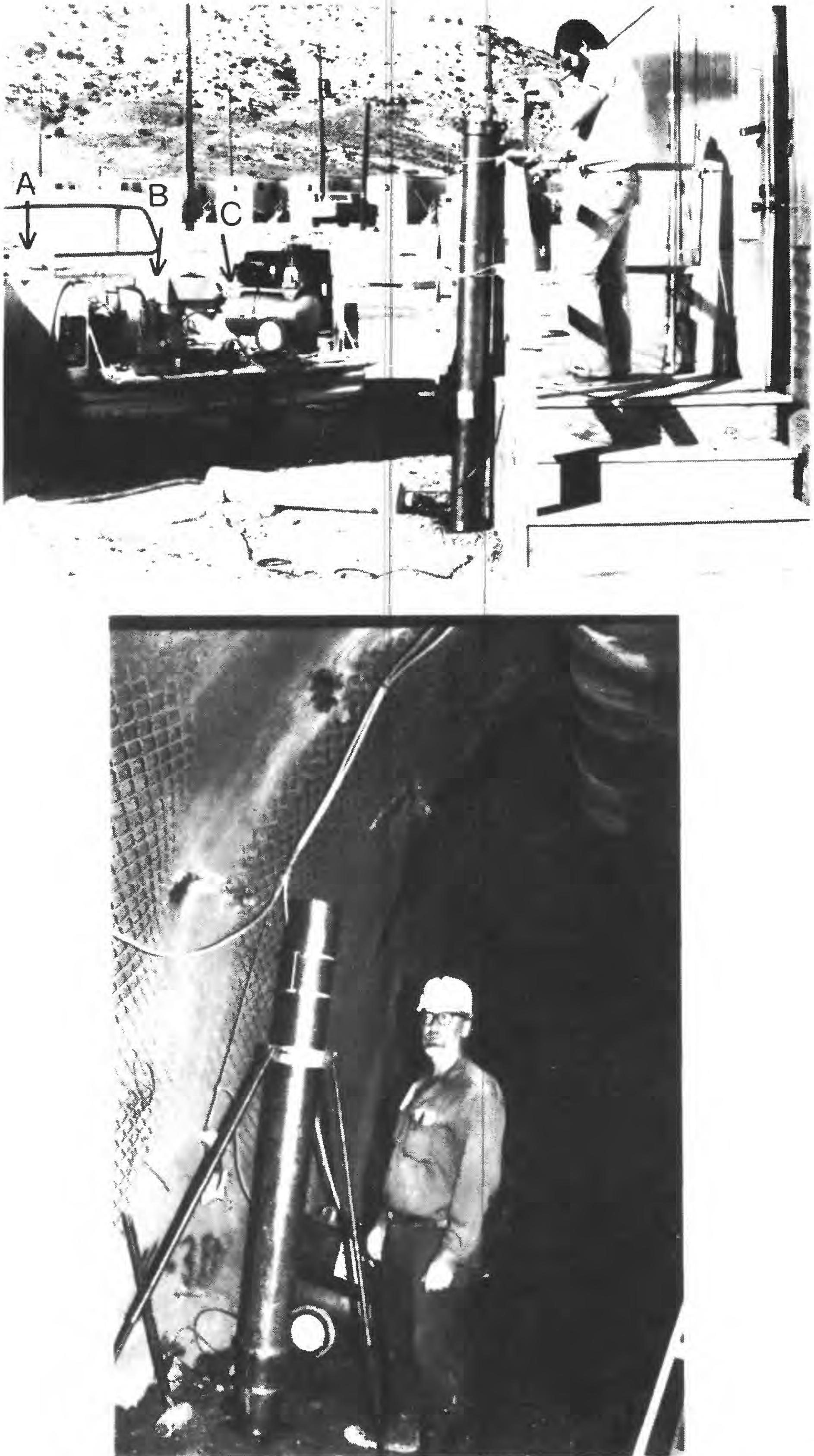

Figure 2.--Upper photograph shows vacuum hammer assembled. A=control box; B=vacuum pump; C=compressor. Bottom photograph is in working mode at N-tunnel site. A ladder is generally used when latching and releasing the piston.

have been made because of relatively infrequent use. Suggestions are made in the appendix where improvements might be considered if continuous use of the system is anticipated and (or) weight is not a factor.

About 5 minutes are required to raise and latch the piston and draw a vacuum. The piston is manually held with the latch while a vacuum is being drawn and released when the gauge on the control box indicates sufficient vacuum. The latch is attached to a removable top cap. In order to prevent the piston from exiting the top of the pipe while it is being raised, the top cap is held in place by steel cables and turnbuckles fastened to eyebolts located in both the top cap and base plate.

The system is maintained upright by three adjustable legs attached to an aluminum bracket mounted on the cylinder. The bracket and the piston latch are the only pieces of the assembly that are not steel. Two carrying handles are mounted on opposite ends of the cylinder as shown on figure 2. Pressure is maintained or evacuated from the cylinder through a steel coupling welded at the base, which, in turn, connects through a PVC coupling to a section of 0.15-m (6-in.) PVC pipe (the chamber assembly). This chamber, which is used to reduce the compression ratio of the system in the event some slight residual air is not evacuated, connects via a water pipe nipple and rubber hose to the vacuum pump. A valve and tee connection isolates the vacuum pump from the compressed air line when the piston is being raised. High-pressure tubing connects the other side of the tee to the control box. Connections at the control box consist of swage lock fittings for high-pressure tubing. The tee connection at the vacuum pump consists of 1.3-cm (1/2-in.) water pipe adapted at the control box end with a swage lock fitting.

A square-section piston seal provides a pressure seal around the free-floating piston. The anvil is secured to the base plate by hardened steel bolts, with the vacuum seal being maintained on the top side of the anvil with "O" rings positioned beneath the bolts. A square-section piston seal around the lower circumference of the anvil insures a vacuum seal between the anvil and cylinder wall. The PVC connections between the chamber assembly and cylinder are press fit and are kept suitably tight with duct seal around the joints. An additional O-ring is located on the base plate where the seal is provided by the weight of the cylinder. Thus four locations--around the piston, below the bolts on the top side of the anvil, around the lower circumference of the anvil, and on the base plate--provide the pressure seals for the system.

Field procedure consists of transporting the unassembled components to the impact location. The base plate and anvil are bolted together and inserted in the base of the cylinder while horizontal. The system is then raised and placed over the desired impact point. The tripod legs are attached and adjusted for a proper seat, and the piston inserted into the cylinder and allowed to drop to the anvil. The top cap, with piston latch attached, is placed atop the cylinder and secured by means of turnbuckles, steel cables, and eyebolts in the appropriate holes in the top cap and base plate. The chamber assembly and PVC couplers are next affixed to the cylinder and sealed at the joints with duct seal. The vacuum pump, control box, and compressed air source are connected and the piston raised by positive air pressure, normally requiring about 4 to 8 psi. The piston is manually latched into the piston eyebolt when it reaches the top of the cylinder. Occasionally more than one attempt is required. The latch is then either tied down or held manually while the lift pressure is evacuated from the system and vacuum applied. When the pressure gauge on the control box indicates adequate vacuum, the pump is turned off and the piston released by manually releasing the latch. Following impact, the procedure is repeated for the next impact.

TUNNEL SURVEYS

Initial proof tests of the system were made over a shallow alluvial surface underlain by indurated sandstone, clay, and conglomerate at the Denver Federal Center. Compressional arrivals exhibiting velocities of 2040 to 2255 m/s were detected from single drops at a range of over 200 meters. Only vertical geophones were used. Further tests were then made in the N-tunnel complex in Rainier Mesa at the NTS.

The tunnels at NTS are driven mainly in zeolitized ash-fall tuff of relatively uniform properties at most experiment locations. The rock at tunnel level may be generally characterized by the following properties,

Overburden........	400 m
Density	1.9 g/cc
Porosity..........	36 percent
Saturation........	95 percent
In situ stress....	6.7 Mpa vertical
	3.5 Mpa horizontal (min.)
Permeability......	0.0003 Darcy (interstitial to water)
P-wave velocity...	2430±250 m/s
S-wave velocity...	1190±90 m/s

Density and in situ stress data regarding tunnels in Rainier Mesa have been published by Carroll (1989), and Ellis and Ege (1976). The hydrologic regime in the Rainier Mesa area has been described by Thordarson (1966). Electrical properties and seismic velocity of rocks in the Rainier Mesa area have been reported by Carroll (1990) and Carroll and Magner (1988).

Seismic recording in NTS tunnels is occasionally hampered by high cultural noise. Consequently, the amplifier gains available during the work described here ranged from 18 to 72 db, and generally were in the range 36 to 42 db. Stacking was not an option with the refraction unit employed in this study.

Misty Rain Drift

Figures 3 and 4 depict typical waveforms obtained with the vacuum hammer in the Misty Rain bypass drift with the source at construction station 13+65. The drift at this location is 3.7 x 3 m (12 x 10 ft), and compressional- and shear-wave velocities are about 2480 and 1160 m/s, respectively. Figure 3 depicts the waveforms obtained using a 12-geophone array with 6.1-m detector spacings, the last geophone being located 85 m from the source. The P-wave arrivals are distinct, and a high-amplitude later arrival containing considerably more energy than the compressional wave is also evident on the record. This later arrival is dominant on seismic records obtained in NTS tunnels, regardless of the energy source. This is the SV-mode shear wave, and evidence for its identification as an SV arrival rather than a surface wave has been published (Carroll, 1986). This record also illustrates some of the problems encountered in these tunnel environments. In this case, the presence on some traces of weak, but distinct, early arrivals prior to onset of the P-wave through the tuff. These arrivals are due to energy being coupled along a 2.4-cm steel grout pipe lying along the invert. These arrivals can generally be eliminated by the use of wooden wedges placed under the grout pipe in the vicinity of the affected geophones.

The shear-wave arrival is more distinctly seen on figure 4. The array used here employed detectors on the same 6.1-m station spacing, however, the last phone in this instance was located 193 m from the source. The P-wave arrivals are poorly defined at this range, however, the SV mode is clearly seen.

In an attempt to obtain polarized SH waves, the hammer was inclined at an angle to the rib and perpendicular to the axis of the tunnel. The weight was released with the base plate set in a ditch. The source was then rotated 180 degrees and the impact repeated in the direction of the opposite rib utilizing a second ditch. A geophone spread consisting of four stations, each with geophones vertical, in-line, and transverse to the tunnel axis, was located on 6.1-m spacing at 84 to 102 m from the source. The results of this test are shown on figure 5.

The significant part of these results is the polarization evident on the transverse detectors. Polarization, or waveforms arriving 180 degrees out of phase with 180-degree reversal of the source, is considered indicative of the SH wave. The presence of arrivals P, SV, and SH is noted on all orientations of the detectors. In the ideal case, only the SH mode should appear on

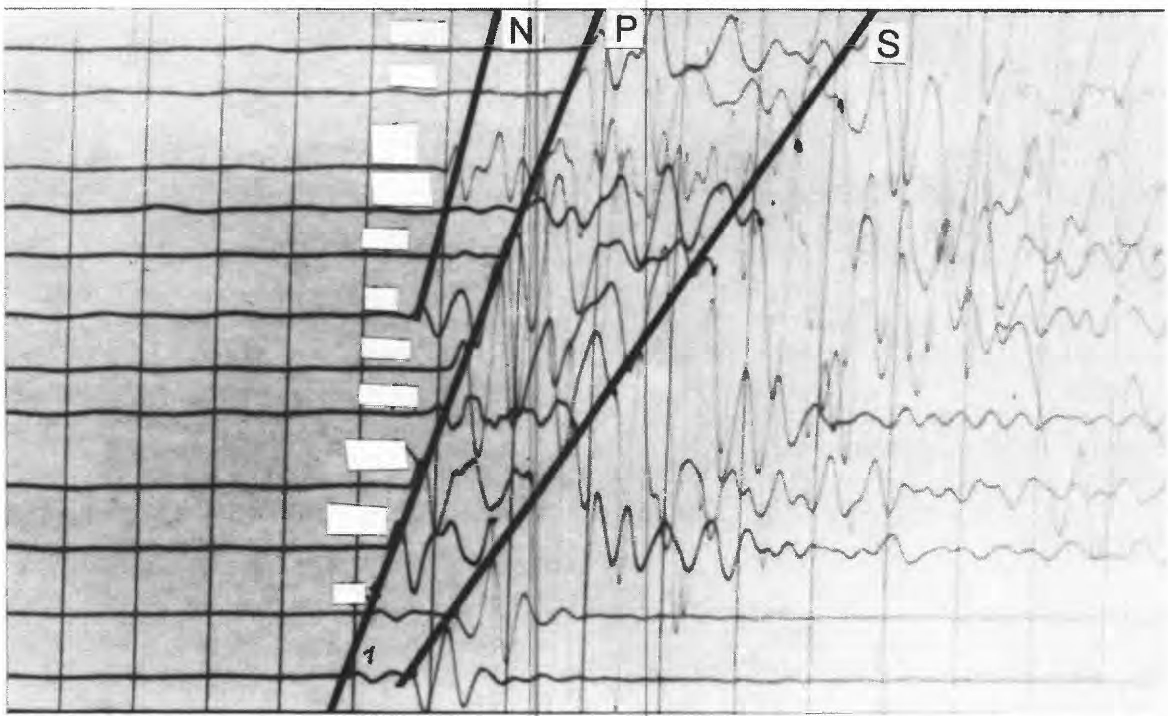

Figure 3.--Record obtained in Misty Rain drift with hammer offset 8.5 m from 12 detector array (6.1 m takeouts). P=compressional arrival; S=dominant mode attributed to SV arrival; N=early arrival due to energy coupling along grout pipe. Timing lines at 10 ms intervals.

Figure 4.--Record obtained in Misty Rain drift showing dominant SV energy. Source offset is 126 meters. Detector spacing 6.1 meters. P=compressional, S=shear arrival. Timing lines at 10 ms intervals.

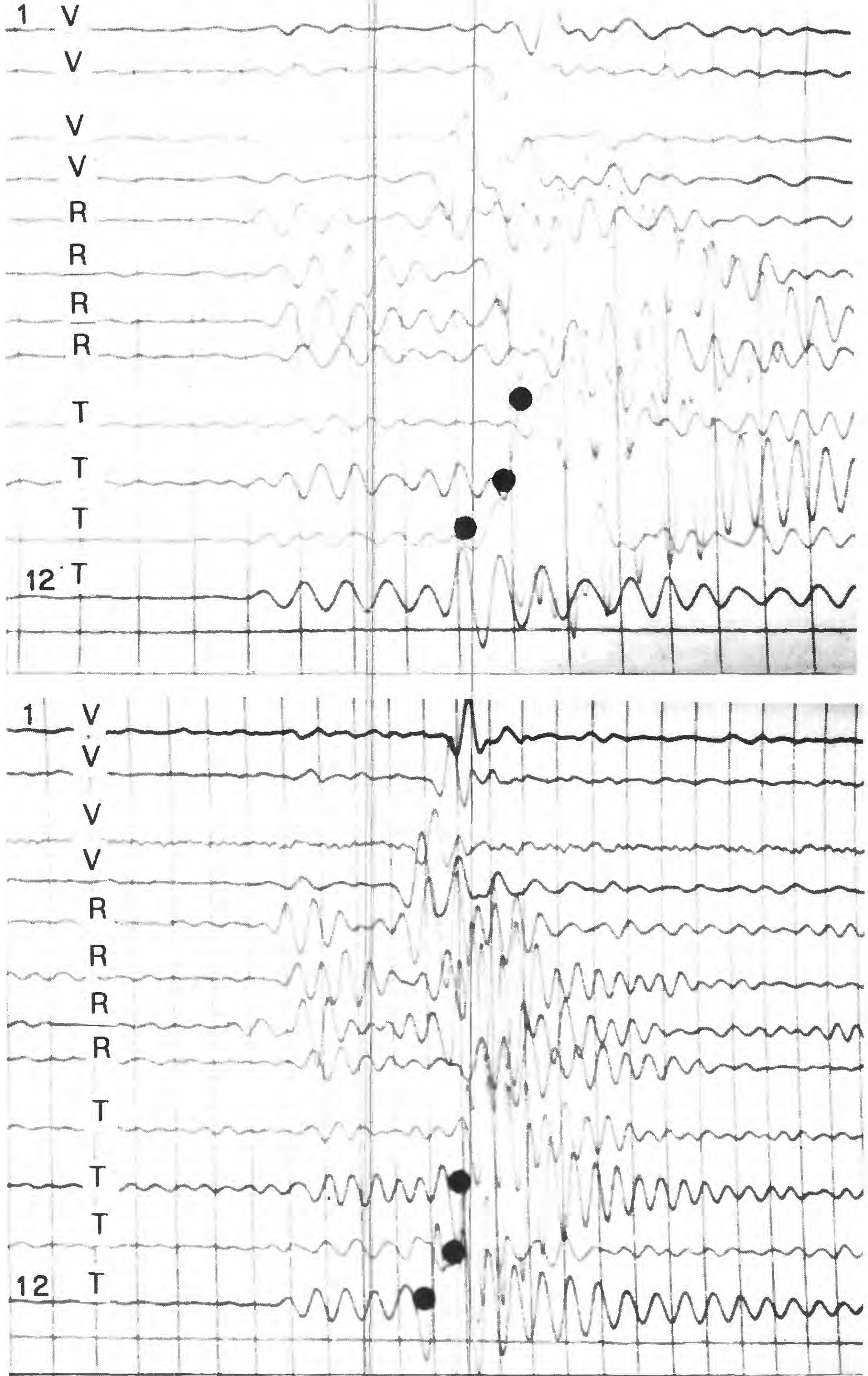

Figure 5.--Records obtained on 3-component geophones in Misty Rain drift. Top, hammer inclined at 54 degrees to left rib. Bottom, hammer inclined at 62 degrees to right rib. "•" indicates reversal of phase on transverse phones. Traces 4,5,12 offset 84 m from source; traces 1,8,9 offset 102 meters. V=vertical; R= radial; T=transverse detectors. Timing lines at 10 ms intervals.

the transverse detectors. Some P- and SV-wave energy is to be expected with the inclined source arrangement used because the orientation is not completely horizontal (0 degrees), but inclined at 50 to 60 degrees above the invert. However, similar arrivals on multicomponent detectors have also been observed with other sources which were presumably generating predominantly SV energy (Carroll, 1986; fig. 4). The reason for this is not completely understood. Possible explanations are conversion of energy at the source, or a wellbore effect due to the geometry of the tunnel. The complexities of the tunnel setup and environment aside, similar peculiarities in the nature of waveforms obtained at 3-component detectors have also been reported when using dynamite charges in crosshole seismic surveys (Geyer and Martner, 1969).

Red Hot Tunnel

Another application of the vacuum hammer involved an investigation of the effects of the explosion produced by the Red Hot nuclear event in G-tunnel within Rainier Mesa. The event setting differed from most nuclear tests conducted in tunnels, in that the device was detonated in a large mined chamber rather than within a small-diameter tunnel. The chamber was mined in the hemispherical shape shown on figure 6. The flat face of the chamber, inclined at an angle of 21 degrees, was excavated with a horizontal diameter of 40 m and a vertical diameter of 37 meters. The detonation point (WP) was located at the center of the flat face at a distance of 23 m from the spherical surface.

The Red Hot event was detonated in 1966. The work described here was completed in 1986 as part of a larger investigation to more completely define the history and mechanisms of the pressure and temperature decay arising from the original detonation. As one facet of this investigation, an exploratory hole was drilled to investigate the nature of the tuff immediately behind the flat face of the chamber. One of the measurements proposed for this hole was to qualitatively determine the range of blast damage by measuring the seismic velocity. Changes in seismic velocity have been demonstrated to be a significant indicator of the range effects of fracturing arising from nuclear explosions (Carroll, 1983).

P- and S-wave velocities of 2300 and 1190 m/s were measured at Red Hot by J.H. Scott and D.R. Cunningham of the U.S. Geological Survey prior to the detonation of the event (written commun.; 1966). In that investigation, extensive velocity data were obtained from accelerometer arrays along the horizontal and vertical diameters of the flat face, as well as along equatorial arrays at the top and center of the chamber. The listed velocities are characteristic of undisturbed tuff. A low velocity layer (970 m/s), attributed to the effects of stress relief on the excavation boundary, was also measured behind the

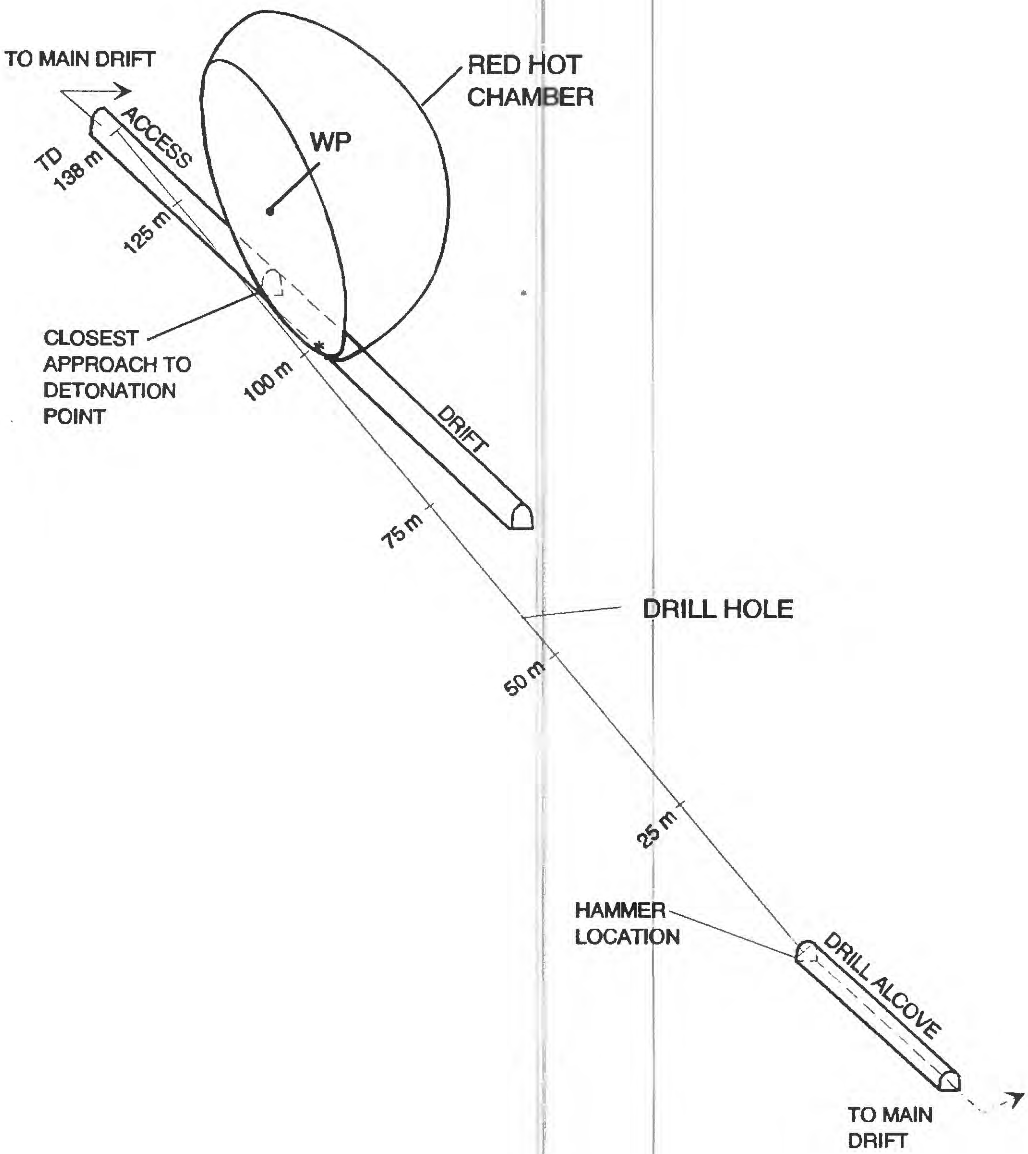

Figure 6.--Schematic showing location of Red Hot chamber and exploratory hole.

flat face. The thickness of this layer was estimated to range from 0.5 to 1.4 m with an average of 1.1 meters.

The NQ-diameter hole selected for the seismic measurements is about 15 m from the extension of the Red Hot access drift, and was drilled to a total depth of 138 meters. The hole was drilled on approximately a 1-degree upward incline, the bottom of the hole being nearly 3 m higher than the collar. The closest approach to the WP is at a depth of 110 m, where the hole is 12.2 m below the WP and 6.4 m from the pre-explosion flat face. As a result of the explosion an expanded flat face and crater were created in the vicinity of the WP. At the 110-m depth, the hole is 4.3 m from the expanded face and 5.2 m from the edge of the explosion crater.

The vacuum hammer was employed in conjunction with a fabricated geophone probe to obtain an in hole velocity survey. The probe was a modification of a tool built to obtain similar measurements in holes drilled in the floor and back at another tunnel complex within Rainier Mesa (Carroll and Magner, 1986). Three geophone inserts (Mark Products L-25D) were packaged inline on 6.1-m centers, separated by 2.5-cm-diameter PVC tubing. Provision was made for pressure contact of the sensors against the wall of the hole utilizing an air bladder arrangement employed in the original tool, however, it was found that gravity contact was adequate. The 12.2-m probe assembly was manually positioned in the hole using 6.1-m sections of 2.5-cm-diameter PVC pipe. Stations were occupied at 12.2-m intervals, thus providing a one-geophone overlap. The hammer was located at the hole collar.

Figure 7 is a plot of the results of the in hole velocity survey. Times of arrival are depicted for both impact source (going in the hole) and dynamite source (coming out of the hole). Because of noise levels in the tunnel, small charges were required for the deepest geophone station, the recording system used not being suitable for signal stacking. With the ability to stack, complete coverage could probably have been obtained with the vacuum hammer. A comparison of the waveforms obtained with hammer and dynamite at the 37- to 49-m interval in the hole is shown on figure 8. No shear-wave energy was recognized on the seismic records.

The compressional-wave velocity has obviously been significantly lowered in the vicinity of this event. Measurements of compressional velocity have been compared for several pre- and post-event velocity surveys obtained elsewhere within Rainier Mesa tunnels (Carroll, 1983). With the exception of a horizontal distance within about $31W^{1/3}$ meters from the WP (W=explosion yield in kilotons), explosion-induced decreases in compressional velocity are rarely sufficient to place the measured post-event velocity outside the range of compressional velocities recorded

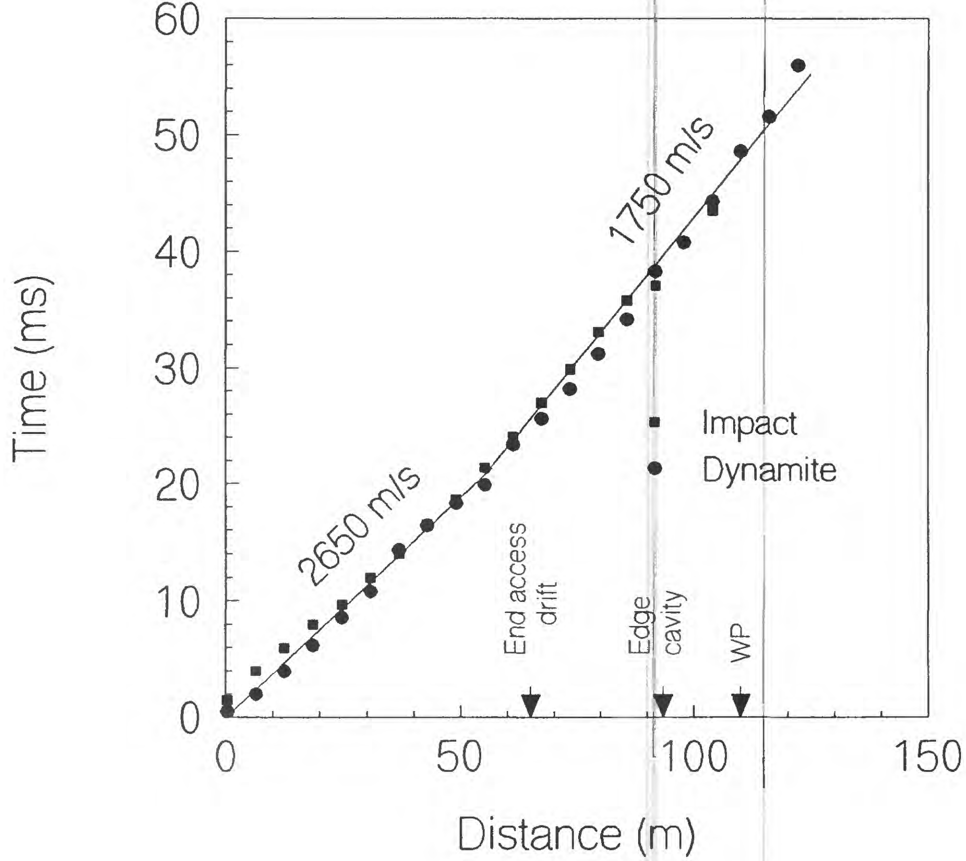

Figure 7.--Velocities obtained in Red Hot exploratory hole

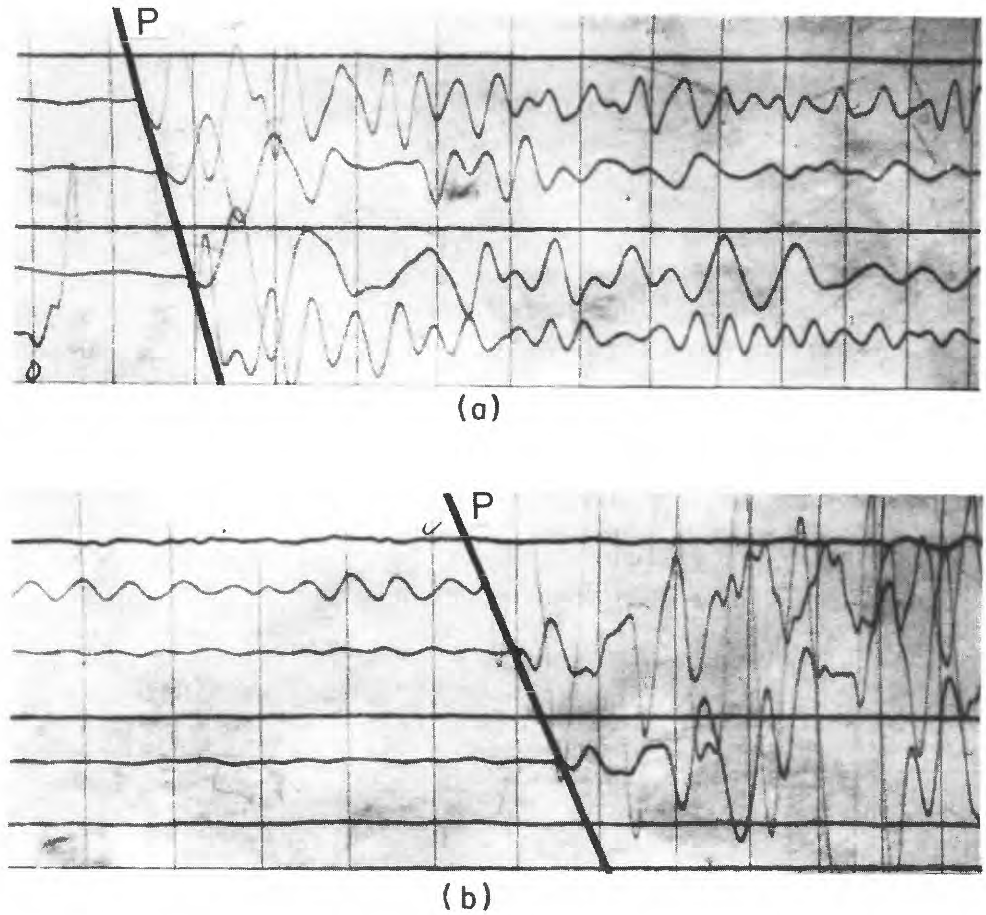

Figure 8.--Records obtained in interval 37 to 49 m in Red Hot exploratory hole. Source is (a) impact hammer, and (b) dynamite charge. P=compressional arrival. Timing lines at 10 ms intervals.

for virgin tuff at most sites.[2] This does not mean that compressional velocity changes do not occur, however, without a knowledge of the pre- and post-event velocity at the same location one generally cannot determine that the velocity has changed based strictly on a comparison of the post-event velocity with the experience histogram of velocities recorded in unshocked tunnels.[3]

The compressional velocity of 1750 m/s recorded in the deeper portion of the Red Hot hole, however, is outside any experience for compressional velocity of virgin tuff in tunnel surveys, and has only been observed near tamped events in the extremely close-in region. Initially this suggests that energy decoupling due to the chamber was not greatly effective in preventing large compressional velocity decreases in the tuff due to ground shock, at least to a range of 25 m from the edge of the cavity. Effects of the explosion were also observed in core beginning at about the hole depth (76 m) where the velocity break occurs. However, to ascribe the dramatically decreased velocity strictly to shock effects must be tempered by two factors; the coincidence of the end of the access drift (4.6-m diameter, 12 m from the hole at the rib prior to the explosion) with the onset of the velocity change, and the fact that over 20 years have elapsed since initial mining. Although refraction velocities obtained along the invert in newly mined drifts in Rainier Mesa do not show effects of ground relief i.e., the presence of a low-velocity layer, even after many months, there are no velocity data measuring the effects of stress relief on compressional velocity around tunnel openings in virgin ground over this period of time. Thus, separating the contribution of shock damage in lowering the seismic velocity from what might be due to normal stress relief is speculative.

SUMMARY

The vacuum hammer has proven a useful seismic energy source in underground applications. The present system is semi portable and requires only electrical power. Accessory items needed are a small vacuum pump and a compressed air supply from either a

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[2] This equation is not strictly applicable to the Red Hot event because the relationship was derived from observations involving nuclear events in which the energy was more highly coupled to the earth than was the case for Red Hot.

[3] This is not true of the shear-wave velocity. Shear-wave velocity of shocked tuff is almost universally lower than the shear velocity of the virgin material for some distance beyond the $31W^{1/3}$ range.

compressor, air line, or bottle. Energy detection at ranges over 200 m were obtained for SV waves, however, the compressional wave was detected at no more than half this range. The above observations are tempered by the existing noise levels in the tunnel environment. The data presented in this report were often obtained at no more than 48 db of gain and without stacking. Quieter conditions would enhance the range, and stacking could be advantageous. The system is also capable of producing polarized SH waves. Because the hammer cannot be employed as a source in a completely horizontal mode, some P and SV energy is also produced.

Frequent use of the vacuum hammer and (or) the availability of a more portable transportation system might benefit from some modification of components. This would result in a system weight which would be difficult to handle manually. Details are discussed in the appendix; however, they essentially entail permanent fixture of the base plate and anvil, and the top cap. In addition, the latching mechanism for the piston would benefit from the use of an improved method, such as an electromechanical system, to latch and release the piston.

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APPENDIX A

DETAILS OF HAMMER COMPONENTS

Photographs showing details of the system components are shown on Figures A1 and A2. Detailed drawings of these components are also presented on the following pages. Dimensions are presented in English units as is customary on machine drawings. Notes pertinent to individual components are in the accompanying text. It should be emphasized that this system is a working prototype, designed for portability and rapid assembly to provide energy where isolated circumstances dictate. Suggestions are presented in the following sections where improvements might be made if frequent use is planned and (or) weight is not a consideration.

With the exception of the aluminum tripod bracket and piston latch, all the components used in the fabrication of the system are steel. The system was fabricated in an in-house machine shop at a cost, less compressor and vacuum pump, of less than $2000 in 1983 dollars. Weights of the system components are as follows,

Cap and latch assembly	7 kg (16 lb)
Piston	43 kg (94 lb)
Cylinder w/collar, handles	84 kg (185 lb)
Base plate w/bolts, eyebolts	9 kg (20 lb)
Anvil	18 kg (39 lb)
Tripod legs	10 kg (22 lb)
TOTAL	171 kg (376 lb)

TOP CAP AND PISTON LATCH

The top cap and piston latch specifications are shown on figures A3 and A4. The top cap fits over the top of the cylinder after insertion of the piston. The cap serves two functions; 1) it prevents the piston from exiting the cylinder while it is being raised under positive pressure, and 2) it houses the piston latch which prevents the piston from prematurely falling. Pins for two 1/2-in. pivot latch pin holes (one of which is redundant) are press fit. The top cap also contains three 1/2-in. eyebolts, used to secure the cap to the base plate with 1/16-in. cable and turnbuckles.

The prototype design requires communication between an operator for the pressure control box and an individual manually latching and releasing the piston. One immediate improvement in the system would be to lengthen the arm of the latch. Presently, once the piston is latched, the latch is manually secured using the closed end of a box-end wrench as a lever arm while the cylinder is evacuated. The latch could be further improved by providing an electromechanical technique for latching and releasing the piston. Because aluminum is malleable and tends to produce shavings under extended use, steel is probably more appropriate for the latch. If weight considerations are not important, the entire top cap and latch system could be permanently welded and sealed to the cylinder.

PISTON

The piston specifications are shown on figure A5. The piston's pressure seal is maintained with a 6-in.-diameter, square-section piston seal. Provision is made on the piston to accommodate a second seal, however, in practice only one seal is used because of excessive friction when a second seal is employed. One seal has been found to provide an adequate pressure seal. The rounded base of the piston insures uniform impact on the anvil. The piston and inner barrel of the cylinder should be generously oiled.

CYLINDER

The cylinder specifications are shown on figure A6. The cylinder consists of standard 6-in.-I.D., 3/8-in.-thick tubing. Near the base of the cylinder is welded a 2-in.-diameter steel coupling. The coupling accepts a 2-in. PVC slip-joint adapter to which the air chamber is connected. A 2-in. PVC plug is inserted during system transport and storage to protect the threads.

In an attempt to reduce the weight of the cylinder by one-third, tests were made employing steel tubing of 1/4-in. wall thickness. However, when seated on the tunnel invert, the cylinder mass was not sufficient to prevent excessive rebound of the system, inordinately straining the turnbuckle and cables holding the top cap.

BASE PLATE AND ANVIL

The base plate specifications are depicted on figure A7 and the anvil on figure A8. The base plate contains one of the two lower pressure seals for the system, consisting of an O-ring fitted into a groove in the upper surface of the base plate. This seal is optional, and is maintained by the weight of the cylinder on the O-ring. Two 1/2-in. eyebolts are threaded into opposite outer-corners of the base plate to accept the cable and turnbuckles that hold down the top cap.

The anvil is secured within the inner groove of the base plate by three 1/2-in. hardened bolts. The pressure seal is maintained at the piston end of the bolts with O-rings, and the bolts secured on the underside of the base plate with nuts. When tight, the nuts are sufficiently recessed so as to be below the impact surface of the base plate. The 1-in. hole in the anvil center was initially designed to evacuate any slight residual air from the system when aligned with the 2-in. coupling on the cylinder. However, to prevent this air from stagnating on release of the piston, the upper diameter of the anvil is cut back 1/2 inch. This also eliminates the need for aligning the anvil hole with the hole in the cylinder. The second lower pressure seal, between the cylinder wall and anvil, is maintained by a square-section piston seal on the circumference of the lower part of the anvil.

Again, if the system were to be routinely employed in a mode where weight is not a concern, the entire base plate and anvil assembly could be welded to pressure seal the system. This would make the weight of the cylinder-anvil-base plate assembly 244 pounds. Even at this weight, however, the system is generally not disassembled if transportation is available underground to move to a new impact point. Repeated use of the system requires checking, and occasionally replacing, the O-ring seals at the head of the bolts, and less frequently the bolts themselves.

HANDLE MOUNTS

Details of the carrying handles for the cylinder are shown on figure A9. The mounts are not removed from the cylinder.

TRIPOD BRACKET AND LEGS

The tripod bracket (figure A10) is aluminum and is press fit on the circumference of the cylinder. The bracket is provided with holes for press fitting 3/8-in. pins to accommodate the adjustable bracket legs and hold the system upright (fig. A11). Other than the standard locations for the pins on 120-degree centers for vertical stability, two additional pin locations are provided to allow the cylinder system to be inclined to provide impacts with a significant shear-wave (SH) component.

The tripod legs consist of 3/4-in. water pipe inside which 3/4-in. tubing (the inner barrel) is moved to obtain the desired length of each tripod leg. A single hole is provided on the lower end of the water pipe, and the inner barrel length is adjusted by means of a pin insert through any of several holes provided. A small foot is inserted in the inner barrel to prevent dirt from clogging the pipe.

CHAMBER ASSEMBLY

The chamber assembly (fig. A12) is made from 6-in. Schedule 40 PVC, sealed at each end with end caps. One end contains a 1/2-in. water pipe coupling (for the hose to the vacuum pump/compressor tee) and the other contains a 2-in. PVC slip-joint coupling. The PVC coupling accommodates a small section of PVC pipe (shown in the photograph in fig. A1) connecting the chamber assembly to the cylinder. No threaded or permanently sealed connections are used to join the chamber assembly to the cylinder through this PVC pipe. The connections are press fit and then sealed with duct seal. This is adequate to maintain the pressure integrity of the system.

The chamber assembly was added to provide a large volume for any compression to dissipate in the advent a small amount of residual air is retained in the system after evacuation. The chamber prevents stagnation of the air upon release of the piston, which can occur if only a small diameter path is available at the cylinder coupling.

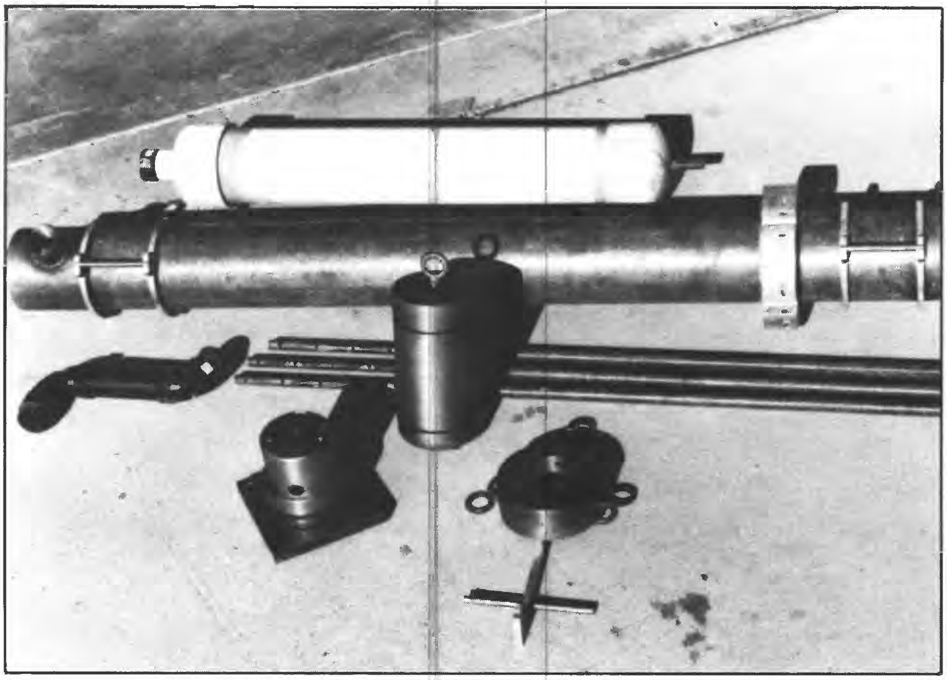
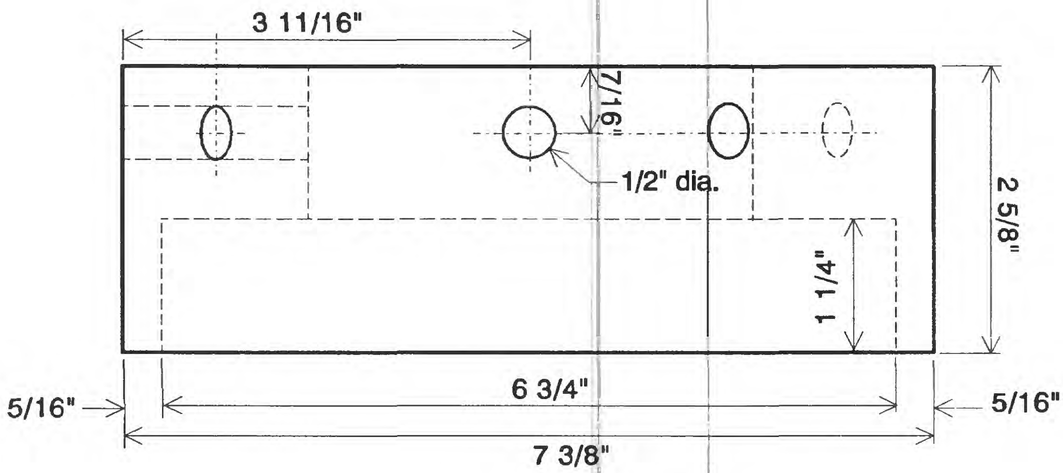
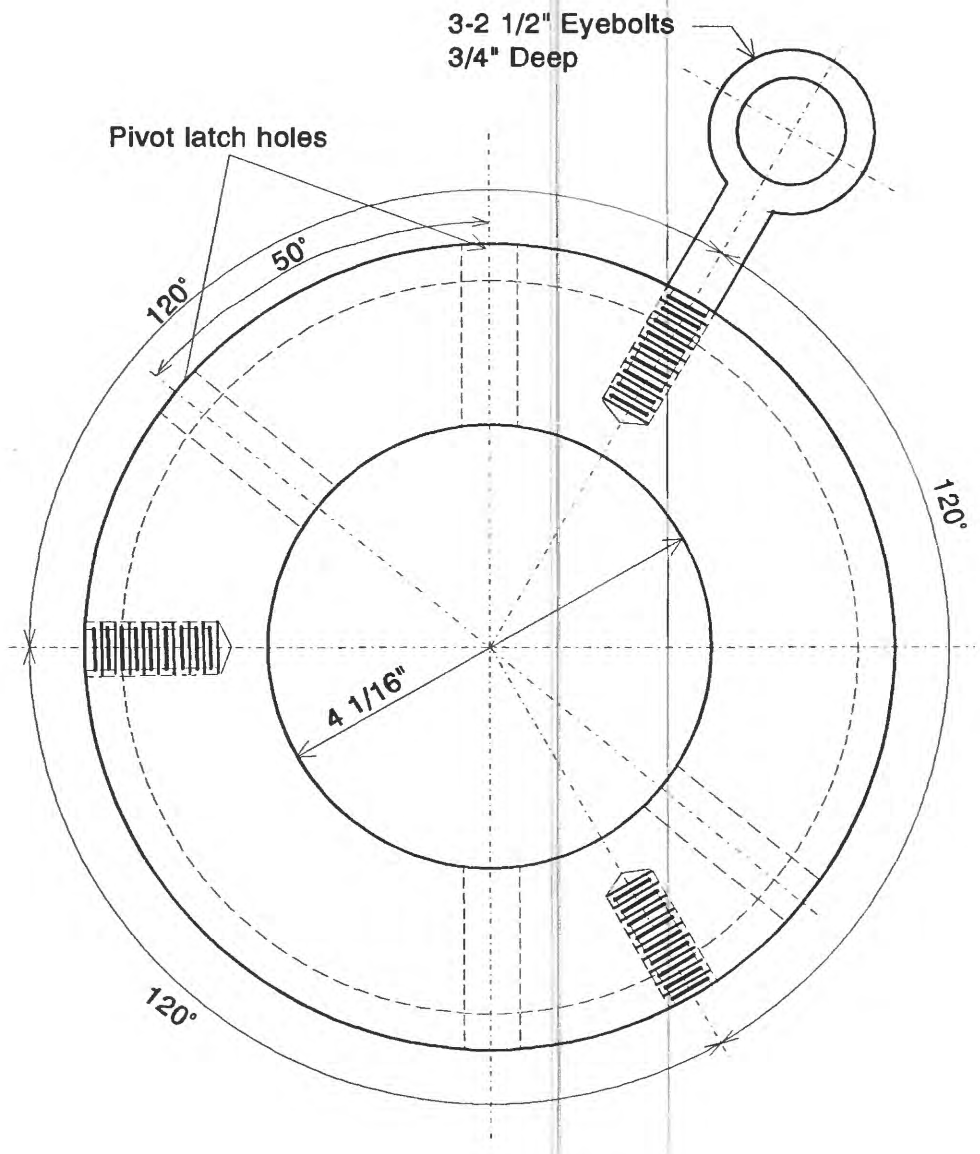


Figure A1.--Components comprising vacuum hammer system. At rear behind cylinder is chamber assembly. Shown on cylinder are tripod bracket and handle mounts. Coupling to air chamber is exposed at base (left) of cylinder. PVC section to connect air chamber and cylinder, and tripod legs are shown in front of cylinder. Anvil and base plate, piston, top cap, and piston latch (with pin inserted) are shown in foreground.

Figure A2.--Closeup of (a) anvil and base plate, piston, top cap, and piston latch, and (b) base plate (with O-ring seals for 1/2-in. anvil seating bolts), anvil, and anvil/cylinder seals.





TOP CAP

Figure A3.--Details of top cap.

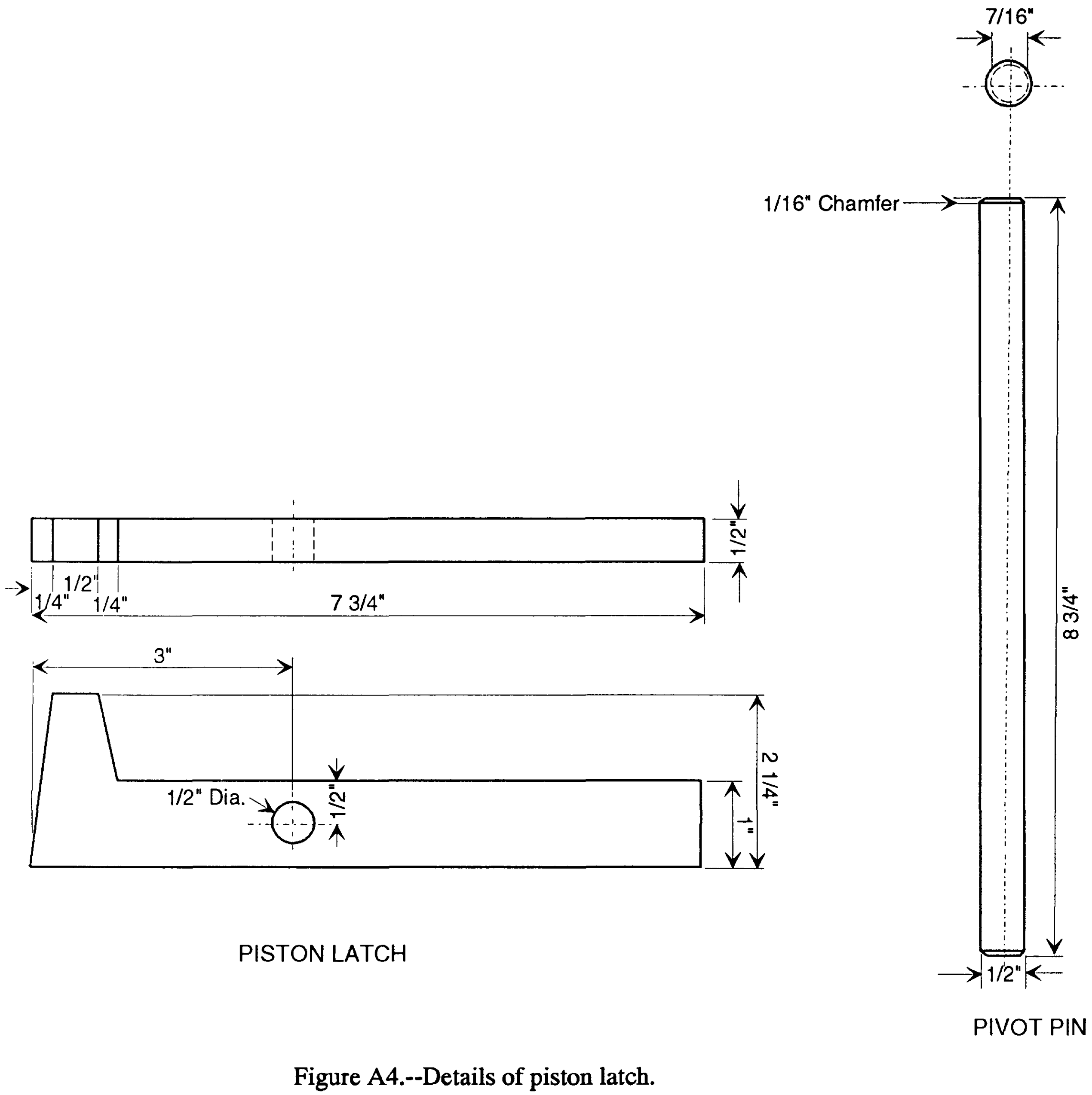
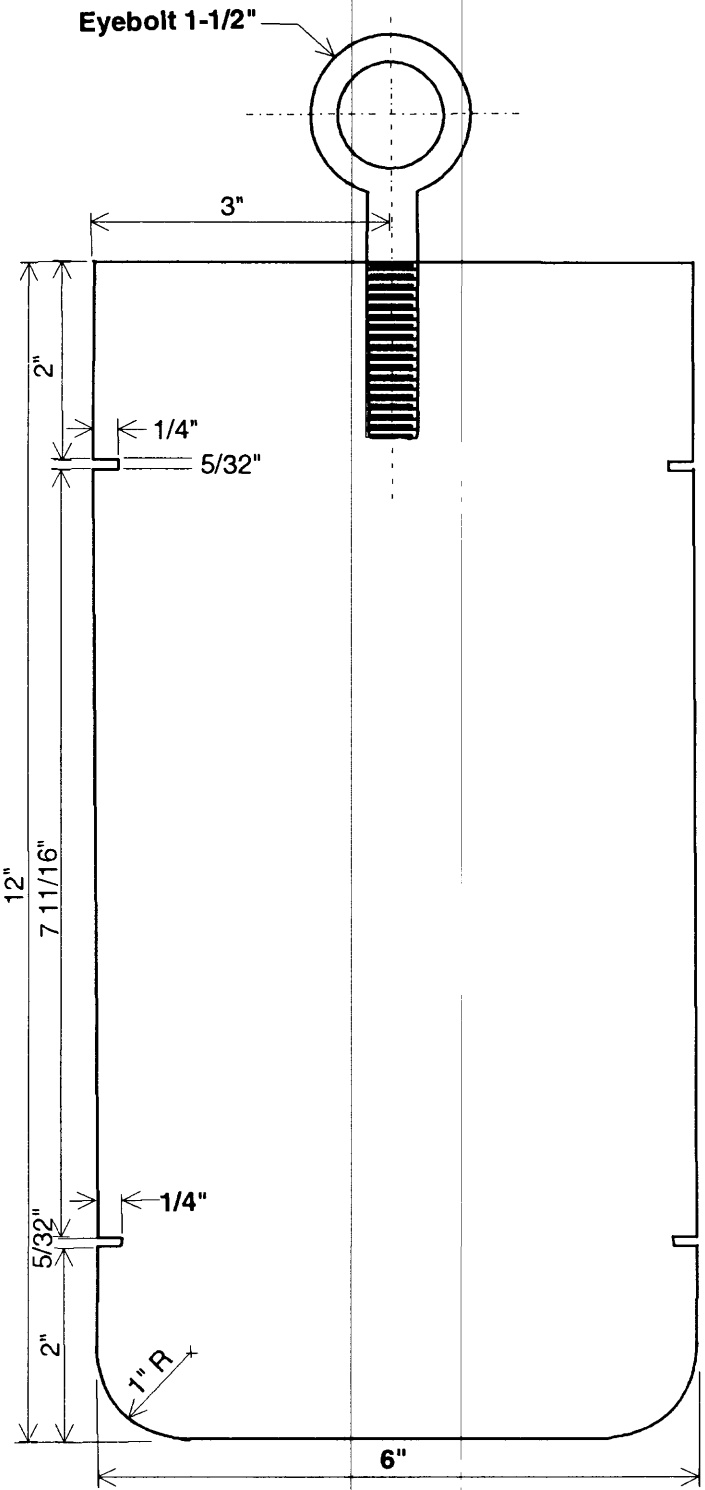


Figure A4.--Details of piston latch.



PISTON

Figure A5.--Details of piston.

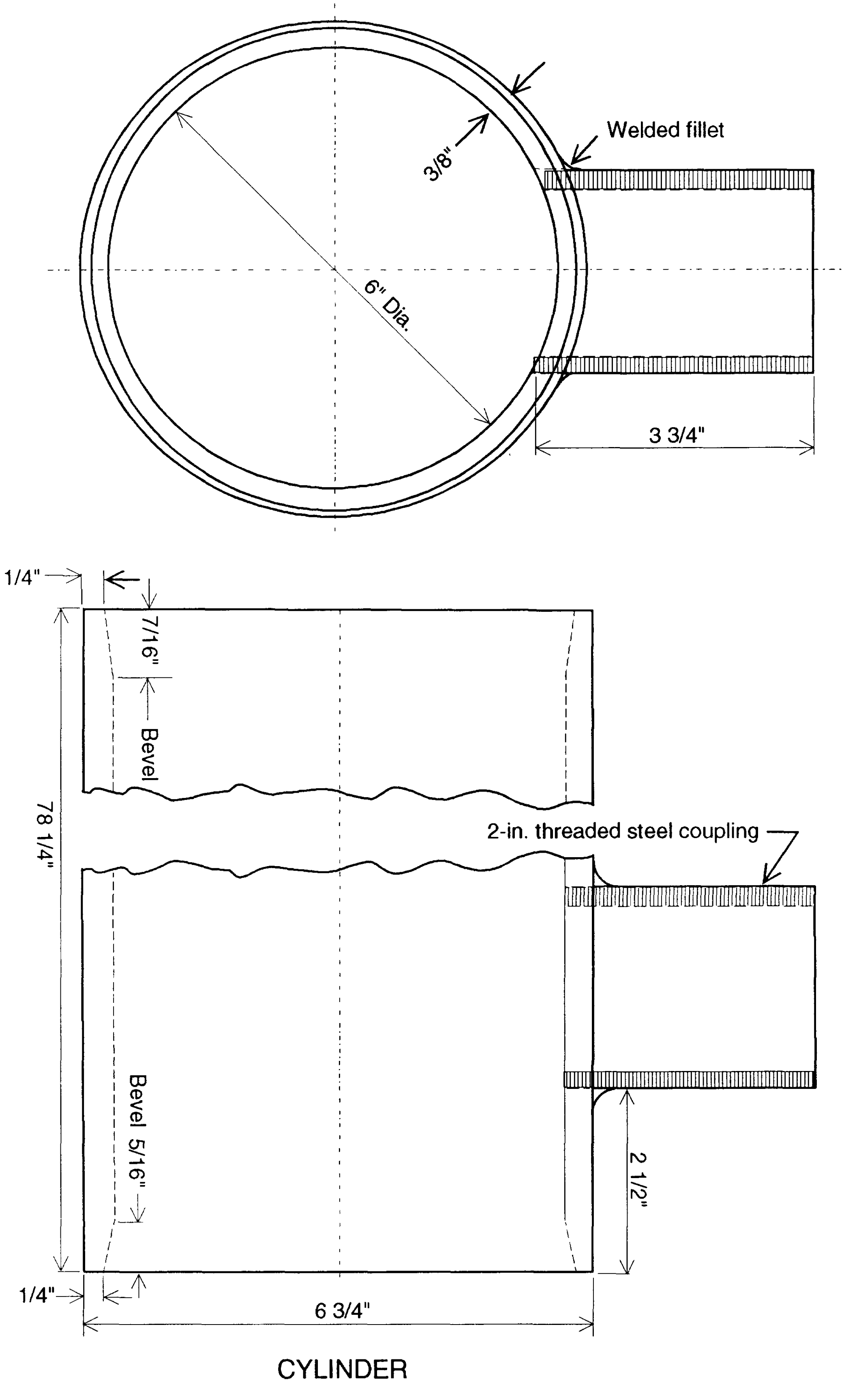


Figure A6.--Details of cylinder.

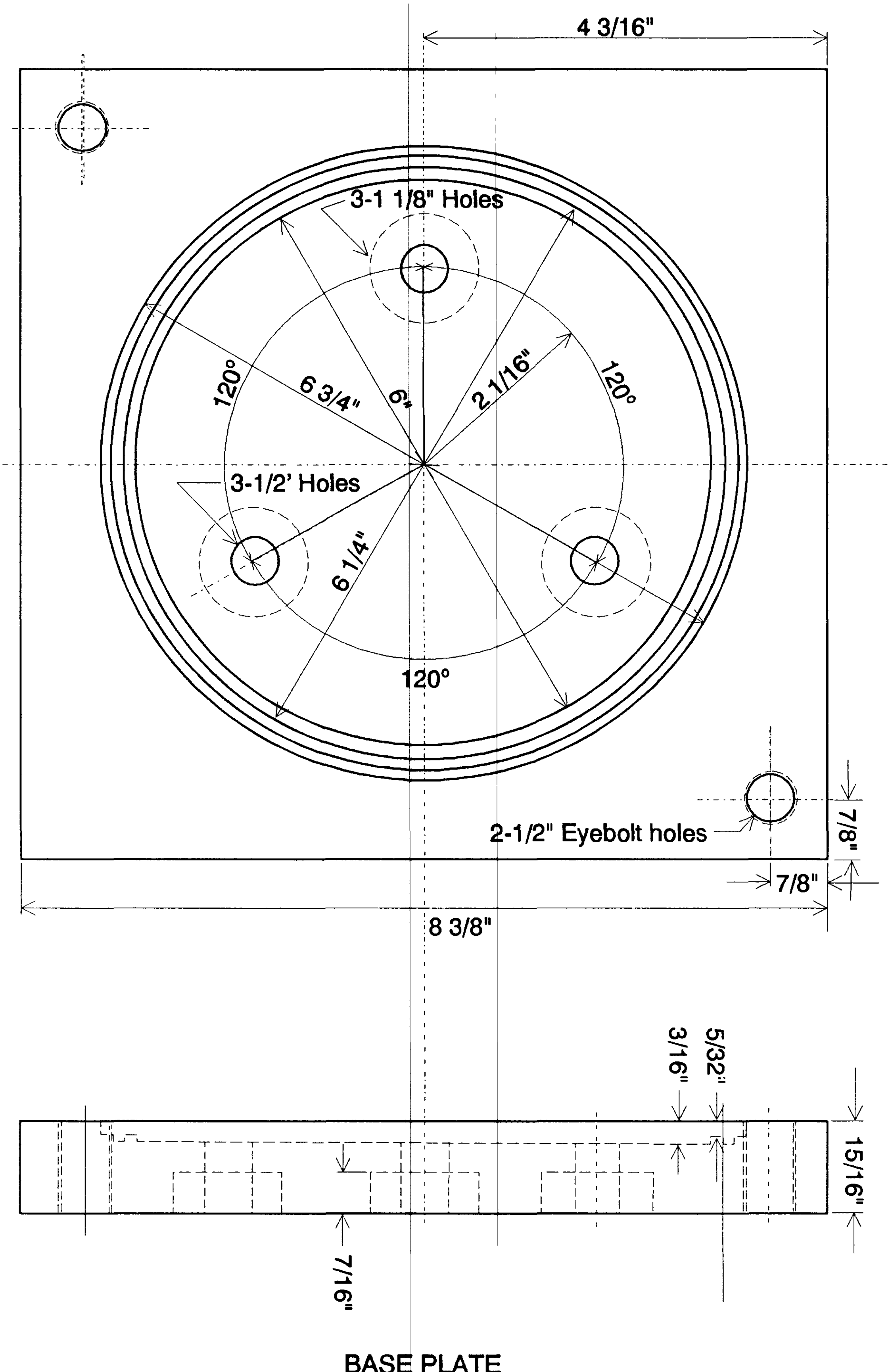
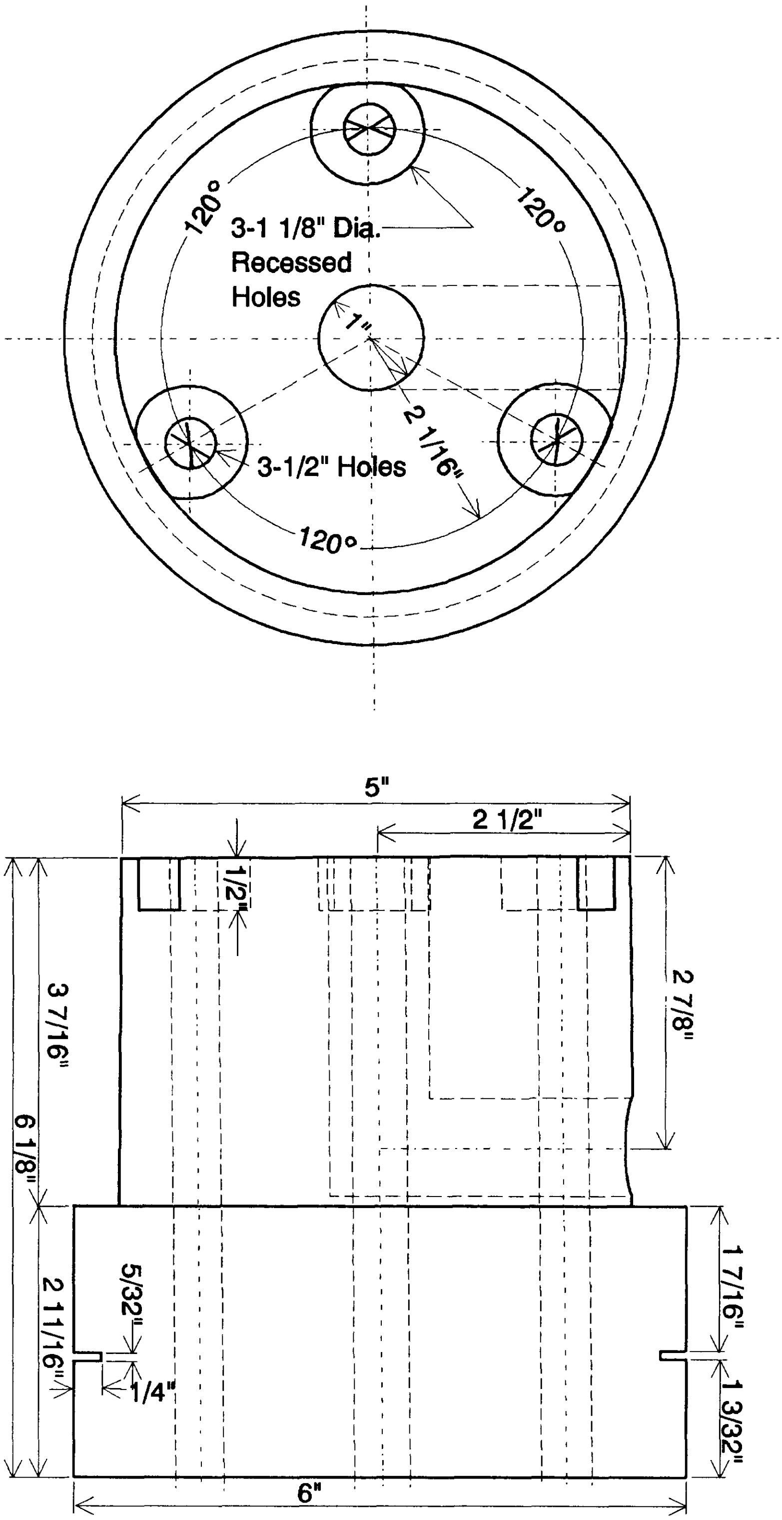


Figure A7.--Details of base plate.



Anvil

Figure A8.--Details of anvil.

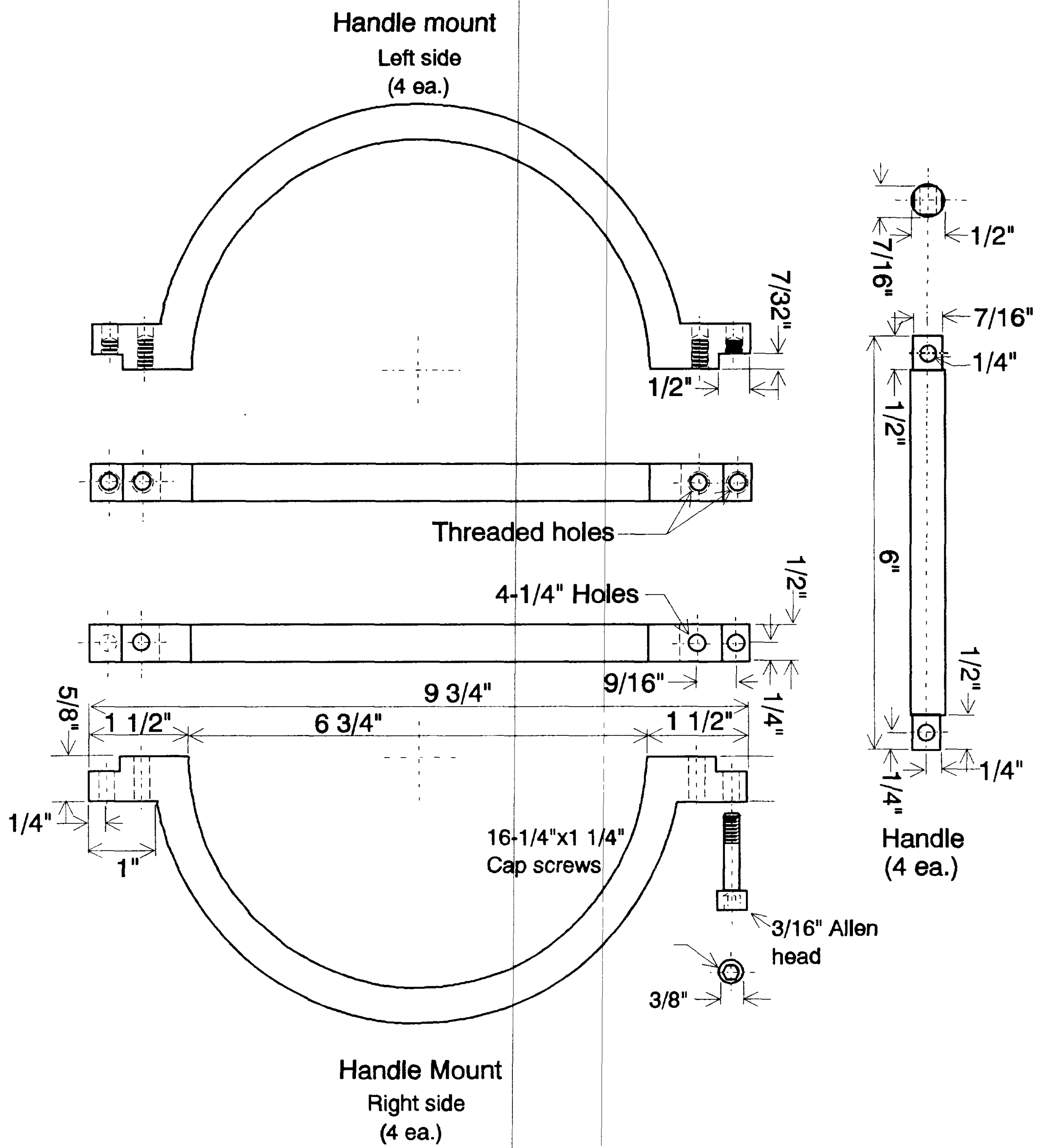
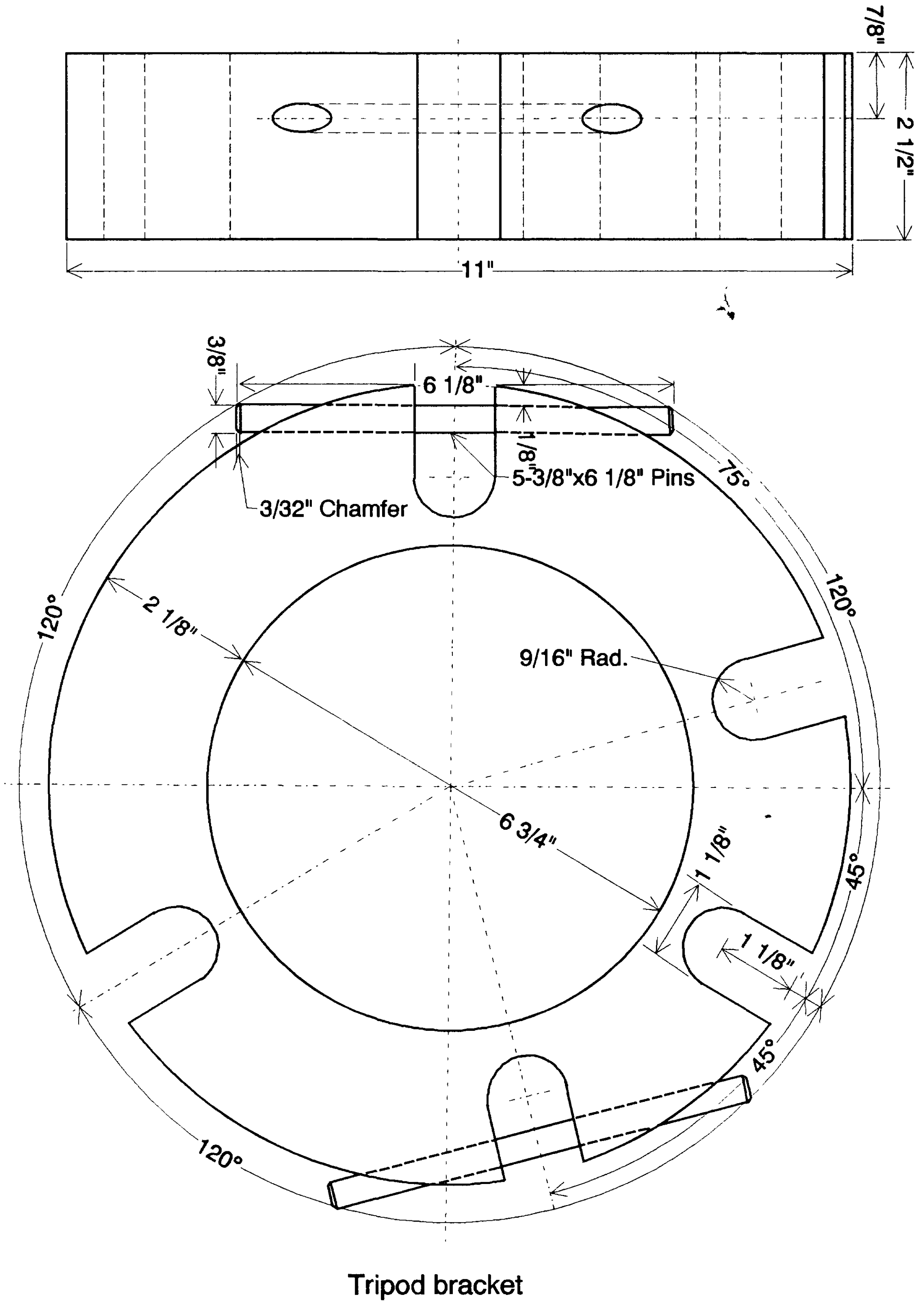


Figure A9.--Details of handle mount.



Tripod bracket

Figure A10.--Details of tripod bracket. Only two pin holes depicted.

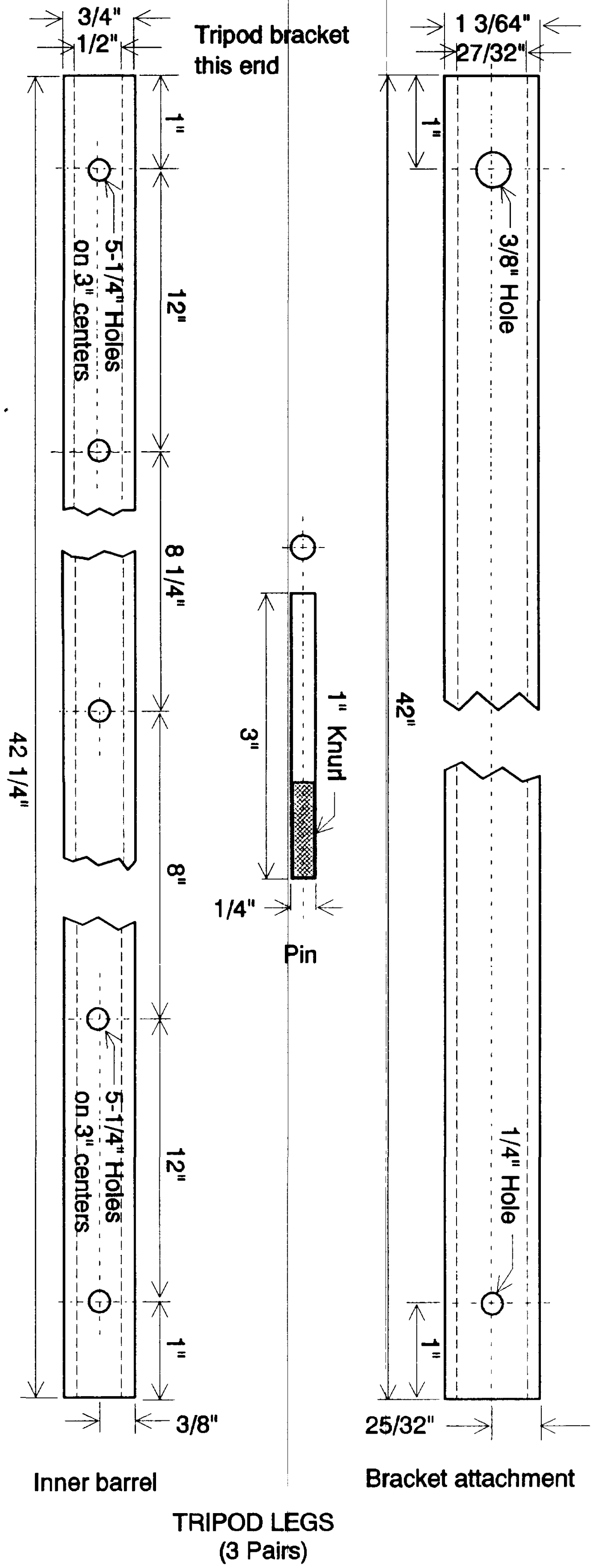
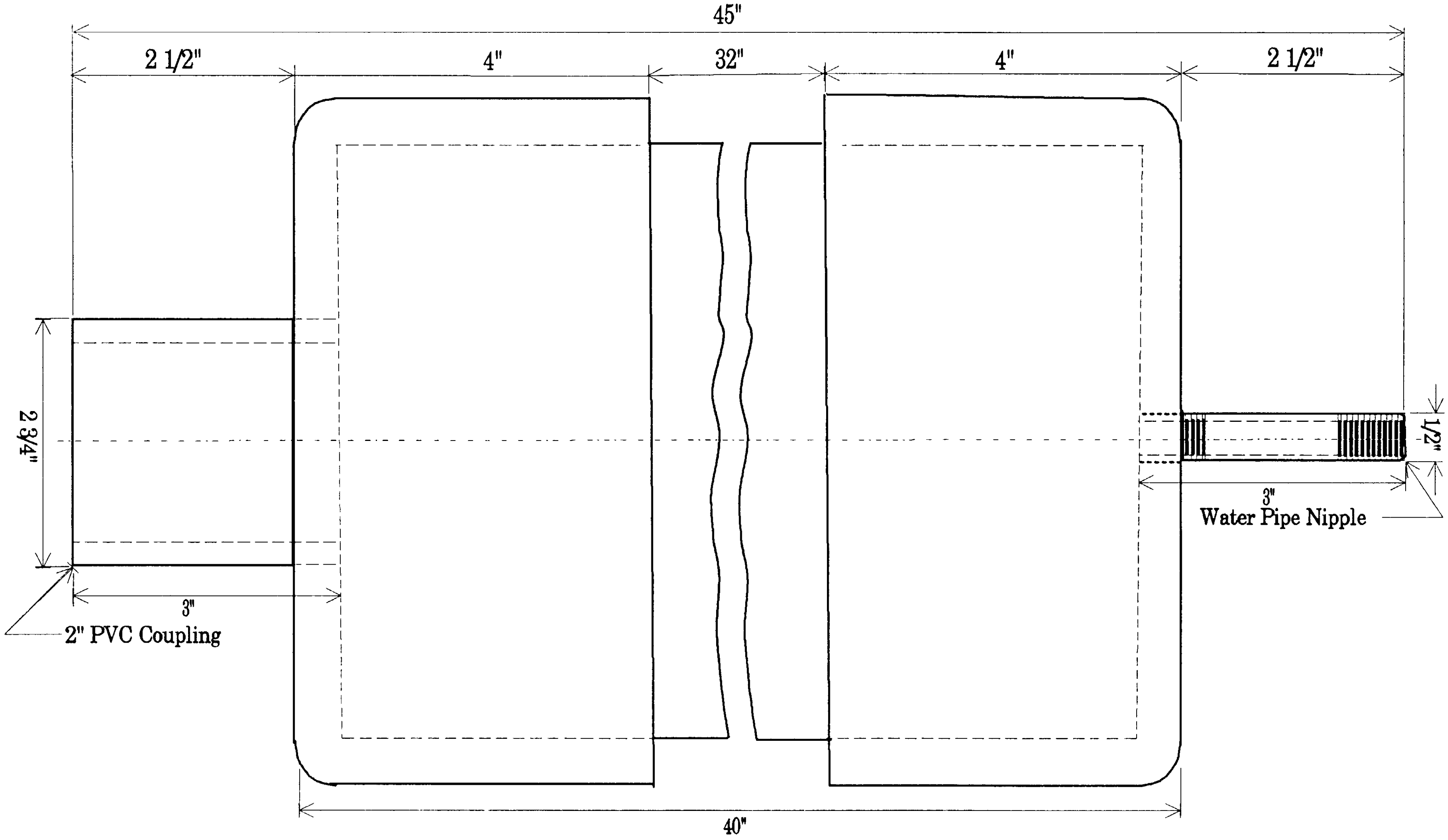


Figure A11.--Details of tripod legs.



CHAMBER ASSEMBLY

Figure A12.--Details of chamber assembly.

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