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An Electrically Detonated Downhole Seismic Gun

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SUMMARY

An electrically detonated downhole seismic gun (EDG) that will fire blank 8-gauge shells underwater has been constructed and tested to 80 m depth (hydrostatic pressures of 130 psi or 8.9×10^5 Pa). Although other engineering seismic guns which fire blank or projectile sources are available, they are for near-surface shots and are not meant to be used for downhole seismic surveys in water-filled boreholes. The EDG was designed primarily for checkshot surveys (well travel-time surveys) and high-quality reflection/refraction tests, but potential applications include shallow vertical seismic profiling and borehole to borehole or borehole to surface tomography, as well as optimum offset and common midpoint seismic reflection surveys.

The EDG consists of four steel subassemblies: (1) chamber; (2) breech; (3) pipe; and (4) hanger. A blank 8-gauge electrical shell is held by the chamber and is detonated by an electrode located inside the breech. O-ring seals prevent water from entering the breech and causing short circuits. The breech is screwed into a pipe which is also fitted with o-ring seals to keep the internal wiring dry. A hanger subassembly provides a convenient attaching point for the hoist cable. Arming of the EDG with an explosives blaster occurs only after lowering to operating depth. The EDG has been tested with various size black powder loads up to 750 grains.

Frequency bandwidth and repeatability tests were carried out under saturated conditions in a fluvial and lacustrine sedimentary section. These preliminary tests show significant frequency content in the 25-200 Hz band (peak near 100 Hz) for reflections from depths of 150-300 m, and acceptable waveform repeatability for different shot records obtained with identical geometry and acquisition parameters.

INTRODUCTION

High-resolution seismic reflection imaging of the shallow subsurface (target depths of 5-300 m) has become an important tool in engineering, environmental, and groundwater geophysics; see Hunter et al. (1984), Knapp and Steeples (1986a,b), and Steeples and Miller (1990) for a description of the methodology and its applications. A variety of sources have been proposed for shallow seismic work (Miller et al., 1986), but seismic guns firing projectiles or blanks (e.g., Pullan and MacAulay, 1987; Seiber and Steeples, 1986) are perhaps the most commonly used explosive sources. Seismic guns are fired within augered holes at depths of 1 m or less for routine data acquisition, and are consequently not designed to operate underwater at significant hydrostatic pressure. We describe here an electrically detonated downhole seismic gun (EDG) that is designed for use at water depths up to 100 m (hydrostatic pressures of 160 psi or 1.1×10^6 Pa). The EDG may be used for optimum offset or common midpoint (CMP) reflection data acquisition, but it was developed primarily to be a source for checkshot surveys (well travel-time surveys) and high-quality reflection/refraction tests. In the latter

two applications the EDG is placed in a borehole that is deep enough to reach below the water table to provide improved source coupling, while receivers are deployed either within an adjacent deeper borehole (check shot survey) or at the surface (reflection/refraction test). Other potential applications include shallow vertical seismic profiling (VSP) and shallow borehole to surface or borehole to borehole seismic tomography.

DESIGN AND ASSEMBLY

Design of the EDG took into account several requirements: (1) the gun must be functional at water depths up to 100 m; (2) it must be capable of using a variety of 8-gauge source energies; (3) reloading must involve only a simple shell change with no need to dry the detonation circuitry; (4) the gun must accurately and precisely trigger a seismograph; (5) it must be easy and safe to use with standard precautions. Early tests using mechanical and electromechanical designs suggested that an electrical gun with no moving parts best met the above requirements. Based on this suggestion, the EDG was designed around four subassemblies: (1) chamber, (2) breech, (3) pipe, and (4) hanger; see Figures 3 and 4. Straight threads were used throughout so that mating parts could be compressed and not simply locked together. Pipe threads were not acceptable since they are designed for 125 psi, less than the anticipated pressures that the gun would encounter. Assembled, the EDG is approximately 2 m long and weighs 55 pounds.

Chamber

The basic source is an 8-gauge (21mm) industrial blank shell with an electrical primer. Standard 8-gauge hulls will hold a maximum of 300 grains of black powder, or a comparable amount of Pyrodex powder. The chamber was made to accommodate a standard 8-gauge hull and was constructed from a high strength steel alloy. Overall length of the chamber is the same as the un-trimmed hull of the shell so that the chamber can be placed in mud with no barrel to plug, thereby avoiding a dangerous situation.

A second chamber was constructed to hold 8-gauge shells loaded with more than 300 grains. To prepare a load over 300 grains, the hull is removed and a sleeve is placed over the brass rim. The resulting oversized shell can be made to hold any size load by simply adjusting the length of the sleeve. An alternate method of constructing 8-gauge shells to hold more than 300 grains is to insert a piece of 1/2-inch thin-walled PVC-tubing into the shell hull. The PVC-tubing is glued inside the hull; tubing length is determined by the size of load. Both methods of preparing 8-gauge loads greater than 300 grains are commercially available up to a maximum load of 500 grains.

A rupture seal-holder was made from cold rolled steel and is threaded onto the chamber with 1-3/4 x 8 thread. This seal-holder holds a piece of 1/16-inch to 1/4-inch thick rubber or neoprene seal material against the chamber end. The seal ruptures when the shell is detonated. A rupture seal is needed for water

depths greater than approximately 8 m to prevent water from entering the 8-gauge shell before firing and wetting the powder, preventing ignition.

Breech

The breech was designed to hold and protect the firing electrode. It was made from cold rolled round steel, cut down to the same diameter as 2-inch schedule-160 pipe, and fitted with two o-ring seals. The first o-ring seal, between the breech and the main pipe, is designed to prevent water from entering the gun and shorting the firing circuit. Seating of the o-ring is accomplished by threading the parts together. The thread design between the breech and pipe is 1-7/8 x 8.

A second o-ring seal was placed on top of a threaded boss (threads 1-1/8 x 12) between the breech and the chamber. This o-ring prevents water from covering the back of the shell which could also short the firing circuit. The boss thread design allows use of a separate expendable polystyrene capsule which can be threaded onto the breech. These commercially available capsules can hold shells with loads up to 500 grains. In this case, no chamber is used and the capsule is destroyed upon detonation.

Housed inside the breech is a commercially available firing electrode made from 303 stainless steel. The electrode is fitted with an o-ring seal which will withstand 14,000 m of water depth (20,000 psi or 1.4×10^8 Pa); this far exceeds the EDG's specifications with respect to hydrostatic pressure. Stainless steel was more desirable than plated brass as the electrode must withstand the force of detonation. The electrode is attached to the wiring in the EDG with a neoprene boot. The stainless steel firing pin was covered with shrink-tubing and surrounded by nylon bushings to insulate it from the breech. Nylon bushings were needed to insulate an area as large as the primer on the shell. To prevent recoiling of the gun from driving the nylon bushings into the breech (or electrode), the breech was machined with a shoulder stop. Although the grounding circuit could have been attached anywhere along the EDG, it was attached to the breech.

Pipe

The pipe was designed to protect the internal wiring, give the gun weight to reduce recoiling, and allow straight threads to be used in the construction of the gun. The material chosen for the pipe was 2-inch schedule-160 black pipe at a length of 1.5 m. This black pipe has extra thick walls (approximately 3/8 inch, 0.9 cm) which allow the large 1-7/8 x 8 threads to be used. The 1.5 m length of the gun was determined by the well in which it was first used. The well was uncased for the last 1.2 m, and the authors did not want to risk catching the EDG under the edge of the casing.

One end of the pipe was chamfered (the hanger end) to allow an end plug to be welded to the pipe. The end plug, formed from 2-1/2 inch cold rolled round steel, was cut down to match the diameter of the pipe. The end plug has 1-7/8 x 8 external threads to allow the hanger to be attached to the gun. Welding the end plug to the pipe was accomplished with a deep V-bead.

A commercially available bulkhead connector is threaded into the end plug. The o-ring seal and mating cable for this connector will withstand 14,000 m of water depth (20,000 psi or 1.4×10^8 Pa), which again far exceeds the actual need with respect to hydrostatic pressure. Wires soldered to pig-tails of the

bulkhead connector completed the circuit to the breech end of the gun. The soldered junction was covered with shrink tubing for protection.

Hanger

The hanger encloses the blasting line electrical connector and provides a secure connection for the hoist cable. It was constructed of a 20-cm length of 2-inch schedule-160 black pipe which was screwed to the EDG. To prevent this connection from separating in the well it was setscrew-locked to the end plug. At the top of the hanger a clevis pin is used to attach 1/4-inch aircraft steel cable with tensile strength of 6,200 N (1,400 lbs) for hoisting.

TESTING

Testing of the EDG was accomplished in three stages. The first stage test placed the loaded gun under 1.5 m of water for approximately 3/4-hour before detonation. After detonation, the shell and breech were examined for signs of water entering the breech or chamber areas. Second stage tests fired the gun under 10 m of water in a 6-inch well. The third stage test fired the gun under 80 m of water (approximately 130 psi or 8.9×10^5 Pa) in an aquifer test well, which was at the limit of the hoist cable length. In all tests the gun seals functioned properly and the EDG performed as desired. Although the gun has been test fired at 80 m, it is expected to work at greater depths. The lowest rated seal is the rupture seal which is anticipated to work at a depth of at least 100 m.

DISCUSSION

The EDG allows for repeat shots by changing the shell and rupture seal (if needed). The breech does not need to be disassembled and dried between shots. There is no need for a drop-rod, and an explosives blaster performs the arming, detonation, and timing signal coordination with the seismograph. Operation of the EDG is simple but requires the usual safety precautions for working with seismic guns and electrically detonated explosives.

Frequency bandwidth and repeatability characteristics of the EDG were measured at a site in the Boise River valley in southwest Idaho. The upper few hundred meters of the geologic section at the site are composed of fluvial and lacustrine sediments with the water table at a depth of 4 meters. Several fixed-source noise tests were conducted with the EDG deployed in a steel-cased well and the chamber positioned in saturated conditions at the well bottom (15 m depth). Geophones (100 Hz) were deployed in a profile at the surface. Analog acquisition filters were set for a bandpass of 100-2000 Hz with 12 dB/octave rolloff on the low end. The average amplitude spectrum for near vertical-incidence reflections from depths of 150-300 m is shown in Figure 1; the spectrum is peaked near 100 Hz with a 3-octave bandwidth (25-200 Hz) measured at 10% relative amplitude. Figure 2 provides a visual comparison of three trace pairs recorded by two different shots with all other acquisition parameters held constant; the traces within each pair show consistent waveforms (except at later times where the S/N ratio deteriorates) indicating that the EDG provides acceptable repeatability. Future plans include a similar test to measure the bandwidth of

more shallow reflections (less than 30 m depth) generated by the EDG.

The primary advantages of the EDG are that it is relatively inexpensive to build (\$250 for materials, cables extra) and can be used in a variety of surface or borehole seismic experiments requiring an impulsive source of easily adjustable energy output. However, experiments which require many repeated shots in a deep borehole may be impractical with the EDG because of the need to raise it to the surface between shots for reloading. No experiments have been carried out to investigate the EDG's potential to inflict damage to a permanent borehole.

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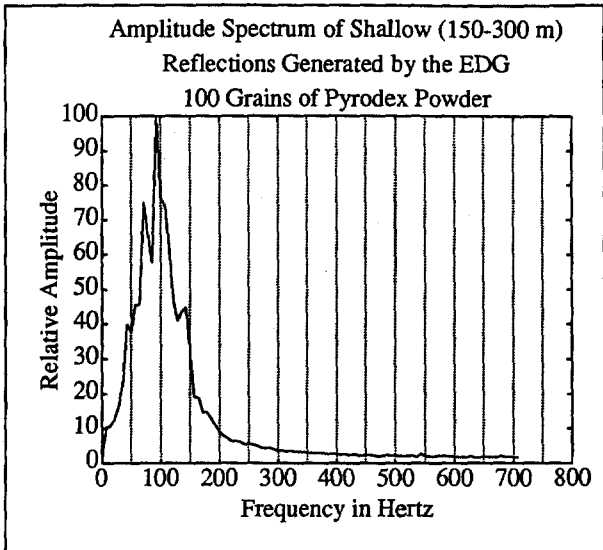


Figure 1

Amplitude spectrum of reflections from interfaces located between 150 to 300 meters below surface. This figure shows about 3 octaves of bandwidth (25-200 Hz.) at the 20 dB down points (10% relative amplitude).

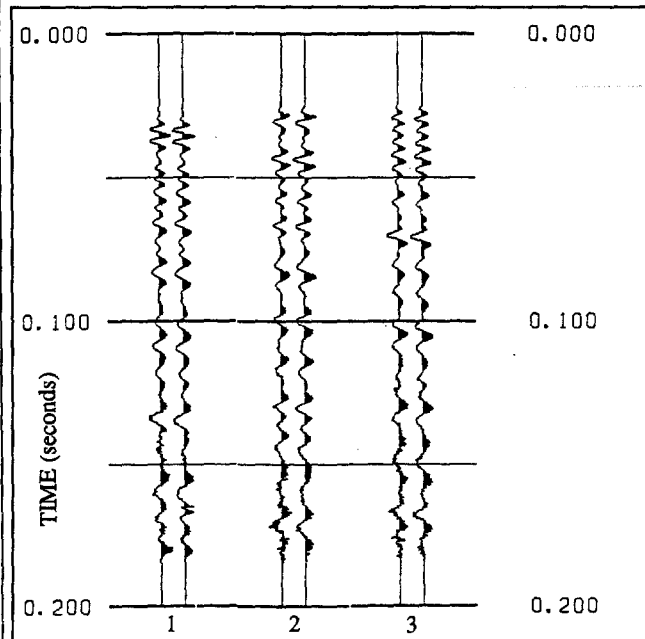


Figure 2

Side by side trace comparisons for three pairs of traces from two different shot files recorded with identical geometry. The traces within each pair are consistent copies of one another. The distances from the source for pairs 1, 2, and 3 are 28.8 m, 30.0 m, and 31.3 m, respectively.

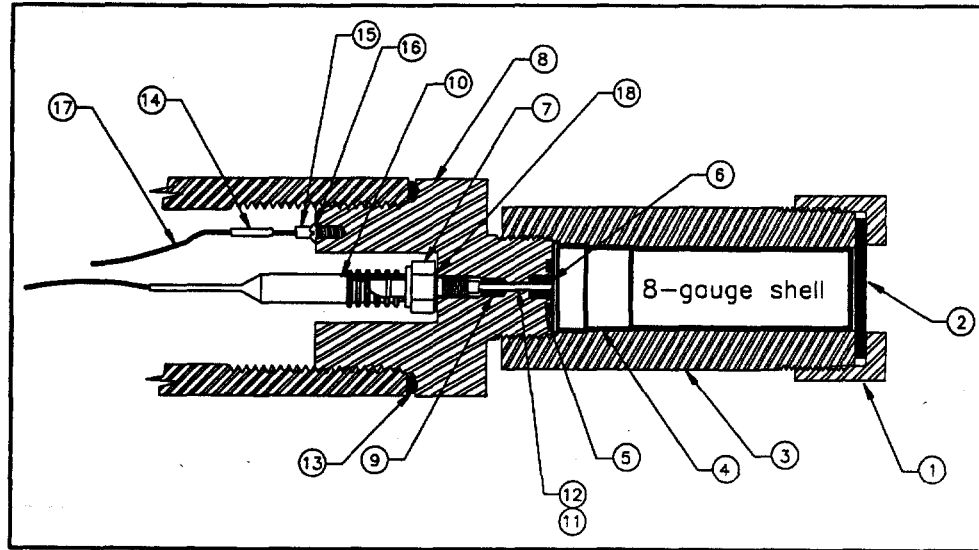


Figure 3

Breech end of the EDG. Items identified in this figure: (1) rupture seal holder, (2) rupture seal, (3) chamber, (4) shell, (5) o-ring, (6) nylon bushing, (7) firing electrode, (8) breech, (9) nylon bushing, (10) electrode cover, (11) silicon grease, (12) shrink tubing, (13) o-ring, (14) bullet connector, (15) spade connector, (16) ground screw, (17) wiring, (18) o-ring.

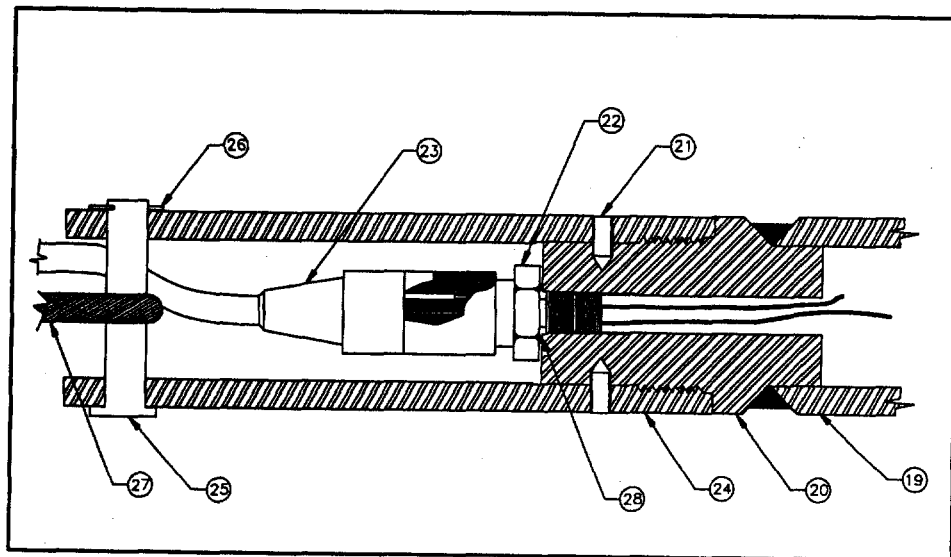


Figure 4

Hanger end of the EDG. Items identified in this figure: (19) pipe, (20) end plug, (21) setscrew, (22) bulkhead connector, (23) electrical cable, (24) hanger, (25) clevis pin, (26) locking pin, (27) aircraft cable, (28) o-ring.