POTENTIAL DESTRUCTIVENESS OF GAS DETONATIONS

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Background

The potential destructiveness of gas detonations was evaluated in terms of the depth of earth that could be heaved when various gas mixtures were detonated in long underground excavations. A number of years ago, a spectacular destruction of 26.8 miles of underground pipeline in Texas was ascribed to the occurrence of a detonation. The pipeline had carried crude oil and was being cleaned by forcing a scraper plug along its length with compressed air. It is not known whether the event was a gas detonation or a heterogeneous detonation of a film on the wall.[1/] The intermittent cratering that occurred seemed curious but now may be explained in terms of the impulse needed to heave the earth cover. No explanation can be offered for the apparent low velocity of propagation indicated by the total elapsed time. An average velocity of only 296 feet per second was reported.

This investigation primarily covered propane-air, acetylene-air and MAPP[2/]-air mixtures. In some cases a partial pressure of oxygen greater than in air was employed. Limits of detonability were obtained from plots of propagation velocity versus fuel concentration in a 7-inch diameter by 12-foot long pipe which was closed at both ends. Impulse, which determines the momentum that can be imparted to a load, was measured from pressure versus time transients in a 24-inch diameter by 163-foot long steel pipe that could be closed at one end. The soil mechanical problems related to earth movement were studied in hand-dug tunnels of 3 foot x 5 foot cross-section and 150 feet length incorporating right angle turns and side entries.

Detonation Velocities and Limits of Detonability

Fuel/air mixtures were admitted to the 7-inch apparatus of figure 1 by the partial pressure method, recirculated via the sideline for 10 minutes, and sampled for gas chromatographic analysis. A solid explosive initiator ranging from 1.1 grams PETN to 100 grams tetryl was detonated and the velocity of the resulting ionization wave was measured between velocity stations with electronic time-interval meters.

A plot of this wave velocity versus fuel concentration is given in figure 2 for MAPP/air mixtures. Velocities in excess of 1400 meters/sec indicate detonation while velocities of about 1000 meters/sec or less are obtained from shocks accompanying deflagration. The difference is clearly shown by the pressure traces of figure 3, wherein trace A indicates deflagration with pressure rising over a period of about 25 milliseconds while in trace B the first pressure pulse is the strongest.

Limits of detonability as defined by this method are somewhat sensitive to the strength of the initiator. Thus, the detonable range for MAPP/air widens appreciably as the initiator is increased from 1 to 10 grams PETN (table 1). Both propane/air and acetylene/air detonate over the full reported range of flammability when initiated with 10 grams PETN.

Pressure-time Transients and Impulses

The major part of the experimental program was carried out using the 24-inch steel tube shown in figure 4. Fuel was metered through calibrated spray nozzles into the 260 cfm output stream of a gasoline-powered blower, which stream was passed through the tube to give three changes of atmosphere. Gas sampling and detonation pressure measurements were accomplished at five stations spaced evenly along the length of the pipe. Initiation was typically effected with 100 grams tetryl, usually at the upstream end of the pipe near the end closure.

Pressure transients at the five stations were compared with predictions derived from standard references[3,4] dealing with one-dimensional gas detonations. Figure 5 shows the predicted transient for stoichiometric acetylene/air at a point 60 feet from an initiation source at the closed end of a 150-foot long pipe. The peak (C-J) pressure was assumed to be twice the constant volume explosion pressure and this proved to be a fairly accurate assumption for measurements within 2 stations (53 feet) of the initiation. For example, with 7.2 percent MAPP in air, the predicted peak was 281 psig while nine measurements averaged 278 $\pm$6 psig. At greater distance from the initiator, peak pressures became progressively more erratic as though the detonation were departing from its one-dimensional character.

The gas expansion behind the C-J plane was calculated by Taylor's equations using an equilibrium gamma which was typically about 1.17. This gave excellent agreement with experimental pressures in the static gas zone, however, the duration of the gas expansion (from D to E in figure 5) was typically underestimated by about 20 percent. Neither this deviation from prediction nor the erratic peak pressures were of any practical consequence to the impulse of the explosion.

The duration of the pressure plateau, EH in figure 5, was about 20 percent overestimated because no account had been taken of the three-dimensional expansion of the wave as it emerged from the open end of the pipe; that is, the interval FG in the figure should actually be shorter than indicated and the rarefaction starts back through the pipe at an earlier time than G. Since the dominant factor in the time interval EH is the velocity of sound in the burned gases, off-stoichiometric mixtures with lower burned gas temperatures had relatively long pressure histories and high impulses. This trend is shown in table 2; note that 4.9 percent MAPP in air is close to stoichiometric while 3.4 percent MAPP is the reported lean limit of flammability.

For the same reason, propane/air and gasoline/air mixtures had impulses comparable to those of acetylene/air and MAPP/air even though their pressure peaks were lower. Thus, the average of impulses at the 5 pressure stations in 6 MAPP/air detonations was 7.7 psi sec, in 6 propane/air detonations 7.4 psi sec and in 3 gasoline/air detonations 7.5 psi sec.

When both ends of the pipe were open, the pressure plateau was nearly eliminated. This is shown by the transients of figure 6 (compare curves C and D with curves A and B). In 7 MAPP/air detonations the average impulse was only 3.2 psi sec and in 5 acetylene/air detonations 3.1 psi sec. Even a partial temporary closure, as exemplified by loose-fitting sandbags in the ends of the pipe, brought the average impulse (for 7.2 percent MAPP/air) back to about 6.3 psi sec.

No particular difference in average impulse could be detected as a result of initiating the detonation at the longitudinal midpoint of the tube or simultaneously at the two ends.

In the dry-walled steel tube, suspended aluminum powder (even though much of it was deposited on the walls) could participate in the post-detonative reactions to give about 50 percent greater impulse. Comparative values are given in table 3. But in dirt tunnels, the powder was collected on the damp walls and played no apparent part in the explosion.

Destructiveness of Gas Detonations to Earthen Structures

In field tests, a surprising fraction, usually 50-100 percent, of the impulse of the explosion was converted into momentum of the overburden. This means that soil mechanical factors such as plasticity and shear strength were unimportant so that the overburden was behaving essentially as a frictionless piston. When the earth velocity was made to exceed 20 ft/sec, as measured at ground level by Fastax photography, the tunnel usually failed. Because of the weakness of end closures, as compared with an end plate on a steel pipe, the largest impulse attained in the field was about 6 psi sec and the greatest depth of burden defeated by a single gas detonation was 8 feet.

REFERENCES

1/ Armistead, George, Jr. Safety in Petroleum Refining and Related Industries, 2nd Edition, Simmonds, N. Y., 1959, p. 43.

2/ MAPP is a commercial mixture of methylacetylene, propadiene and propylene.

3/ Zeldovich, Ya. B., and A. S. Kompaneets, "Theory of Detonation," Academic Press, New York, N. Y., 1960.

4/ Taylor, G. I., "The Dynamics of the Combustion Products behind Plane and Spherical Detonation Fronts in Explosives," Proc. Roy. Soc., v. 200, 1950, p. 285.

TABLE 1. - Limits of Flammability and of Detonability

Mixture	Initiator	Flammable Range	Detonable Range
Propane/air	Spark	2.1 - 9.5%	--
	10 g PETN	--	2.2 - 9.2%
Acetylene/air	Spark	2.5 - 100%	--
	10 g PETN	--	2.0 - 100%
MAPP/air	Spark	3.4 - 10.8%*	--
	1 g PETN	--	4.1 - 7.6%
	10 g PETN	--	2.4 - 13.7%

*Hembree, J. O., et al, Welding Journal, May 1963.

TABLE 2. - Plateau Durations, Plateau Pressures, and Impulses of MAPP/Air Detonations in 24" Diameter by 163' Long Steel Tube with Initiation End Closed

MAPP Concentration (%)	Plateau Duration (milliseconds) at Instrument Stations #1	#2	#3	#4	#5	Averaged Plateau Pressure (psig)	Averaged Impulse (psi sec)
3.4	71	54	35	12	2	85	6.8
4.9	58	46	32	15	--	103	8.9
6.1	64	49	35	14	--	98	8.3
8.7	64	52	33	14	--	99	7.8

TABLE 3. - Impulses Obtained in Detonations in the Steel Tunnel with and without Added Aluminum Powder

Gaseous Fuel	Closure of Initiation End	Aluminum (#422)	Impulse (psi sec)*
Acetylene	Open	None	3.0, 3.9
Acetylene	Open	2 lbs on floor	4.5
Acetylene	Closed	None	3.9
Acetylene	Closed	2 lbs on floor	6.5
MAPP	Open	None	3.4
MAPP	Open	2 lbs suspended	5.6
MAPP	Closed	None	4.3
MAPP	Closed	2 lbs on floor	6.6

*As measured at a station close to the open downstream end of the tunnel.

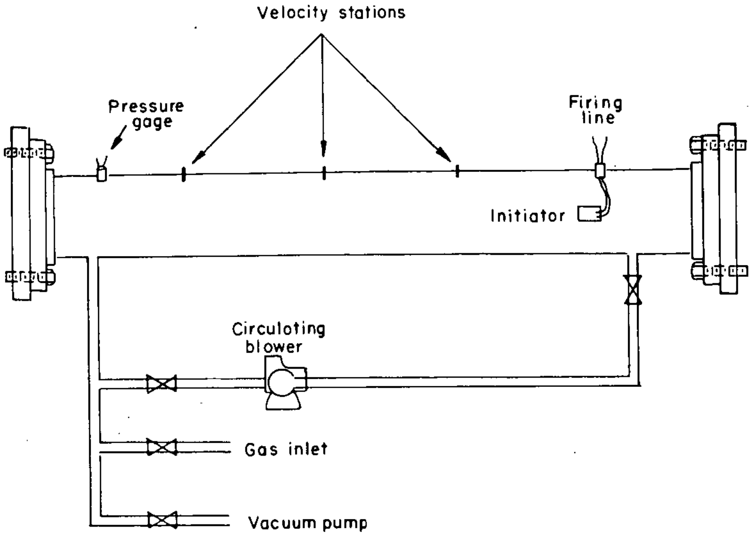

FIGURE 1. - LABORATORY DETONATION TUBE.

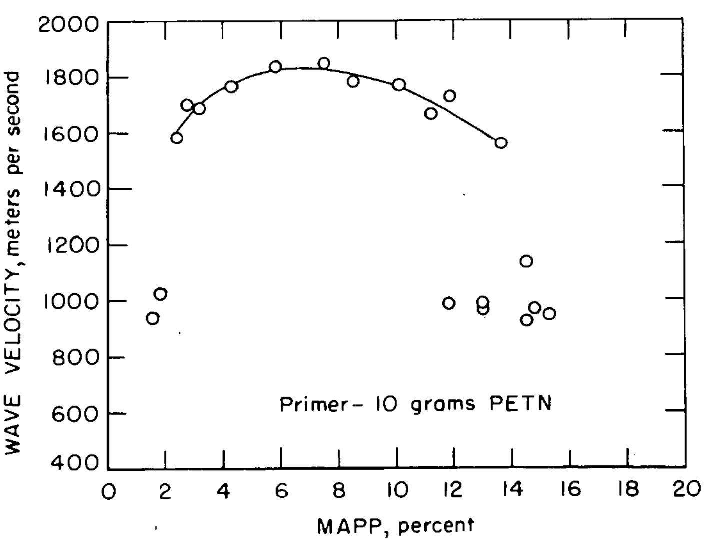

FIGURE 2. - DETONABLE LIMITS OF MAPP/AIR.

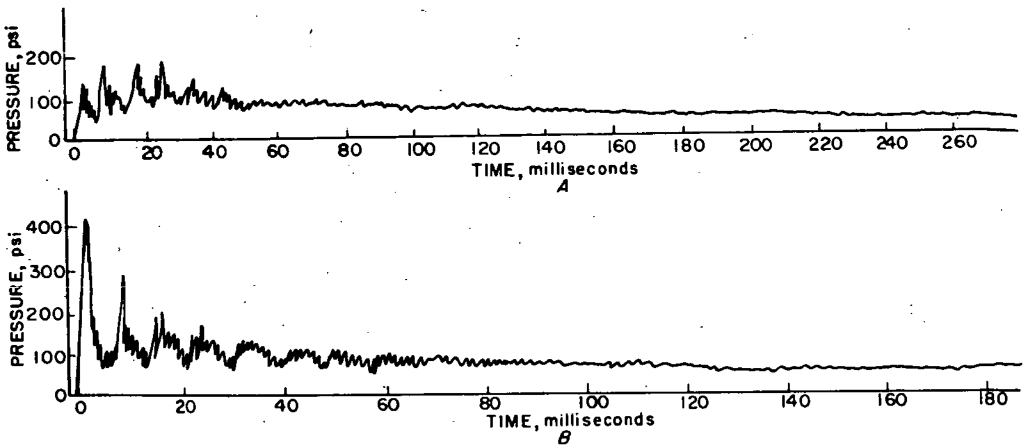

FIGURE 3. - PRESSURE TRANSIENTS IN CLOSED CHAMBER
A. Deflagration
B. Detonation

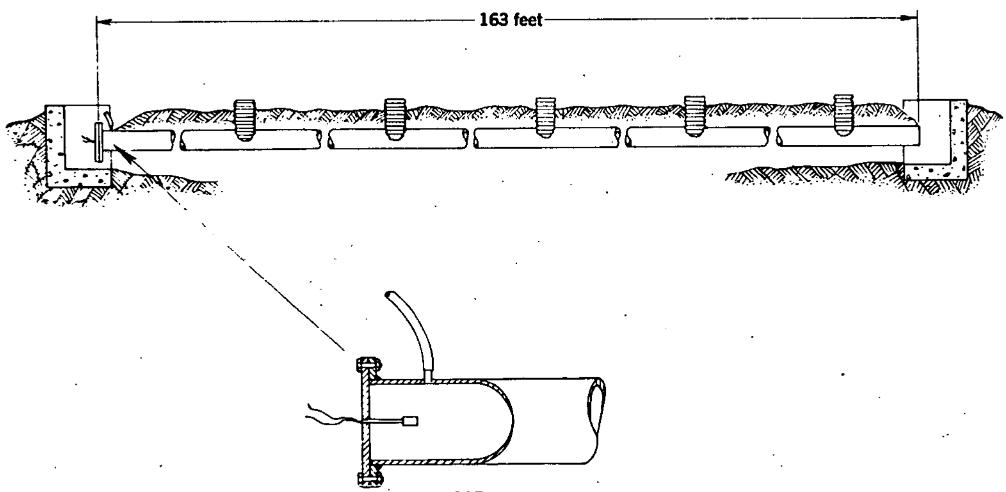

FIGURE 4. - LARGE DETONATION TUBE (2 x 163 FEET).

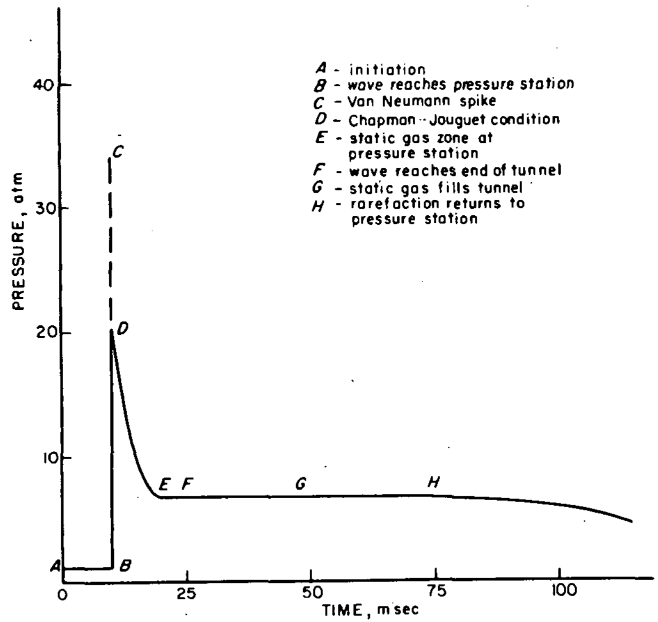

FIGURE 5. - PREDICTED PRESSURE TRANSIENT.

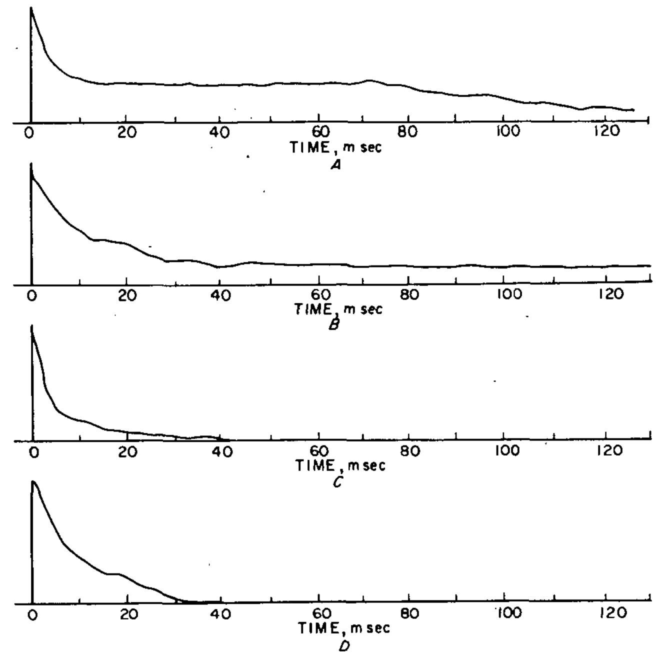

FIGURE 6. - OBSERVED PRESSURE TRANSIENTS
A,B - Initiation end closed; C,D - both ends open
A,C - Transducer near initiation; B,D - transducer downstream