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Pipe Closure by Explosives

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ABSTRACT

High explosive is used to close aluminum, copper, and steel pipes in various sizes up to three feet in diameter. Closure times of less than one millisecond are typical.

INTRODUCTION

The requirement of line-of-sight access with subsequent closing for some underground nuclear devices at the Nevada Test Site has led to the development of a technique for closing metal pipes with explosives. Explosive pipe closures serve best in applications where extremely fast closures are required and less than airtight sealing can be tolerated. Closure times of less than 1 msec are obtainable with pipe 2 ft or less in diameter. Varying degrees of sealing are obtainable, with watertight closures at low head typical. Steel, copper, and aluminum alloy pipe in various sizes up to 3 ft in diameter (larger pipes were not investigated) were found amenable to closure by high explosives. The experiments showed that linear scaling of dimensions of the closure design is reasonably valid for the small pipes and a good first approximation for the closure design of the larger pipes.

GENERAL FEATURES OF EXPLOSIVE PIPE CLOSURES

It has been known for some time that high explosives could collapse relatively thick walled pipes of ductile material. Figure 1 shows some results of early experiments. In these experiments the amount and position of the explosive were the primary variables.

Early tests revealed the need for an intermediate attenuating layer between the pipe wall and the externally mounted high explosive. The benefit of "standoff" has long been known for high-energy-rate forming processes utilizing high explosives. A 1-in.-thick layer of 2 lb/ft^3 polyurethane foam plastic was found to be adequate for pipes smaller than 12 in. in diameter. Explosive located closer to the pipe usually resulted in spalling of the metal or severance of the pipe wall (Fig. 1). A 1-in. standoff was also satisfactory for 2-ft-diam copper pipe; however, a greater standoff was needed for large diameter steel pipes. Although both flexible and rigid 2 lb/ft^3 plastic performed satisfactorily in tests, rigid plastic is preferred because it can support the weight of the explosive.

DuPont Detasheet C, a moderately sensitive high explosive, was used in all tests because of its flexibility and the ease with which it could be assembled with tape and glue. Detasheet C is an integral mixture of PETN and elastomeric binder and has a detonation pressure of about 170 kilobars.* The weight in grams per square inch of this explosive is designated by numbers; e.g., 2 and 4. C-2 is nominally 0.083-in. thick, and C-4 is 0.166-in. thick.

The pipes shown in Fig. 1 have relatively thick walls and are thus reasonably stable during the implosion even when the explosive is detonated at a single circumferential position. (The high explosive detonation velocity of 7 km/sec is several times faster than the material velocity of the pipe; hence, the pipes are quickly engulfed in a more or less uniform pressure.) However, it was not practical to scale this thick-wall system to the larger diameter systems. Not only would the amount of high explosive become unduly large, but pipe would have to be custom fabricated with some difficulty. Standard welded and seamless pipes were a desirable choice for use in larger closures because of their availability and uniform material properties.

In the thinner-walled standard pipe systems, multiple initiation of the explosive was necessary to obtain reproducible results. This made the pipe wall collapse primarily by folding instead of by uniform cylindrical compression thus minimizing the amount of plastic work done and the amount of explosive required. Folds are introduced into the wall of the pipe by the higher pressures created by interaction of the detonation waves in the explosive between detonators. Figures 2 and 3 show sections of "thin-wall" pipe closures. The aluminum pipe (Fig. 2) was closed with 545 g of explosive, and the copper pipe (Fig. 3) with 986 g. Maximum center thickness of the explosive was 0.249 and 0.416 in., respectively, for the systems.

*1 kilobar = 10^9 dynes/cm^2, a pressure of about 1000 atmospheres.

Fig. 1. Sectioned pieces of 2-in.-i.d., 1/2-in.-wall copper pipe closed, or partially closed, by the action of HE. An 0.083-in.-thick layer of HE in contact with the o.d. of the middle sample produced spalling of the inside pipe wall. A 1-in.-thick, 2 lb/ft^3 foam plastic standoff for the HE was used for the upper and lower closures. A 306-g HE charge initiated at four equally spaced points on the circumference provided complete closure in the upper sample.

Eight detonators equally spaced on the circumference of the Detasheet explosive provided reproducible implosion symmetry in pipe with wall-to-diameter ratios of 0.0417 for aluminum and copper and 0.0313 for steel. Interaction of the detonation waves at midpoints between detonators produced an eightfold axially symmetric closure (see Figs. 2 and 3). Generally, the number of initiation points should be reduced with

Fig. 2. A 545-g explosive charge with a 1-in.-thick plastic attenuator layer closed this 6-1/2-in.-o.d., 1/4-in.-wall aluminum pipe. The closure is watertight at essentially zero head.

Fig. 3. A 6-in.-o.d., 1/4-in.-wall copper pipe closed with 986 g of explosive. Note the small holes centered inside each of the eight convolutions. Eight detonators equally spaced around the circumference produced the eightfold symmetry. The attenuating layer was 1 in. of 2 lb/ft^3 foam plastic.

larger wall-to-diameter ratios and, conversely, increased when the pipe wall thickness is reduced.

Pipe should be in an annealed (or otherwise soft) condition for best closure results. This is especially important for steel but also desirable for copper and aluminum. Since steel does not deform and flow plastically as well as copper and aluminum, an aluminum "liner" was found to enhance final closure of steel and copper pipe (see Fig. 4). The liner fills the eight convolution areas that sometimes fail to seal and also increases the final collapse diameter of the stronger outer metal. Both features tend to reduce the amount of strain imposed on the pipe. Aluminum alloy 6061-T6 performed better in tests than pure aluminum which did not have enough inherent strength to resist premature collapse inside of the steel.

Commercially available welded and seamless tubing performed well in tests. Shop fabricated pipe had a tendency to rupture along welds or in adjacent heat-affected zones. Placement of the weld seams directly beneath detonators reduced the tendency of welds to fail and positioned the weld on the outside of a pipe wall fold after closure. A similar positioning of the aluminum liner weld-seam was also found desirable. In fact, the aluminum liner does not have to be welded if the butt-jointed free ends are "trapped" during the forming of a pipe wall convolution. Although aluminum liners were used in most tests, copper liners have one distinct advantage over aluminum; they do not sever above and below the closure as readily as does aluminum.

A feature common to successful designs

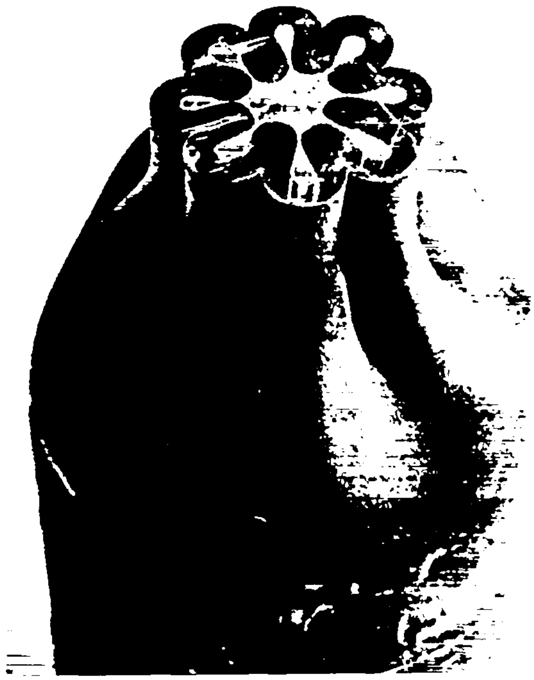

Fig. 4. Section of a 5-1/2-in.-o.d., 1/4-in.-wall copper pipe closed with 876 g of explosive. A 1/8-in.-thick aluminum liner served to fill the convolution voids and reduce the total amount of wall collapse. Eight detonators and a 1-in. HE standoff were used.

was a gradual reduction in the explosive thickness near the edges (see Fig. 5) to produce a transition region between the fully closed area and the open pipe.

Although most closures were not adversely affected by small changes in the various design parameters, best results could be obtained only by following the above recommendations very carefully. As an example, Fig. 6 shows the influence of about 10% excess explosive and small errors in detonator spacing on the closure of a 12-in.-diam copper-aluminum system. The overdriven pipe wall bounced back after converging to spoil the final closure. Asymmetries in the initiation of the explosive invariably were manifested as asymmetries in the pipe wall convolutions.

A TYPICAL CLOSURE DESIGN

Figure 7 depicts a typical 12-in.-diam pipe closure design. The pipe is a welded sched-

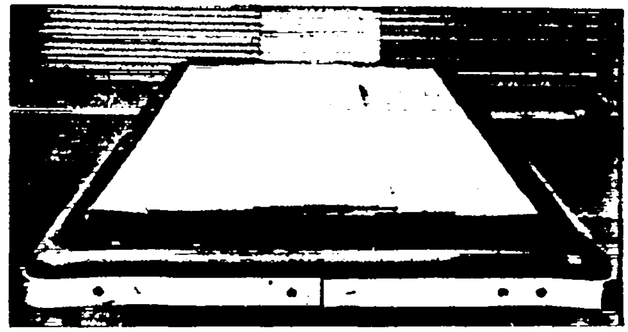

Fig. 5. Sheets of DuPont Detasheet C glued into the complete explosive charge. Note the pyramidal shape of the cross section. This shaping reduces the impulse near the edges, thus ensuring a gentle transition in the pipe wall between the closed section and the undisturbed pipe.

ule 40 steel pipe. The explosive is DuPont Detasheet C flexible explosive. The 1-in.-thick layer of 2 lb/ft^3 rigid plastic is polyurethane. The aluminum liner is 6061-T6 alloy.

The explosive used on this shot was designed for an underground application where there was a surrounding open volume of only 18 ft^3. A short-duration pressure pulse with a maximum value of about 150 psi could be expected from the buildup of explosive gases in such a void. The pressure from these gases assists in the closure; therefore, the total amount of explosive needed in an underground environment is less than that required where there is no confinement and gases are free to expand away from the pipe.

The preferred method of assembling the explosive is to glue the explosive layers together on a flat surface (see Fig. 5) before wrapping it around the pipe. Excessive glue should be avoided because intervening glue layers resist and sometimes disrupt the propagation of the detonation waves. Butt joints in the explosive, if present, can also perturb the detonation wave; therefore, all joints should be placed so as to minimize the butt-joint gap. Problems with thick, uneven glue layers and butt-joint gaps could be eliminated by using continuous rolls, instead of cut sheets, of explosives with a controlled thickness of adhesive on one side.

Fig. 6. A 12-in.-diam copper-aluminum closure showing the adverse effect of 10% excess explosive and asymmetries in the pipe wall folds caused by errors in detonator spacing.

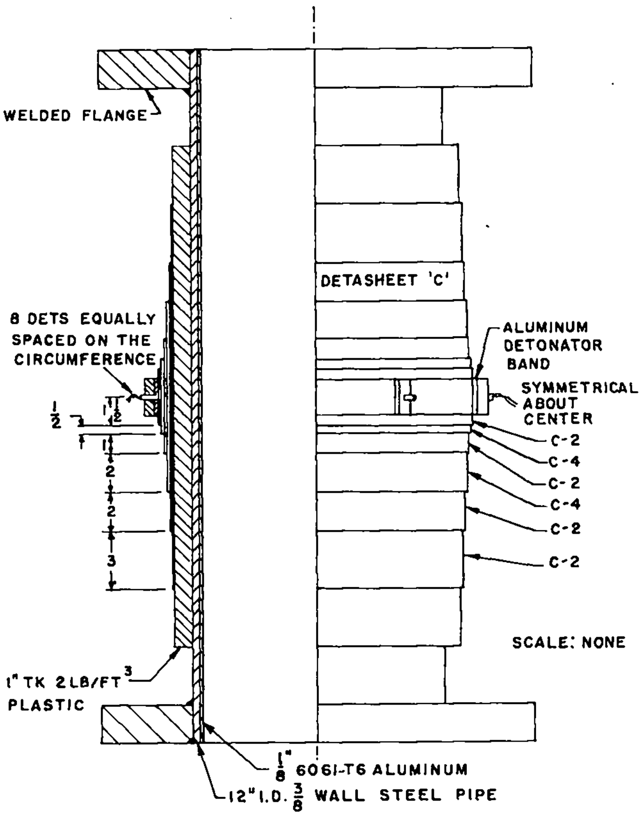

Fig. 7. A 12-in.-diam steel pipe closure assembly. The heavy welded steel end-flanges prevent the pipe ends from collapsing when subjected to the buildup of high pressure HE gases in confined places. A 16-2/10-lb DuPont Detasheet explosive charge is initiated at eight places on the circumference midway between top and bottom.

Eight SE-1 detonators equally spaced around the circumference of the explosive provided the initiation. A two-piece aluminum circumferential band .d and spaced the detonators which were mounted in individual plastic blocks (see Fig. 7). Clamps and tape secured the detonator band after final assembly. Generous amounts of tape should be used in securing the explosive to the pipe. Compatible glues can also be used between the rigid 1-in. plastic layer and the explosive, if desired.

The end flanges shown in the figure are required only in applications where explosive gases are not allowed to expand freely; e.g., in an underground application. Confinement of the explosive gases frequently produces ambient pressures which collapse the unsupported pipe ends. Copper and aluminum pipe are especially susceptible to collapse from the external buildup of high pressure gases; therefore, these pipes require even greater end support. The transient high pressure loading of the flange on the closure side in combination with explosive shocks can also produce tension failure in the necked-down portion of the pipe. This can be avoided by placing the closure section of pipe under a small initial compression as when closure is located near the bottom of a vertical standing pipe or surrounded by bodies with large inertia. Closures fired in air show none of these detrimental effects because the explosive gases are allowed to expand freely away from the pipe.

Dirt or other foreign materials should not be allowed in contact with the explosive system in a confining environment; hence, an outer protective cylinder or cover (not shown) is recommended.

RESULTS OF LARGER DIAMETER CLOSURES

The 24-in.-diam system shown before and after collapse in Figs. 8 and 9 was an extrapolation from the 6-in.-diam closure design of Fig. 4. One hundred and seventy-five pounds of explosive were used in this above-ground test. Closure was accomplished in less than 1 msec.

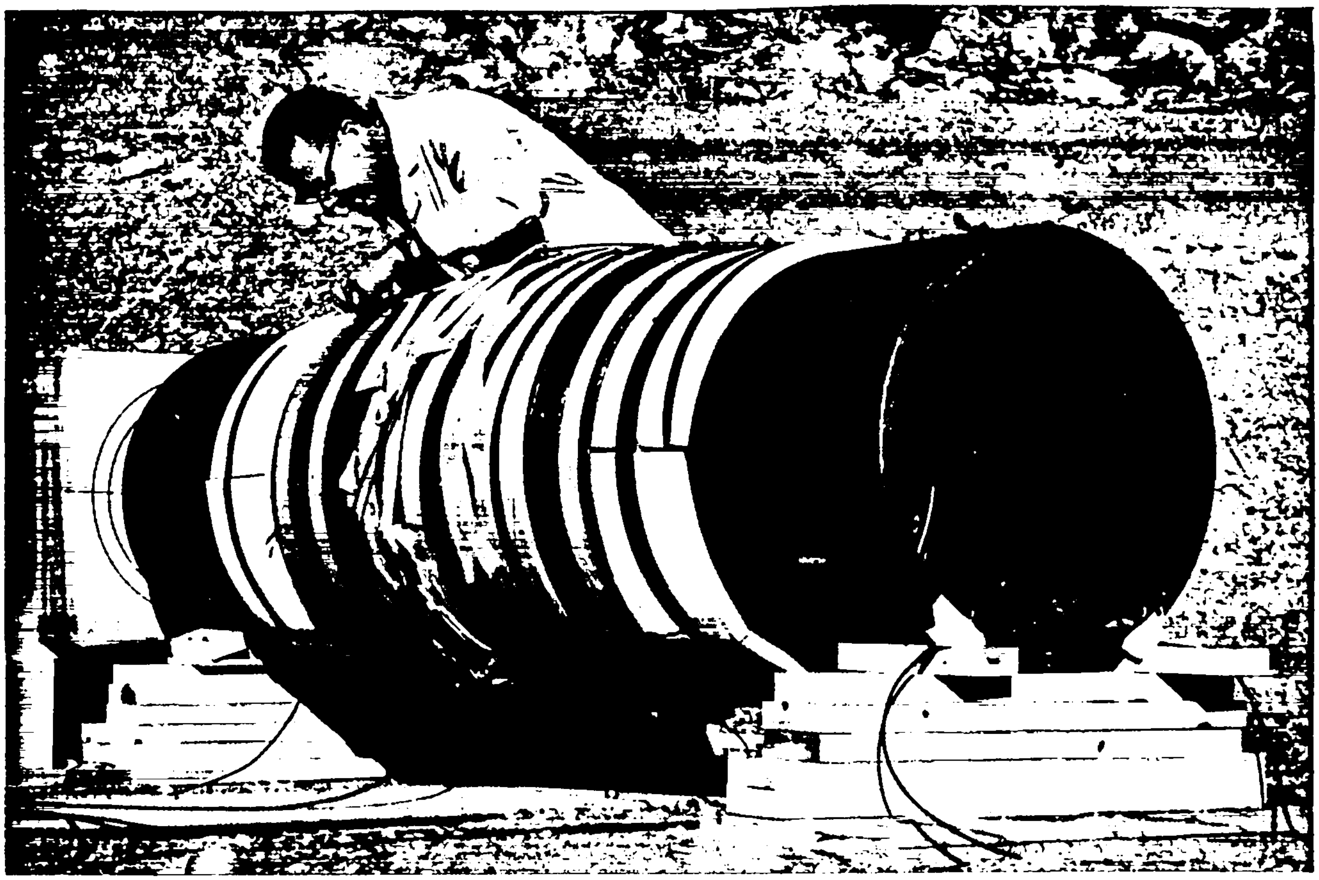

Fig. 8. A 2-ft-diam, 1-in.-wall copper pipe with externally mounted explosive charge prior to test. The 1-in.-thick layer of 2 lb/ft^3 foam plastic is seen between the explosive and the pipe. For development tests the detonators were taped in position and only a minimum amount of tape was used to secure the HE to the pipe.

Figure 10 shows the largest aluminum pipe (2-in. wall and 36-in. i.d.) which was closed; 260 lb of explosive were used.

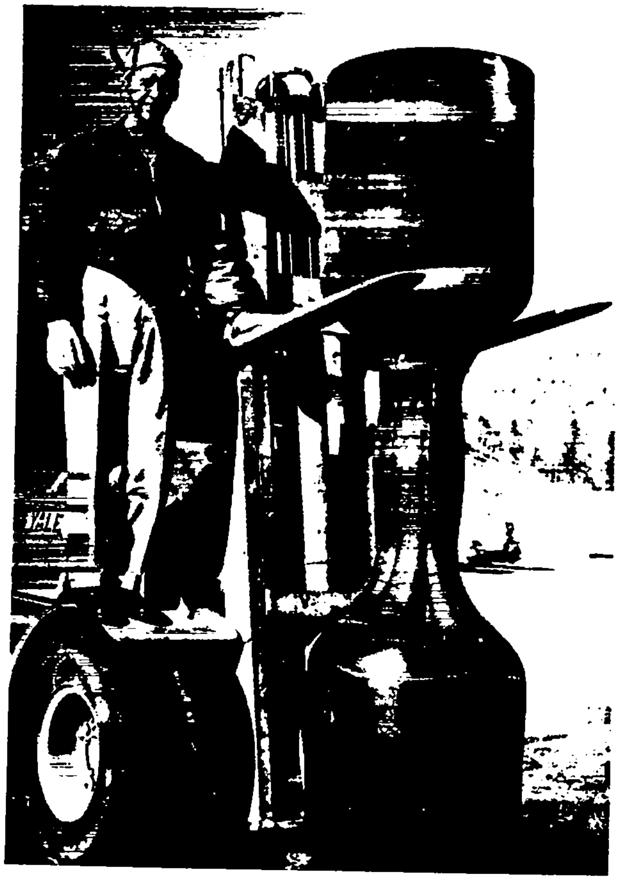

Fig. 9. The 2-ft-diam copper pipe after closure. Vertical seams identify explosive interaction lines; the circumferential lines were created by higher shock impedance paths along glue joints in the underlying foam plastic.

Fig. 10. A 36-in.-diam aluminum pipe closure. The pipe was fabricated from 2-in.-thick 1100 series aluminum sheet which was rolled and welded. A 260-lb explosive charge was required for the closure.