United States Patent [19]

Wuenschel

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[54] **REPRODUCIBLE SHOT HOLE APPARATUS**

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[73] Assignee: **Gulf Research & Development Company,** Pittsburgh, Pa.

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[21] Appl. No.: **267,955**

Related U.S. Application Data

[62] Division of Ser. No. 82,907, Oct. 22, 1970, Pat. No. 3,693,717.

[52] **U.S. Cl.** **166/207**

[51] **Int. Cl.** **E21b 17/02**

[58] **Field of Search** .... 166/315, 299, 285, 207, 166/187, 203; 285/45, 133 R

[56] **References Cited**

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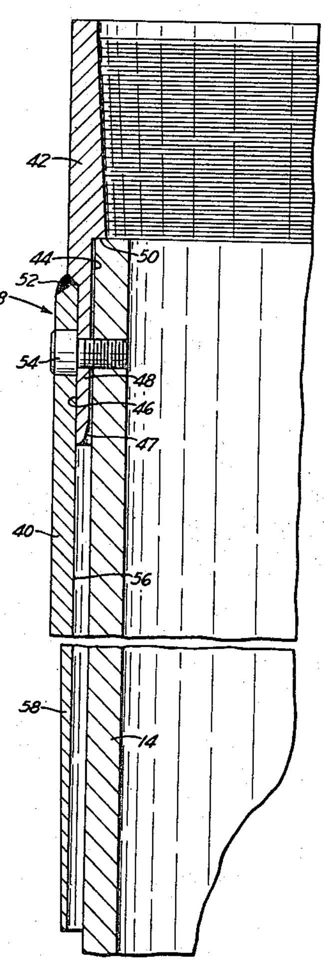
Primary Examiner—David H. Brown

[57] **ABSTRACT**

A reproducible shot hole for geophysical use wherein a deformable metal liner, such as aluminum, of predetermined diameter, wall thickness, and alloy is selected, and the annulus between the liner and the hole filled with sand-cement under pressure, so that the lined hole will withstand repeated explosions by expanding.

9 Claims, 4 Drawing Figures



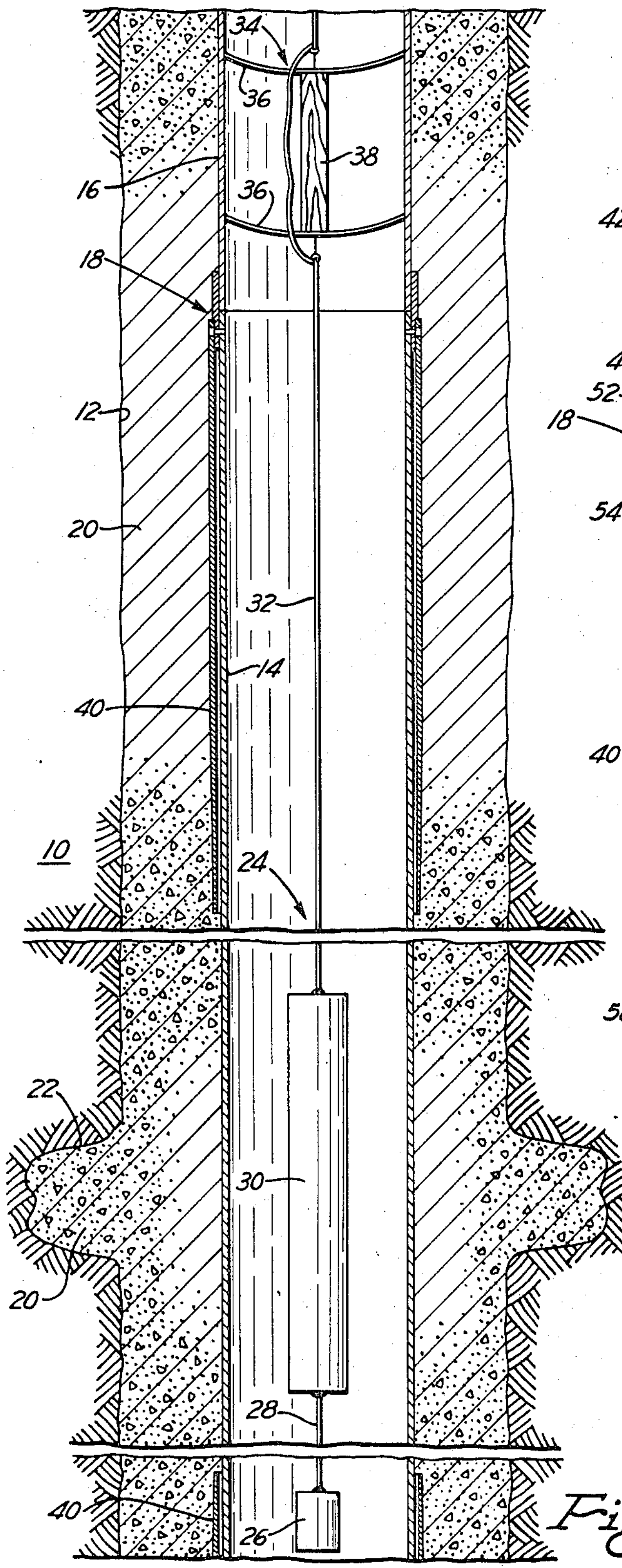

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Fig.1

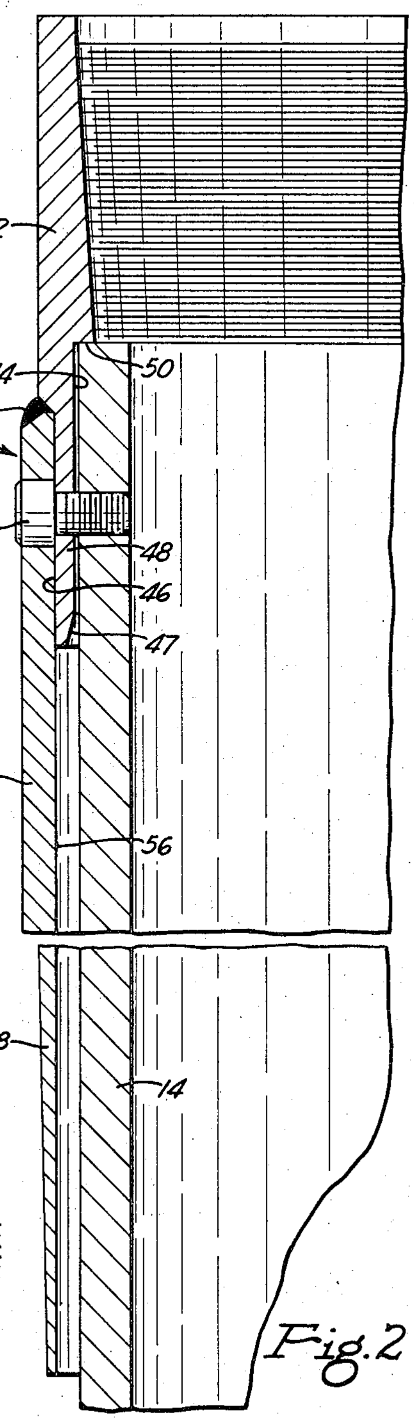
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Fig.2

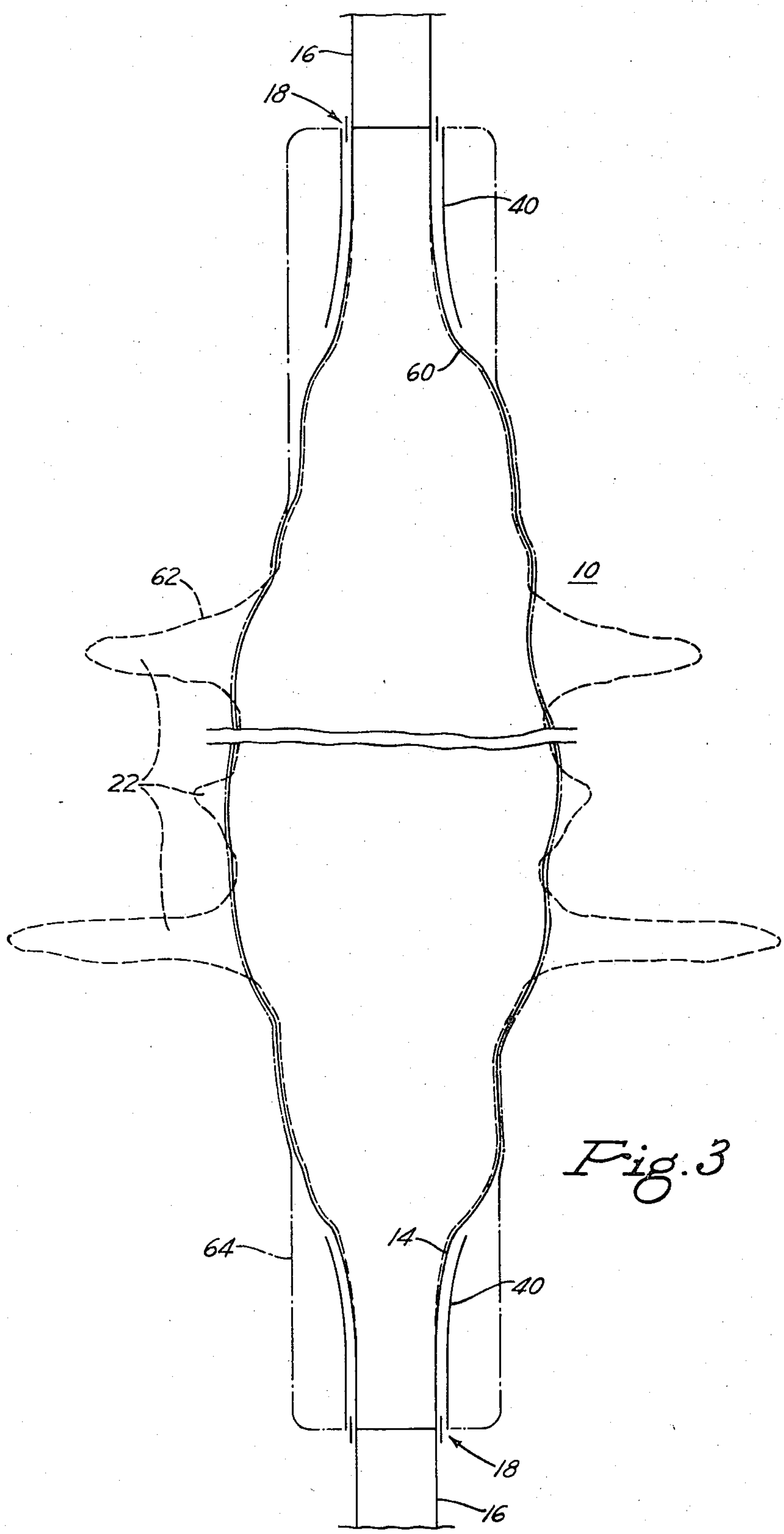

Fig. 3

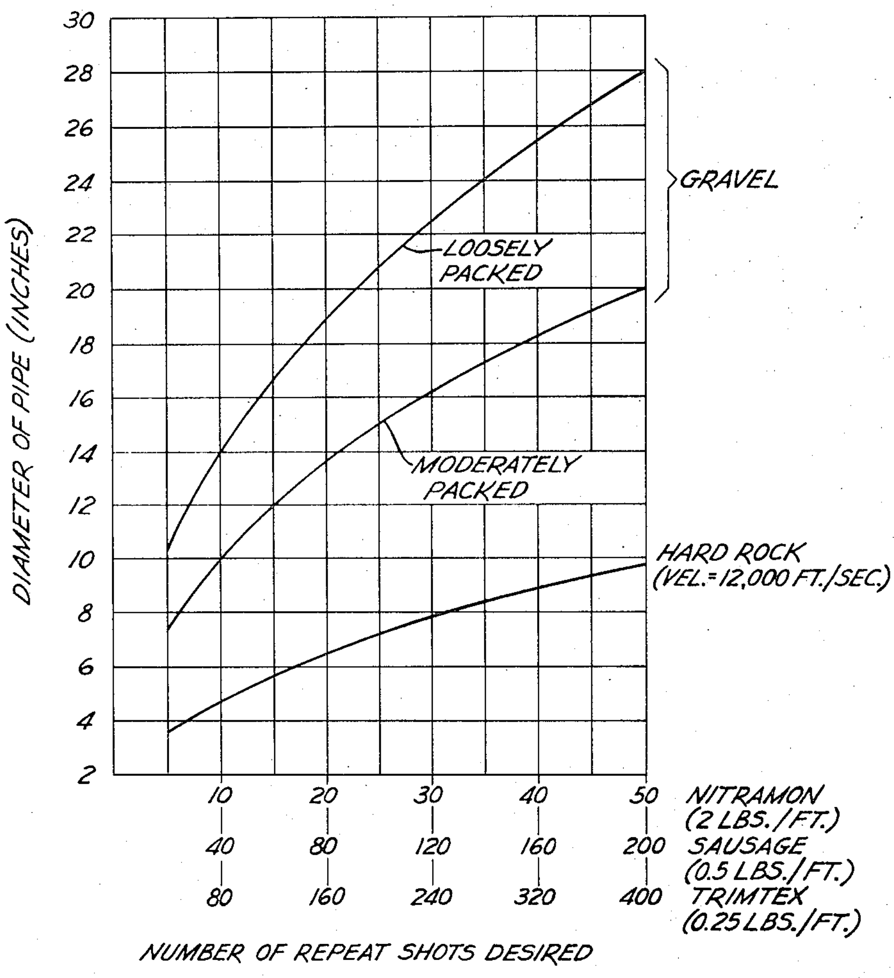
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
DIAMETER OF PIPE (INCHES)
GRAVEL
LOOSELY PACKED
MODERATELY PACKED
HARD ROCK
(VEL.=12,000 FT./SEC.)
10 20 30 40 50 NITRAMON (2 LBS./FT.)
40 80 120 160 200 SAUSAGE (0.5 LBS./FT.)
80 160 240 320 400 TRIMTEX (0.25 LBS./FT.)
NUMBER OF REPEAT SHOTS DESIRED

Fig. 4

REPRODUCIBLE SHOT HOLE APPARATUS

This application is a division of my prior copending application Ser. No. 82,907 filed Oct. 22, 1970, entitled "Reproducible Shot Hole", assigned to the same assignee as the present invention, and now U.S. Pat. No. 3,693,717.

This invention pertains to geophysical exploration, particularly seismic exploration. In seismic exploration a reproducible source of elastic waves in the earth, such as is generated by the detonation of a charge of explosives, is highly desirable. In conventional seismic exploration, a hole is drilled, explosives put in the hole, a relatively large array of detectors are placed about the area, and the shot fired. The hole, or the part of the hole where the shot is detonated, is destroyed in the process, so that a shallower level in the same hole must be used, or a new hole must be drilled for the next shot, if a repeat shot is desired. It would be very much preferred to have the ability to fire many charges from one hole at the same depth, with assurance that the waves produced will be substantially the same from shot to shot, while moving a much smaller array of detectors about the area to be explored.

Heretofore, a reproducible shot hole of the character described was completely unknown in the art. If the liner or pipe used to protect the hole was made sufficiently strong to resist expansion from the explosions, then it was found to restrict the radiation of the elastic waves and hence would be a poor source. On the other hand, heretofore, if the pipe or liner was made so that it was a good wave radiator, it was not strong enough to stand more than one or a very few shots. The invention provides steps and apparatus to provide a lined shot hole which will expand upon repeated firings of charges while maintaining substantially constant good wave radiation qualities, and yet maintaining freedom of passage so that the next charge can be put in place.

The invention is not to be confused with the many different kinds of surface seismic sources which are presently in use. Such surface types have many advantages, including claimed reproducibility, but all suffer nevertheless from the disadvantage that the waves produced must pass from the surface device, through the "weathered layer" before passing through the deeper areas of interest. Such surface sources include vehicles which drop heavy weights on the ground, means which vibrate the ground, or means which set off small charges of gas in a "bomb" or other strong enclosure which is in contact with the surface. The "weathered layer" is the topmost part of the crust of the earth, varying in thickness according to location, and is highly variable in its ability to transmit elastic waves. The present invention, like conventional seismic exploration, utilizes a shot hole drilled to below the weathered layer which overcomes this disadvantage in surface types in that the source, the explosive charge, is fired at a location below the weathered layer.

Another advantage of the use of dynamite as a seismic source is the ability to excite a specific band of frequencies by the choice of the appropriate charge size and shooting medium. The present invention will apply to a wide range of shooting media consisting of loosely consolidated gravel at one end of the range to a well cemented shale at the other end of the range, and it will accommodate linear charge densities of virtually any size.

Repeat shots from a single hole to a moving relatively small array of detectors produces a result virtually identical to that produced by a single shot shooting to a very large array of many hundreds of detectors. Such a large array, as a practical matter, is impossible, and in any case would be prohibitively expensive. The invention requires that only one shot hole be drilled, thereby not substantially increasing the cost of the method of the invention as compared to conventional seismic exploration.

The invention entails a balancing of many different parameters to achieve the final reproducible shot hole. Examples are set forth in detail in the specification below, but generally the method requires balancing the degree of rigidity, consolidation or hardness of the surrounding formation with the diameter of and ductility of the liner used to case the shot hole. The invention includes a liner consisting of certain grades of aluminum, and means to protect the junction of the aluminum pipe with the normal steel well casing used to lower the aluminum liner to the area at which the explosions will be detonated. The means of supporting a ductile pipe, such as aluminum, along with means to prevent shearing of the pipe at its ends, are important parts, along with others set forth below, of the method and apparatus of the invention.

The liner can be made of materials other than aluminum. Steel for example, can be used, but the diameters required when shooting in a soft formation would be prohibitive. Aluminum, because of its ductility can be of reasonable dimensions and this is the reason for the preference for liners of the more ductile materials.

The present invention is one of a family of related inventions all pertaining to improvement of the seismic method. The related inventions, all copending with the present invention and all assigned to the same assignee, in addition to the parent application identified above of which the present application is a division, are:

"Clamped Detector" by Carl A. Gustavson, Emmett B. Shutes and Paul C. Wuenschel, Ser. No. 255,229, filed May 19, 1972 and now U.S. Pat. No. 3,777,814.

"Device for Gripping and Imparting Slack in A Cable" by Carl A. Gustavson, Emmett B. Shutes and Paul C. Wuenschel, Ser. No. 256,780, filed May 25, 1972.

"Precision Seismology" by Paul C. Wuenschel, Ser. No. 227,985, filed Feb. 22, 1972 and now abandoned.

The invention entitled "Precision Seismology" identified above is an overall method of using the present invention as well as the other inventions in a single integrated seismic exploration system.

The above and other advantages of the invention will be pointed out or will become evident in the following detailed description and claims, and in the accompanying drawing also forming a part of the disclosure in which: FIG. 1 is a cross-sectional view through a portion of the earth showing a completed but unfired reproducible shot hole of the invention in place; FIG. 2 is an enlarged view of part of the apparatus of the invention; FIG. 3 is a composite diagrammatic showing of the reproducible shot hole of the invention after a number of shots have been fired and illustrating the configuration of the hole when certain steps in the method are omitted; and FIG. 4 is an accurate chart which summarizes a large amount of experimental work, and which can be used in practicing the invention.

Referring now to the drawings and in particular to FIG. 1, there is shown a cross-section of the earth **10** in which the shots are to be fired. The method of the invention will be set forth below in conjunction with the description of FIG. 1, it being understood that FIG. 1 shows conditions after the hole has been prepared and is ready to have the first shot fired.

The first step is to determine the nature of formation **10**, specifically the rigidity of the rock. This can be determined from previous experience or by drilling a small diameter hole, studying the samples obtained while drilling, observing the drilling rate, and running logs in the hole after drilling. With this information and with knowledge of the seismic frequency band desired, one skilled in the art will know the linear charge density of the explosive required. The linear charge density and the rigidity of the rock together in turn determine the selection of the material for and diameter of the liner **14**, which, of course, in turn determines the final hole diameter **12**. It is desired to have the liner as snugly fitted in the hole **12** as possible, so that the liner will be supported by the formation.

The general considerations in selecting the liner **14** include that its ductility should be inversely proportional to the degree of consolidation. Restated, the softer the formation, the more ductile the material of the liner. The reason for this relationship is that the liner **14** will expand more against a softer formation than it will against a harder formation. The invention accommodates to this fact by providing the ability to expand rather than by trying to make the liner so strong that it cannot expand. Heretofore, and in preliminary tests run in conjunction with development of the present invention, it was found that less ductile materials, such as various grades of steel, promptly burst after one or two explosions because they did not have the ability to expand in response to the explosive force. As is evident, once the liner is burst, the hole quickly fills with debris which enters the hole via the fissure, thus precluding further access to that depth.

Wall thickness of the liner is not crucial when the pipe is supported by a formation, but should be in ratio to the pipe diameter at about 3:100. If the wall is too thin, the pipe will break due to small irregularities in the supporting medium. If it is too thick, the stiffness will limit the radiation efficiency of the explosion. The tolerance on the value given above is believed quite large but has not as yet been established by experiment.

The next step comprises assembling liner **14** into a string of conventional steel casing **16** which will be used to lower liner **14** to the specific depth at which the charges are to be detonated. Means **18** are provided to protect the joints between liner **14** and casing string **16**. Protection means **18** will be described in detail below in conjunction with the description of FIG. 2.

Once the liner **14** is located at the depth of interest, it is necessary to stabilize the borehole **12** in the vicinity of the explosions and to support the liner **14** with respect to the borehole. Conventional well cement has been found to be not satisfactory in that it does not have sufficient strength. Accordingly, the invention comprises the use of a sand-cement mixture **20** filling the annulus between the liner **14** and casing **16** and the borehole **12**. For the same reason, i.e., stabilizing the borehole, it has been advantageous to "squeeze" the sandcement **20** into the annulus. The reason for pressurizing the sand-cement during its placement is to assure that any voids, or small local unconsolidated regions, are filled to provide a uniform strength around liner **14**. Such local discontinuities, are caused by, for example, gravel streaks in formation **10**, sand and the like. Such a weak place is indicated in FIG. 1 by reference numeral **22**, and is shown after the squeezing of sandcement **20** as being filled with mixture **20**. After setting, the strength of the support around liner **14** will be uniform.

The final step is locating the charge assembly **24** in the completed reproducible shot hole. Charge assembly **24** comprises, starting at the lower end, a weight **26** to pull the remainder of the assembly **24** down the hole with the aid of gravity. A cable or other suitable means **28** interconnects weight **26** with the charge **30**. The charge **30** may be any explosive normally used in seismic exploration, one such explosive being a type of dynamite sold under the DuPont registered trademark "Nitramon" having a strength of 2 pounds per foot. The legends on FIG. 4 indicate the tradenames and strengths of other charges which may be used. The top of charge **30** is connected by a cable **32** to a centralizing sub-assembly **34** comprising upper and lower bow springs **36** interconnected by a support member **38**. The cable **32** bridges across the sub-assembly **34** to deliver electricity to the charge. The supporting member **38** is preferably made of wood or other light material since it is desired that it remain intact as it is frequently shot out of the hole upon explosion of charge **30**. It is desired that sub-assembly **34** remain intact so that it can be removed and reused and not hinder placement of the next shot. Further, a hard wood such as maple is preferred to a soft wood such as pine because the latter tends to shatter and the hard wood does not. The use of centralizer sub-assembly **34**, or other means to centralize the charge **30** in the hole, is important to successful use of the invention in that if the charge be very much closer to one side of the hole than to the other, that side is more susceptible to bursting. As is conventional, the entire hole may be filled with water to couple the explosive force to the borehole. Water is readily available and inexpensive, but other fluids such as drilling mud could be used in other circumstances.

Referring now to FIG. 2, the joint protection means **18** are shown in detail. The essence of the manner of protection of the joint between the "soft" aluminum liner **14** and the "hard" steel casing **16** is the provision of a tapered sleeve **40** extending from the joint in closely spaced relation to each end of the liner **14** to provide a differential and increasing force from the end of the sleeve towards the joint tending to resist expansion of the liner. Thus, at the joint virtually no expansion of the liner occurs while between the ends of the two sleeves **40**, the liner **14** is supported only by the sand-cement mixture **20** and the formation **10**.

Referring in detail to FIG. 2, the casing string **16** is joined to the liner by means of casing couplings **42**. The coupling **42** at each end of the liner **14** is modified for cooperation with the liner by cutting away part of one set of threads as at **44** and by undercutting the outside of the coupling opposite cut-out **44** as at **46**. A taper **47** is provided at the end of undercut **44**. Thus, an annular flange **48** is formed between cut-out **44** and undercut **46**. A shoulder **50** is formed at the inner end of cut-out

44 against which an end of the liner **14** seats. The thick end of sleeve **40** fits in undercut **46** on the outside of flange **48** and is fixed thereto by suitable means such as a bead of welding **52.** The assembly of sleeve **40,** flange **48,** and liner **14** is finally secured together by a row of bolts **54** provided in mating openings in these three members and threaded into the liner **14.** The heads of the bolts are preferably of the socket type so that a minimum obstruction is provided on the outside of the sleeve **40.** The inside surface **56** of the sleeve is cylindrical, and the outside surface **58** thereof tapers towards surface **56** to provide a thinnest portion of the sleeve at the end thereof furthest from bolts **54.** A clearance space, of roughly the thickness of flange **48,** is provided between sleeve **40** and liner **14.**

Thus, the joint between the casing string **16** and the liner **14** is protected by virtue of the tapered sleeve **40** in that the liner will have very little additional resistance to expansion opposite the thin end of the sleeve, but that such resistance will gradually increase moving towards the bolts **54.** As will appear more clearly below, absent the sleeve, the liner would simply shear off the coupling on the lower end of casing **16.**

During the development of the present invention a relatively large number of tests were run. Initially, these tests were in the nature of feasibility studies to see if a reproducible shot hole could actually be made and to verify that the deformation produced by several small charges is equivalent to the deformation produced by one large charge whose magnitude is the sum of the small charges. This was found to be true for unsupported pipes by Johnson, et al., and it was necessary to establish the same relationship for supported pipes. This work is reported in a paper entitled "The Explosive Expansion of Unrestrained Tubes" by W. Johnson, E. Doege, and F. W. Travis, in the 1964–5 Proceedings of the Institution of Mechanical Engineers, Vol. 179, Part 1, No. 7, pages 240–256.

After this initial work was successfully completed it was then necessary to evaluate the support provided by various types of wall rock. Two extreme cases as to rigidity were chosen, a loosely consolidated gravel and a well silicified shale whose compressional velocity is 12,000 feet per second. An aluminum pipe of alloy **3003-0** with a wall thickness to diameter ratio of 0.03 was found to withstand a strain of 180 percent before breaking when expanded with gravel support and was emplaced according to the invention. With this knowledge and data obtained from all experiments conducted in gravel and hard rock it became possible to summarize the design parameters for a viable tool in a single graph, as is reproduced in FIG. **4.**

The ordinate in FIG. **4** is the pipe diameter required to permit the desired number of repeat shots at various linear charge densities as given by the abscissa and identified by DuPont tradenames and corresponding weights for a total strain of 180 percent. The parameters used in FIG. **4** are the supporting medium. Loosely consolidated gravel provides the least support while hard rock provides the most support. An intermediate medium of moderately packed gravel lies in between these two curves. Other media such as clay, shale, porous limestone, etc. will yield curves falling between the moderately packed gravel and the hard rock.

The curves of FIG. **4** are applicable for a strain of 180 percent and pertain to ductile materials like aluminum. Similar curves can be made for other strains and thereby be applicable to other materials.

Several general principles can be drawn from the specific data presented in FIG. **4,** as well as from other tests not included in drawing the curves. Two of these principles are illustrated in the showing of FIG. **3.** After each shot or each few shots the borehole diameter was physically measured with the use of hole calipering tools. The data presented in diagrammatic form in FIG. **3** was taken from these caliper logs. The solid line labeled **60** shows the measured condition of the borehole when the invention was used in a preferred form. The dotted line **62** was run with all conditions the same as in the test indicated by the line **60** with the exception that the sandcement was not put in under pressure. Note that the liner **14** was pushed deep into the loosely consolidated portions of the formation. The liner will burst when the strain exceeds a critical value which depends on the metal used, for aluminum this value is about 180 percent. The final dot-dash line **64** shows the effect of the protection means **18** and the tapered sleeve **40.** Absent sleeve **40,** the liner promptly shears at its joints with the casing **16.** Note the gradual and gentle expansion of the liner over the outer half of each sleeve. As fabricated in the successfully used and tested embodiments of the invention, the sleeve **40** had a length of about 3 feet tapered over only its outer half. The liner **14** had a length of about 20 feet in all tests.

While the invention has been described in detail above, it is to be understood that this detailed description is by way of example only, and the protection granted is to be limited only within the spirit of the invention and the scope of the following claims.

I claim:

1. In apparatus for making a reproducible shot hole in the earth, the combination comprising a string of casing which includes a length of shot hole liner to be positioned at the depth at which shots are to be fired; a coupling having means to mount an end of said casing string and an end of said liner therein, a tapered sleeve surrounding the end portion of said liner and having its thickest end at said coupling; and means to join said thick end of said sleeve, the end of said liner, and said coupling together; whereby said liner at said coupling is highly resistant to expansion and decreasingly less resistant to expansion at points on said liner spaced along said sleeve moving away from said coupling.

2. The combination of claim **1,** said liner consisting of aluminum.

3. In apparatus for a reproducible shot hole the improvement comprising a string of casing cemented in the shot hole to a depth below the weathered zone at which the shot is to be fired, said string of casing having a cylindrical liner of ductile material through the interval of the hole at which the shot is to be fired, a steel sleeve at each end of the liner surrounding and spaced slightly from the liner and extending from the end of the liner toward the center thereof for a distance to support the ends of the liner and leave the liner unsupported in the interval at which the shot is to be fired.

4. The apparatus of claim **3** in which each of the sleeves is of greatest thickness at the end of the liner and tapers to a reduced thickness at the end of the sleeve nearest the midpoint of the liner.

5. The apparatus of claim 3 in which the liner is in the borehole within a sheath of a cement-sand mixture set under an elevated pressure to fill voids and reinforce weak formations surrounding the liner.

6. Apparatus as set forth in claim 3 in which the liner is aluminum.

7. Apparatus as set forth in claim 3 in which the ratio of the thickness of the liner to its diameter is approximately 3:100.

8. Apparatus for a reproducible shot hole comprising an upper section of steel casing and a lower section of steel casing, an upper coupling at the lower end of the upper section and a lower coupling at the upper end of the lower section, an aluminum liner extending between the upper section and lower section of casing and having its upper end mounted in the upper coupling and its lower end mounted in the lower coupling, an upper sleeve surrounding and secured to the upper coupling and extending therefrom downwardly part of the distance to the lower end of the liner, a lower sleeve surrounding and secured to the lower coupling and extending upwardly therefrom a part of the distance to the lower end of the upper sleeve to leave a central portion of the liner unsurrounded by the sleeve.

9. Apparatus as set forth in claim 8 in which the sleeves taper from a section of maximum thickness at the ends secured to the couplings.

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