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PHOTOGRAPHIC OBSERVATION OF COLLAPSING CYLINDERS

PROGRESS REPORT OF FEBRUARY 7, 1944

WD - Principles + Testing

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PHOTOGRAPHIC OBSERVATION OF COLLAPSING CYLINDERS

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Photographic data on a series of collapsed cylinders have been obtained and analyzed, and the results are presented below. Photographs of thirteen collapses were obtained, but not all of these have equal value.

Charges

All of the charges of this series were identical. Their construction is shown in Fig. 1. The type of end plug shown is used because it results in a pinching-off of the end of the cylinder so that that part of the cylinder covered by the plug is tapered from its original diameter down to complete closure, thus helping to block out of the photograph the effect of any luminous material which may later move in near the axis of the charge. The pertinent data on the construction of the charges is:

Mass Ratio (Explosive to cylinder)	0.87
Thickness-density Ratio	0.51
Density of Pentolite	1.6
Inner Diameter of Cylinder	2 inches
Outer Diameter of Cylinder	3 inches
Outer Diameter of Charge	$5\frac{1}{2}$ inches

Cylinder: Seamless tubing, 1020 carbon steel, annealed.

Experimental Set-Up and Procedure

The experiments were performed in the pit and bomb-proof on the South Mesa. Fig. 2 is a photograph of a typical set-up. The line-up is

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made by rotating the mirrors about their supports and aligning the charge by means of the leveling screws;the line-up is verified by means of the image on the ground glass of the camera.

The light source is an He-argon lamp of the type developed at the Bruceton Laboratory. Its diameter is greater than the inside diameter of the steel cylinder, so the lamp forms a complete background for the inside of the cylinder.

The smoke-shutter is simply a length of primacord whose smoke screen, moving across a slit at the front of the camera, serves as a high speed shutter and helps to prevent the exposure of the photographic plate to the luminous material present during the later part of the collapse. The smoke-shutter is timed to close about 3 microseconds after the flashing of the lamp.

The relative timing of the initiation of the explosion of the charge, of the flashing of the lamp, and of the closing of the smoke-shutter are adjusted by using appropriate lengths of primacord in the corresponding fuse lines.

The camera is armored; its focal length is 34 cm, the photographs are taken with an aperture F24, on commercial film. The timing of the camera shutter is 0.02 sec.

To diminish the effect of a luminous shock wave inside the steel cylinder, the ends of the cylinder are closed off with cellophane and the interior filled with butane gas at 1 atm. pressure.

The firing station is in a shelter about 500 feet from the pit. From here the camera is operated electrically. As the camera shutter opens, its mechanism closes a microswitch which completes a second circuit, firing the cap.

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Prior to the explosion a set-up photograph is made with the same camera. The results of the test are determined by a comparison of the two photographs.

Measurement of Photographs. Analysis of Data

Figs. 3 and 4 are reproductions of two representative pairs of photographs.

Measurements of the films are made using a low power microscope with a micrometer eyepiece. On the photograph of the explosion, the exposed area in the center is assumed to represent the cross section of the interior of the cylinder at approximately the center plane of the cylinder at the time of flashing of the lamp. On the set-up photograph the inner diameter of the cylinder is measured at the top of the cylinder. To permit a comparison of the two cross sections, a correction must be applied to account for the different lengths of the optical paths.

Table 1 gives the results of the measurements. Data on the collapse ratio are also given graphically in Fig. 5. Here the measured data are plotted as points. The scattering of the points is too great to justify any attempt to determine a position-time curve in any detail. As an approximate representation of the motion, the parabola was drawn which offered the best fit to the points, attention being paid to the value of the points as indicated in Table 1.

If we assume that the motion of the cylinder is radial, symmetric, non-viscous, and without compression, the pressure on the outer surface at any instant is

$$p = \rho\left[(x\ddot{x} + \dot{x}^2)\log_e(x/y) + \tfrac{1}{2}\dot{x}^2(1 - x^2/y^2)\right]$$

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where x and y are the instantaneous inner and outer radii, respectively. This formula becomes indeterminate as $x \rightarrow 0$, and, because of the assumed incompressibility, becomes invalid as the cylinder approaches the collapsed configuration. However, the formula has an approximate validity for the initial part of the motion. If we apply the equation to the initial instant, for which

$$\dot{x} = \dot{x}_o = 0,$$

it becomes

$$p_o = \rho x_o \ddot{x}_o \log_e (x_o/y_o)$$

If, in agreement with the curve of Fig. 5, we assume the relation between x and t is

$$x/x_o = 1 - (t/t_o)^2 ,$$

where t_o is the intercept of this parabola with the t-axis, then the initial pressure is given by

$$p_o = 2\rho(x_o/t_o)^2 \log_e(y_o/x_o)$$

The density of steel is $\rho = 7.85$ gr/cm; $x_o = 1.00$ in. = 2.54 cm; $y_o/x_o = 3/2$; and, from Fig. 5, $t_o = 29 \times 10^{-6}$ sec. Substitution of these values in the previous equation gives for the initial pressure

$$p_o = 4.88 \times 10^{10} \text{ dynes/cm}^2 = 4.83 \times 10^4 \text{ atm.}$$

This is perhaps 50 per cent lower than the expected value. To avoid the discrepancy one would have to draw the curve in Fig. 5 in such a way as to obtain

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a smaller value of t_o, but this is not compatible with the propriety of fitting the curve to the solid points having high collapse ratios. The discrepancy may be related to the fact that the entire explosive is not detonated simultaneously, but this detonation requires a time of the order of 5×10^{-6} sec. to become complete.

Table I

Data on Collapsing Cylinders

Photo Nos.	Time Delay (10^{-6} sec)	Collapse Ratio	Remarks
KC 9,10	19.5	1.01 ± 0.02	Measurements uncertain. Butane not used.
KC 13,14	19.1	0.75 ± 0.01	
KC 19,20	25.4	0.13 ± 0.01	
KC 21,22	31.7	0.00 ± 0.00	Complete closure.
KC 23,24	6.2	1.02 ± 0.01	Measurements uncertain.
KC 25,26	22.2	0.55 ± 0.09	
KC 27,28	12.7	0.75 ± 0.07	
KC 29,30	15.9	0.66 ± 0.02	Measurements uncertain.
KC 31,32	22.2	1.00 ± 0.00	" "
KC 35,36	22.2	0.64 ± 0.00	" "
KC 37,38	15.9	0.74 ± 0.01	
KC 39,40	6.2	1.05 ± 0.01	
KC 41,42	12.7	0.67 ± 0.01	Measurements uncertain.
KC 43,44	9.5	0.75 ± 0.01	" "
KC 47,48	22.2	0.24 ± 0.01	

The first column gives the identification of the photographs. The second column gives the time delay of the flashing of the lamp with respect to the initiation of the detonation of the main charge. The third column gives the collapse ratio, that is, the ratio of the instantaneous inner diameter to the initial inner diameter; these values were obtained from the mean of four measurements of the inner diameter made in directions differing successively by 45°. The uncertainties tabulated in the third column are obtained from the mean directions from the mean of these four measurements; they give some indication of the symmetry of the inner surface. A part of this uncertainty results from experimental difficulties, as is indicated by the fact that similar measurements on the initial inner diameters made on the set-up photographs had on the average an uncertainty of ± 0.01.

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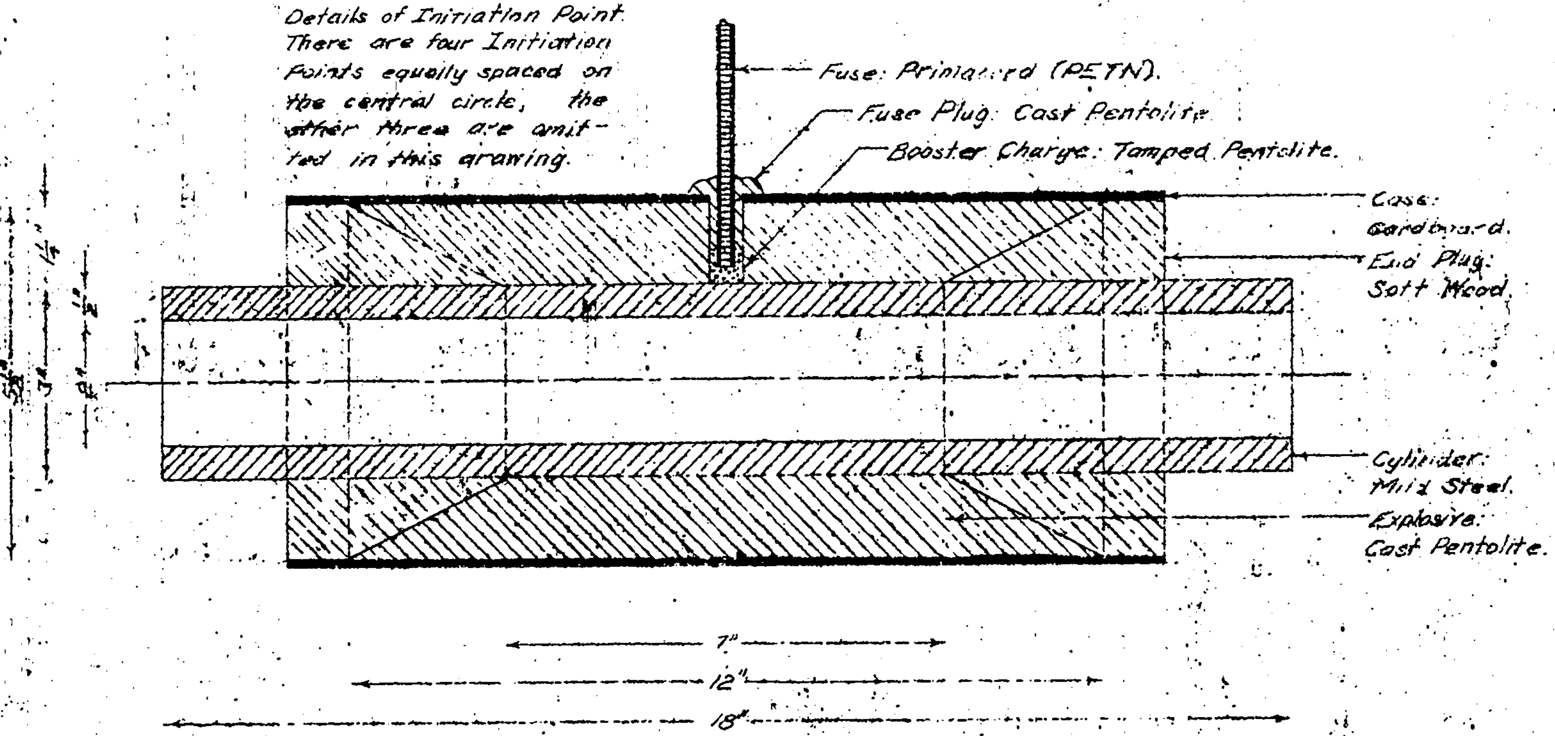

FIG. 2. CHARGE

Sectional View. Scale: $\frac{1}{3}$

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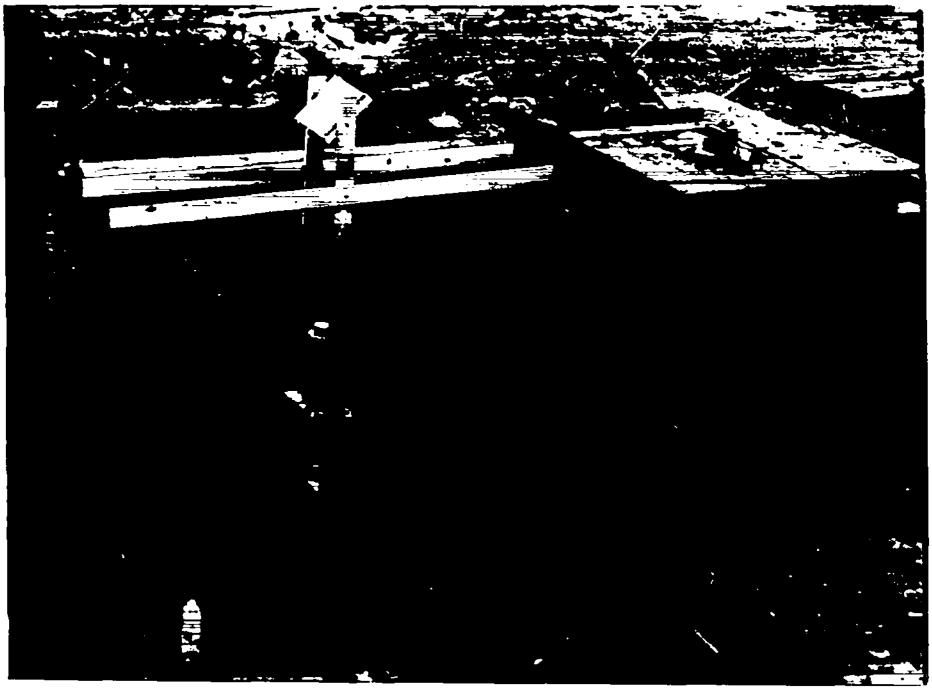

Fig. 2 The Experimental Set-Up

The charge is suspended near the center of the pit by means of the wooden stand; the charge rests on a flat board which is carried by three leveling screws. The He-argon lamp serving as the light source is carried on the base of the stand. To the right of the pit is located the bombproof, which houses the camera. Light from the lamp passes through the cylindrical charge, is reflected by the mirror at the top of the stand, and again by the mirror over the bombproof, passes downward through the bullet-proof glass window on the top of the bombproof and enters the camera, whose axis is vertical. The primacord fuse leads in a branching circuit from the cap to the charge and to the lamp, and has a branch which enters the bombproof through a two-inch pipe and serves as the smoke shutter for the camera.

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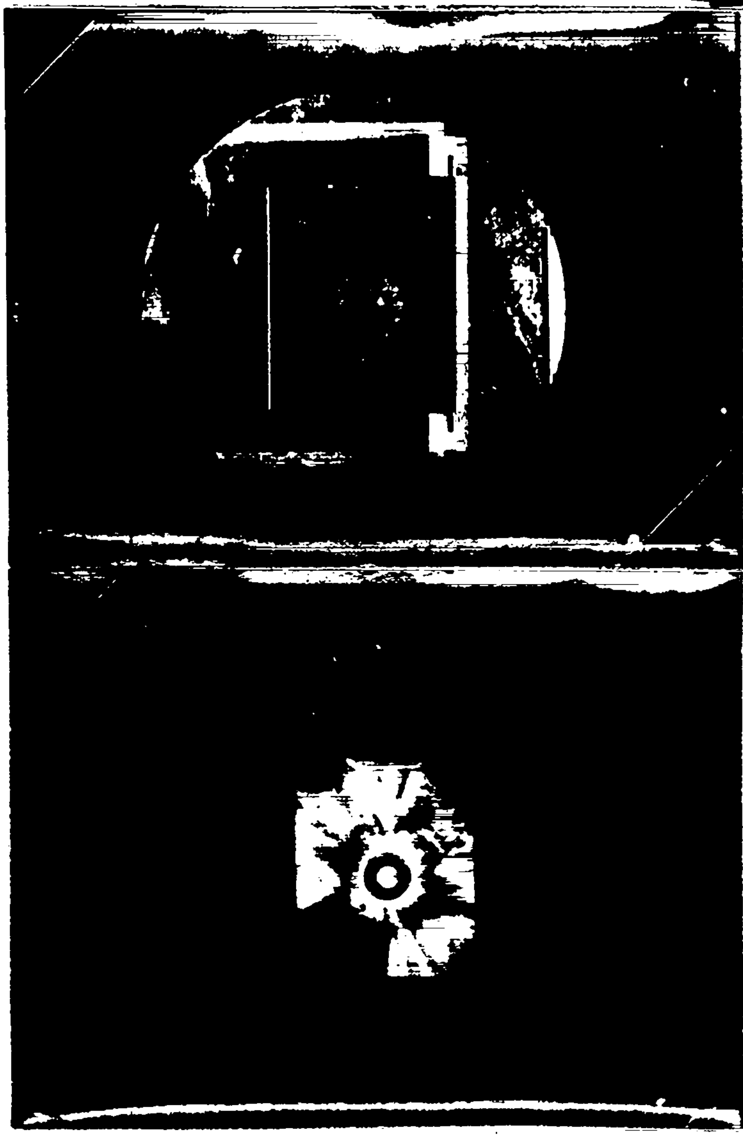

Fig. 3 A Pair of Experimental Photographs (Photographs Nos. 13 and 14)

The set-up photograph appears at the top, the explosion photograph at the bottom. The time delay was 19.1 sec. The collapse ratio measured was 0.75 ± 0.01.

The bright spot in the center of the explosion photograph is probably due to the intensely luminous jet where light apparently penetrates the smoke-screen shutter. The four particularly bright regions on the outside of the charge in the explosion photograph occur midway between the detonation points; they result from the meeting of the detonation waves. The appearance of these bright regions provides a basis for judging the symmetry of the detonation; the indications of the above are very satisfactory.

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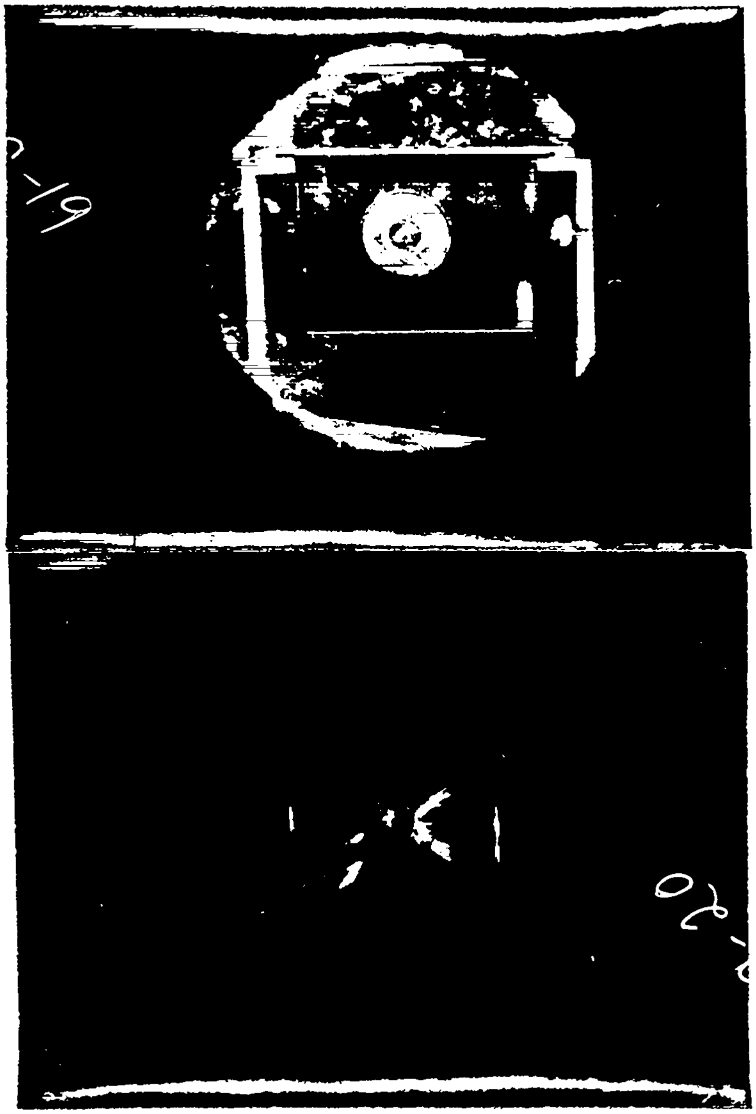

Fig. 4 A Pair of Experimental Photographs (Photographs Nos. 19 and 20)

The set-up photograph appears at the top, the explosion photograph at the bottom. The time delay was 25.4 sec. The collapse ratio measured was 0.13 ± 0.01.

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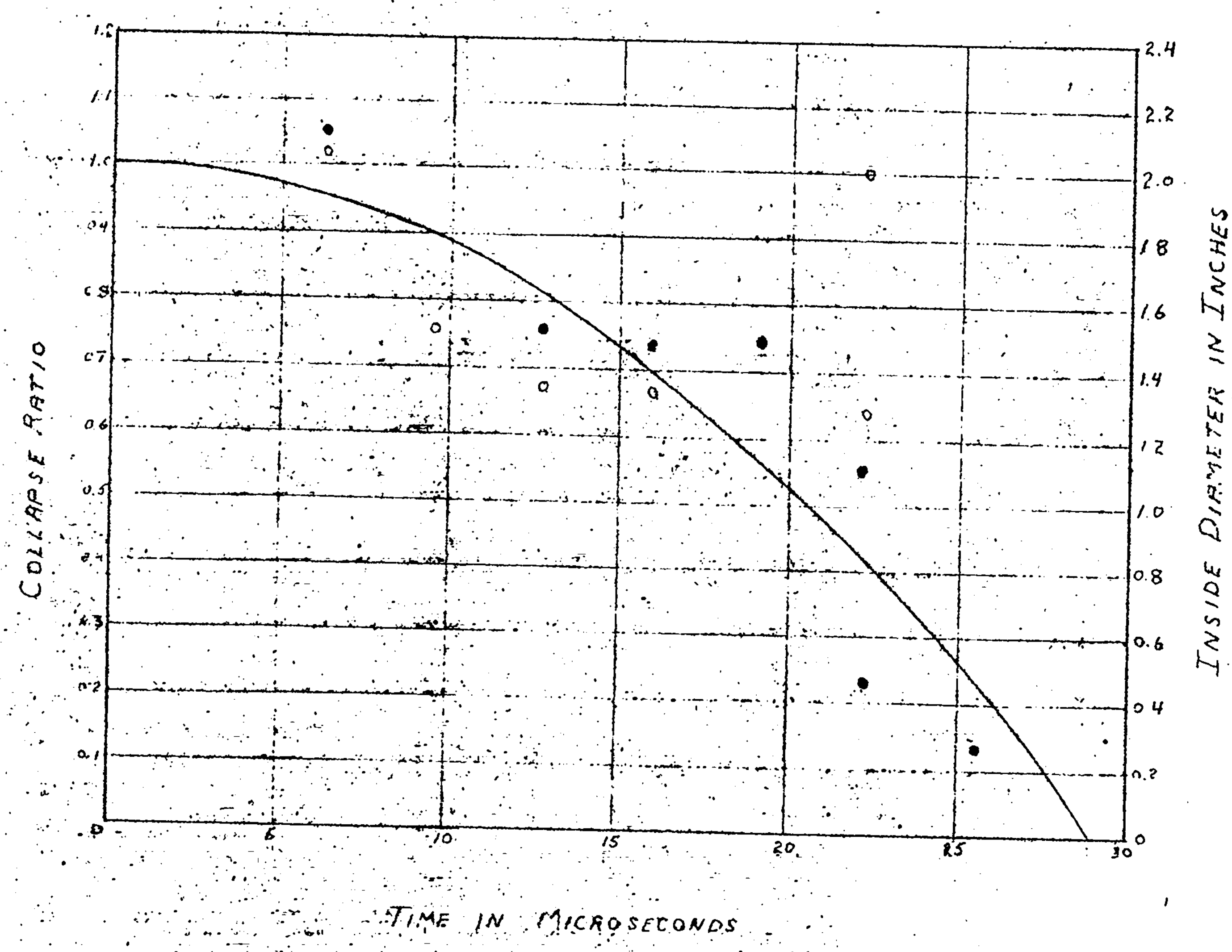

Fig. 5 Data on Collapsing Cylinders

The More Reliable Data Are Plotted As Solid Circles

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