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100-TON TEST, PERMANENT EARTH MOVEMENT; EARTH AND AIR SHOCKS

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ABSTRACT

The earth movement data obtained from the 100-ton shot is discussed and scaled up to the future gadget test at Trinity. These results are of interest to people who will place instruments in the vicinity of the gadget.

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100-TON TEST. PERMANENT EARTH MOVEMENT;

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Permanent Earth Movement

The permanent earth movement in the horizontal direction for the 100 ton shot along four lines, north, south, east and west, of the charge was measured. Steel stakes provided by Mr. Coon, approximately 2 ft. long and 1 inch diameter were driven into the ground so that about 1/2 inch projected above ground level. Scribe marks had been made on the top of the stakes and their points of intersection dotted with a center. punch. The positions of the stakes were very closely 40 ft., 50ft., 60 ft., 80 ft., 100 ft., and 120 ft. from a point on the ground below the center of the charge. Captain Davalos kindly arranged that the stakes were placed in position and the exact distances measured by the surveyors of the Albuquerque Corps of Engineers. Fig. 1 gives a plan; the experimental arrangement and the numbers on the plan give the distances before and after the explosion. The surveyors estimate that the possible error on a 20 ft. length was less than 0.01 ft.

The central stake, of course, was disturbed by the explosion and it is not possible to determine very well the movement on each of the four lines independently from the center. However, by measuring diametrically, one can obtain the average displacement along the east-west line and along the north-south line. Fig. 2 shows the results. The figure shows that very peculiar movements occurred although the symmetry of the explosion was reasonably good. Normally the horizontal movement falls off smoothly with radius very closely as R^{-2} , i.e., the permanent displacement is always outwards and decreases fairly rapidly with radius. However, in the case under consideration, the movement at 60 ft radius was nearly twice that at 40 ft radius and the movement was zero at about 75 ft radius. Between 75 ft radius and 120 ft radius the movement was actually towards the center of the explosion. Whether any significance

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can be attached to the results obtained in the region of 130 ft, where the movement was again outwards, is doubtful because the cumulative error in the survey measurements was possibly 1/2 inch in this region and is, therefore, of the same order as the observed movement. The extraordinary result that on all four lines the distance between the posts 3 and 4, which were at 60 and 80 ft respectively from the center, was actually decreased as a result of the explosion is puzzling but there can be no doubt that the effect is real. The shrinkage on a length 20 ft was about 3 to 4 inches.

In order to estimate upper limits for the horizontal permanent earth movement at distances somewhat greater than those covered by the stakes, it seems reasonable to assume an inverse square law fitted to the observation that at 60 ft radius the movement was 3 inches. Hence, as an upper limit for this explosion we may say that

$$(1) \quad H_p = 3\,(60/R)^2 \text{ inches}$$

where R is the horizontal distance in feet. Scaling these results to larger explosions we have for an explosion of n kilotons

$$(2) \quad H_p = 108{,}000\, n\, R^{-2} \text{ inches}$$

The table summarizes our estimated upper limits for the permanent movements for various equivalents of the gadget. For purposes of comparison the 100 ton shot was assumed to be exactly 100 tons of explosive. No refinements made as a correction for the wood or the composition B have been made.

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Table I

Estimated Upper Limits on Permanent Earth Movement Hp in Inches for Gadget of n Kilotons TNT Equivalent

R (Distance from center of tower base in ft.)

n (Kilotons TNT)	100	200	400	600	2400	4500
.5	5	1.4	.3	.15	.08	.05
1	10	2.2	.7	.3	.16	.1
2	22	5.4	1.3	.6	.32	.2
3	32	8.1	2.0	.9	.47	.3
5	--	13	3.4	1.5	.79	.5
10	--	54	13.4	6.0	3.2	2.0

This table has been prepared on the assumption that a charge of n kilotons is exploded on a 100 ft tower. For value of n less than 5, the values are over-estimates because the charge is higher in proportion than was the 100 ton charge. The values for n = 5 are about correct except in so far as they are based on equation (2) which itself is an overestimate. The values for n greater than 5 have been increased from those scaled for the 5 kiloton shot in the ratio (n/5) in rough agreement with bomb data for these heights. Thus, no values in the table are underestimated.

Since the elastic movement of the ground is practically non-dilational, one might also estimate the horizontal movement in inches at radius R ft at the surface from the formula

(3) $H_p = 12V/2\pi R^2$ inches,

where V is the volume of the crater in cubic ft. Assuming a parabolic form for the crater with a depth 5 ft and diameter 50 ft, we find as an alternative estimate

(4) $H_p = 94{,}000\ n\ R^{-2}$ inches.

This is in excellent agreement with equation (2).

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At distances greater than 1000 ft, the elastic movement of the ground would be more important than the permanent movement but from previous American and British observations on bombs it is safe to say that an upper limit for the elastic movement is quite is twice that of the permanent horizontal movement. Thus, our estimates of upper limits for the elastic movement for various charge equivalents may be obtained from Table 1 simply by doubling the earth movement figure. Of course, for larger distances R, the inverse square law (2) fails and the decay is more like R^{-1}. In preparing Table 1, Mr. Coon's Geophone data[1)] which agrees roughly with an R^{-1} law fitting the tabulated values at 600 ft , was used at the 2400 and 4500 ft distances. In this connection it should be noted that Coon placed a limit of error of 50 percent on his displacement data.

Earth Shock and Air Shock

Certain experiments contemplated for the gadget shot require an approximate knowledge of the time of arrival at various stations of the earth shock and of the air shock. Reasonably accurate figures can be given for the arrival of these shocks at stations between 400 yards and 10,000 yards, except possibly for a 10,000-ton explosion at the 400 to 600 yards distance. The speed of the ground shock can be estimated from the following information. At a 300 yard station in the 100-ton shot, Mr. Chamberlain observed that the ground shock reached his recording apparatus 0.29 seconds before the air shock. Mr. Walker has informed us that according to the piezo-electric gauge records, the air shock reached 300 yards in 0.453 seconds. Hence, the ground shock covered 300 yards in 0.163 seconds and the average speed of propagation was 5500 feet per second. No doubt the speed was greater near to the explosion than it was farther away but no great variation is to be anticipated. Thus, in the estimates made below we assume that the speed of propagation of the earth shock is always 5500 ft

1) J. Coon Memo May 24, 1945

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per second. This constant velocity assumption is made reasonable by the following considerations:

At the distance of {4500 ft this velocity is 10 percent lower; 2400 ft this velocity is 13 percent greater} than the average velocity obtained from Coon's geophones. No geophone data is available closer than 2400 ft. Since Coon's data indicates a monotonic increase in velocity with distance and the value at 2400 ft is lower than the Chamberlain-Walker value at 900 ft. A disagreement of the order of 10 percent exists in the ground shock velocities measured in two different ways. In addition Coon sets a < 10 percent limit on the accuracy of his values. This evidence lends support to the simple assumption of constant earth shock velocity at least to a distance of about 5000 ft. Table 2 makes use of the observed time of arrival of the earth shock as recorded by the piezo-electric gauge in the 100 ton shot over the range 150 yards to 320 yards from the center. It is not to be expected that the air shock from a gadget will behave exactly like the air shock from a normal high explosive charge and for this reason errors of several milliseconds may be found in the table. However, for most purposes, such an error is insignifcant. It will be noticed that in the 10 kiloton explosion the air shock and earth shock arrive practically simultaneously at 400 yards and that from this distance outwards the earth shock arrives first.

Table 2

Time of Arrival of Earth Shock in Milliseconds for Any Gadget Tonnage at Various Radii in Ft.

Distance Ft.	1000	1500	2000	45000	5130
Time Millisecs.	180	270	360	820	930

Time of Arrival of Air Shock in Milliseconds for Various Equivalents

Distance, ft. \ Kilotons	0.1	1.0	2.0	3.0	5.0	10.0
1000	505	312	244	155	---	----
1500	900	650	560	480	390	230
4500	3650	3230	2880	3100	2910	2340
5130	4220	3970	3800	3670	3480	3180

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Possible Reasons for the Peculiar Earth Movements Observed

Unfortunately no previous experiments have been made on earth movements with air burst charges. However, it seems likely that the type of earth displacement observed here would be reproduced in any soil, e.g., clay, chalk, sand, provided a similar geometry also was used.

As for explaining the phenomena, there appear to be three possibilities.

1. The wooden platform gave more protection to the central parts of the ground. The crater was somewhat smaller than anticipated (actually about 0.6 of the linear dimensions anticipated). Since in the gadget shot this large quantity of wood will be replaced by much lighter steel, doubtless this reason will not obtain.

2. The nature of the soil at Trinity is peculiar; the harder compacter soil at depths greater than 2 ft or 3 ft may have affected the permanent earth movements in an unpredictable way. The higher tonnage and hence deeper crater expected for the gadget should make the effect of the surface layer less important and so should not contribute to such an unusual crater as occurred with 100 tons.

3. The maximum in the earth movement which occurred at about 60 ft. was due to the formation of a Mach Y. The pressure at the foot of the Y when it first forms is usually greater than the pressure at slightly smaller radii. This argument applies equally well to the gadget shot because the gadget will be burst at the same scaled height as was the 100 tons.

Proposed Modifications for the Trinity Gadget Shot

If the permanent movement of the ground is to be adequately covered for a possible range of equivalents 500 tons to 10,000 tons, it appears necessary that stakes should cover the range 70 ft to 500 ft from the center. Four lines of stakes are

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satisfactory. Thus, we suggest that for the gadget shot the experimental arrangement is similar to that for the 100 ton shot but that the distances from the center are 70 ft, 90 ft, 120 ft, 150 ft, 200 ft, 250 ft, 300 ft, 400 ft, and 500 ft.

Some consideration must be given to the possibility of measuring the vertical displacement. To do this adequately, however, needs very careful surveying and it is not clear at the moment whether the effort is worthwhile.

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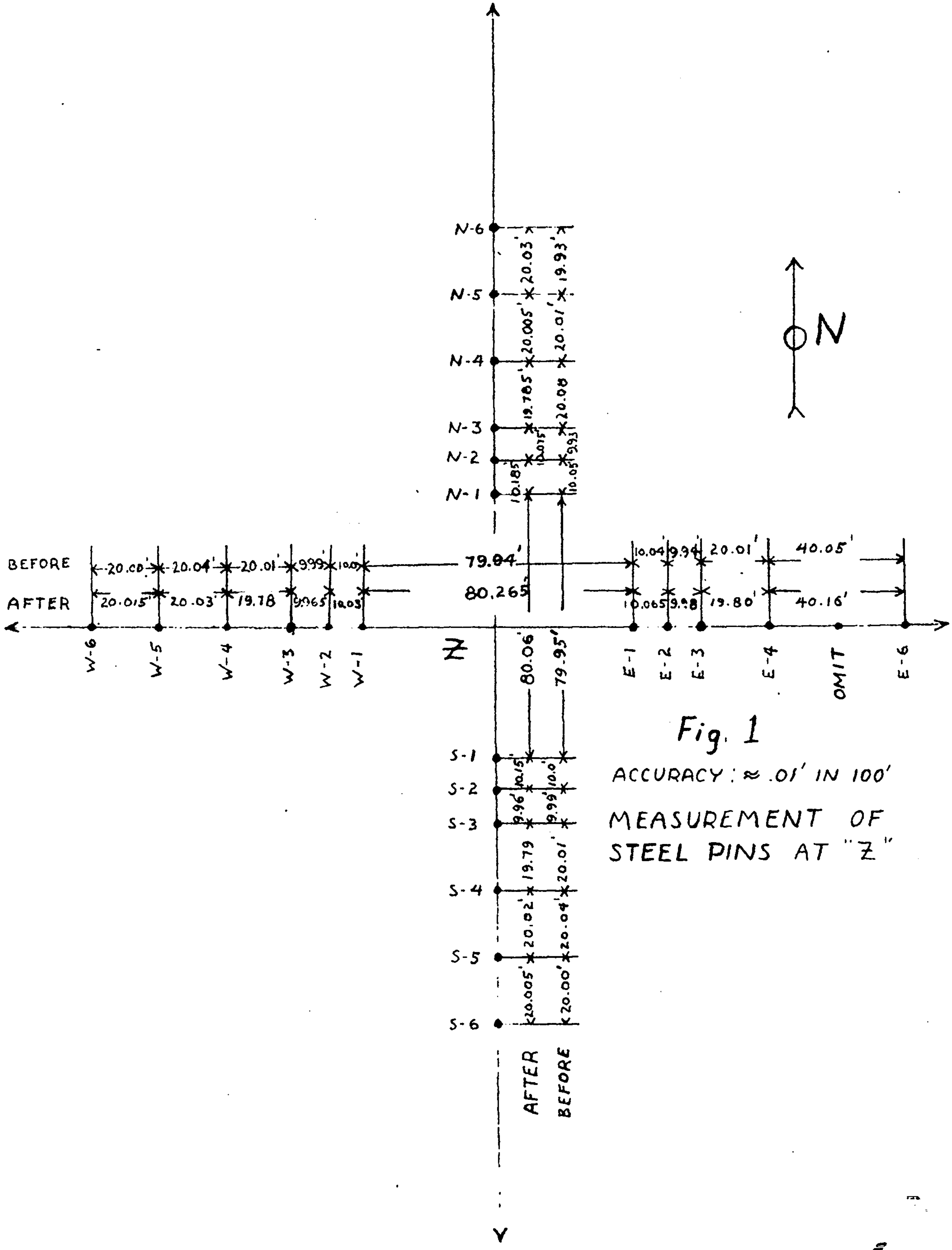
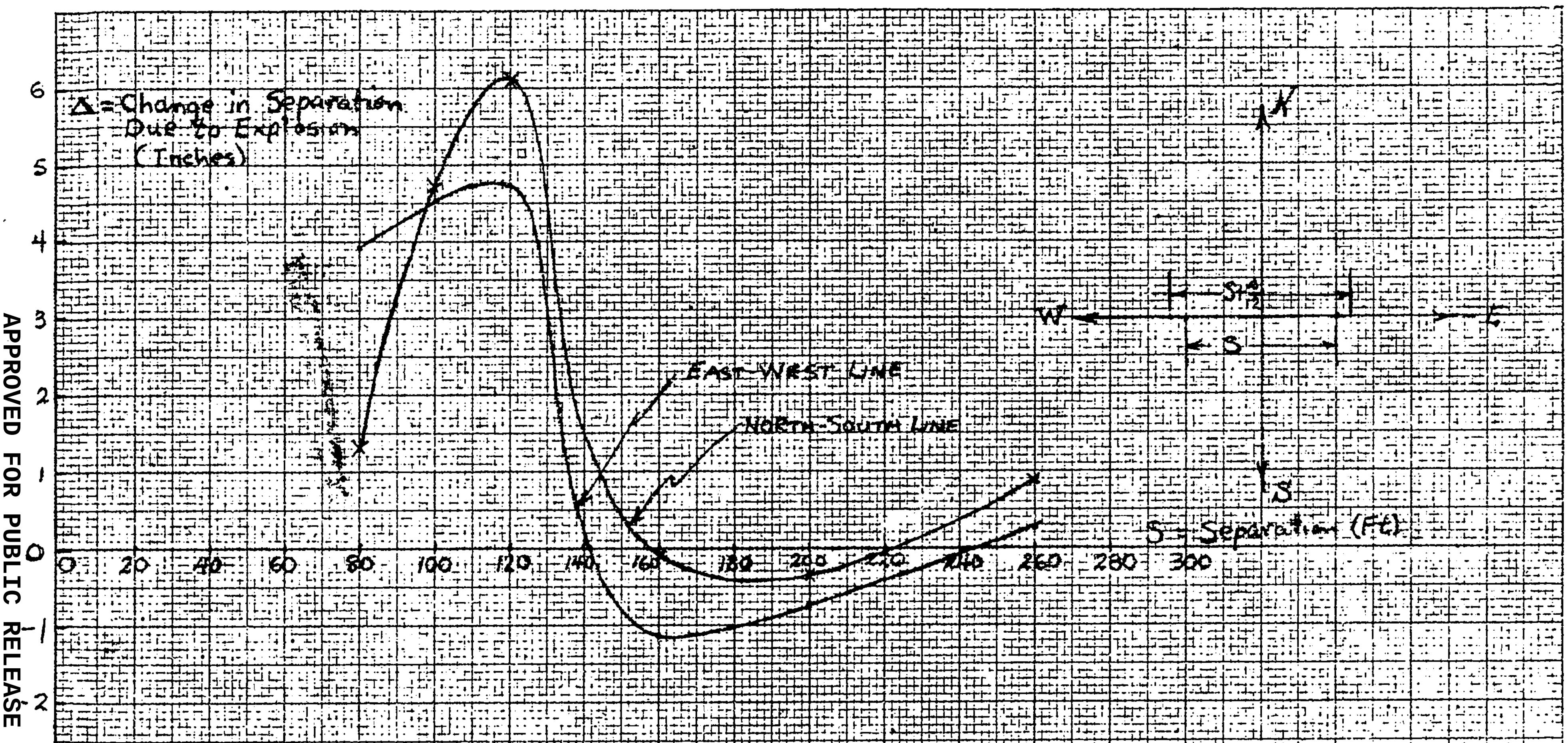


Fig. 1

ACCURACY: ≈ .01' IN 100'

MEASUREMENT OF STEEL PINS AT "Z"



TRINITY
PERMANENT EARTH MOVEMENT
100 TON SHOT
FIG. 2

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