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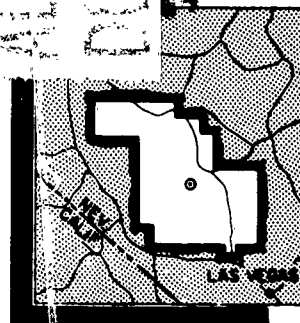
February - May 1955

Project 3.9

RESPONSE OF SMALL PETROLEUM PRODUCTS STORAGE TANKS

Issuance Date: May 6, 1957

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STORAGE TANKS, [U]

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SUMMARY SHOT DATA

SHOT	CODE NAME	DATE	TIME #	AREA	TYPE	LATITUDE & LONGITUDE OF GROUND ZERO
1	Wasp	18 February	1200	T-7-4 ¹	762' Air	37° 05' 11.8856" 116° 01' 18.7366"
2	Moth	22 February	0545	T-3	300' Tower	37° 02' 52.2664" 116° 01' 15.6967"
3	Tesla	1 March	0530	T-9b	300' Tower	37° 07' 31.5737" 116° 02' 51.0077"
4	Turk	7 March	0520	T-2	500' Tower	37° 08' 18.4944" 116° 07' 03.1679"
5	Hornet	12 March	0520	T-3a	300' Tower	37° 02' 25.4043" 116° 01' 31.3674"
6	Bee	22 March	0505	T-7-1a	500' Tower	37° 05' 41.3880" 116° 01' 25.5474"
7	ESS	23 March	1230	T-10a	67' Underground	37° 10' 06.1283" 116° 02' 37.7010"
8	Apple	29 March	0455	T-4	500' Tower	37° 05' 43.9200" 116° 06' 08.9040"
9	Wasp'	29 March	1000	T-7-4 ²	740' Air	37° 05' 11.6856" 116° 01' 18.7366"
10	HA	6 April	1000	T-5 ³	36620' MSL Air	37° 01' 43.3642" 116° 03' 28.2624"
11	Post	9 April	0430	T-9c	300' Tower	37° 07' 19.6965" 116° 02' 03.8860"
12	MET	15 April	1115	FF	400' Tower	36° 47' 52.6887" 115° 55' 44.1086"
13	Apple 2	5 May	0510	T-1	500' Tower	36° 03' 11.1095" 116° 06' 08.4937"
14	Zucchini	15 May	0500	T-7-1a	500' Tower	37° 05' 41.3880" 116° 01' 25.5474"

* APPROXIMATE LOCAL TIME - PST PRIOR TO 24 APRIL, PDT AFTER 24 APRIL

1/ ACTUAL GROUND ZERO 36' NORTH, 426' WEST OF T-7-4

2/ ACTUAL GROUND ZERO 94' NORTH, 62' WEST OF T-7-4

3/ ACTUAL GROUND ZERO 36' SOUTH, 397' WEST OF T-5

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ABSTRACT

The response of one of the two bolted steel tanks and three of the four welded steel tanks which remained substantially undamaged in Operation Upshot-Knothole, Project 3.26.1, was studied for the purpose of obtaining some information on modes of failure of filled small petroleum-products storage tanks. No satisfactory experience or proved analytical methods exist for establishing the plastic response of filled or partially filled tanks. The tanks were located at ranges of 1,200, 1,350, 1,500, and 2,100 feet from Shot 12 in an effort to obtain damage to tank shells ranging from light to severe—three tanks being positioned to obtain severe or at least moderate damage. The first three tanks suffered gradations of severe damage; the most remote tank was overturned but not ruptured. The objectives of this test, as they were ultimately delineated, were met as well as could be expected in any single ad hoc test and more useful data were obtained than expected. Although a paucity of data on response of large tanks still exists, there are now available the observed results of a limited response test of small filled tanks.

FOREWORD

This report presents the final results of one of the 56 projects comprising the Military Effects Program of Operation Teapot, which included 14 test detonations at the Nevada Test Site in 1955.

For overall Teapot military-effects information, the reader is referred to "Summary Report of the Technical Director, Military Effects Program," WT-1153, which includes the following: (1) a description of each detonation including yield, zero-point location and environment, type of device, ambient atmospheric conditions, etc.; (2) a discussion of project results; (3) a summary of the objectives and results of each project; and (4) a listing of project reports for the Military Effects Program.

PREFACE

The project described in this report was planned and designed by the Physical Vulnerability Division of the Directorate of Intelligence, Headquarters, USAF, with assistance from Armour Research Foundation, Chicago, Illinois. The responsibility for the Field Test phase of the project was assumed by Wright Air Development Center in connection with other Air Force Structures projects. The author wishes to acknowledge particularly the principal contributors to this report; namely, Dr. F. Genevese, W. Hiner, C. Walker and S. White of the Directorate of Intelligence, Headquarters, USAF, who, because of the ad hoc nature of the test, are best qualified to assess the results in terms of target application.

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Chapter I

OBJECTIVES

The original objectives advanced at the inception of this project were: (1) to obtain modes of failure for the types of petroleum-products storage tanks tested, under the conditions tested; (2) to utilize observed results as a source of ad hoc data for the size of tanks tested; and (3) to correlate observed results with analytical procedures for prediction of damage to tanks of all sizes if such procedures are successfully developed. Moreover, it was anticipated that whatever degree of success was obtained in this test would be reflected in target analysis techniques of the Air Force.

Concurrent with the establishment of this full-scale test requirement in Operation Teapot, several analytical studies were underway attempting to predict failure of various types of storage tanks under conditions of blast loading. Most of these studies were completed following formulation of the aforementioned objectives. These findings led to the conclusion that the chief value of this test would be in providing ad hoc data on the mode of failure of filled, small tanks. For this reason, the objectives of the test were delineated more specifically as follows: (1) to obtain data on the extent of failure of filled, small petroleum-products storage tanks of the types tested, in pressure regions where damage is sufficient to satisfy offensive planning; (2) to determine from inspection in what pressure regions such tanks would fail by shell rupture directly rather than by rigid-body motion; (3) to determine in what pressure regions such tanks would slide, possibly overturn and rupture; (4) to ascertain in what pressure regions such tanks would slide without overturning or rupturing, but with sufficient force to break pipe connections and thereby cause loss of contents; and (5) to correlate observed results with analytical procedures for prediction of damage to tanks of all sizes—if and when such procedures are developed.

In order to accomplish these objectives, four tanks available from Operation Upshot-Knothole, Project 3.26.1, (Reference 1), were relocated at various ranges and filled to 80-percent capacity with water. No motion-picture photography or instrumentation was to be provided, since a simple and inexpensive test was desired. Limited information was expected from the test. No roofs were provided for the three tanks of welded construction, in keeping with the simplicity and economy of this project. The fourth tank, of bolted construction, was complete with the original Upshot-Knothole roof.

Chapter 2

BACKGROUND AND THEORY

2.1 GENERAL

Up to the present, no satisfactory experience or proved analytical methods exist for establishing the plastic response of filled or partially filled petroleum-products storage tanks. The specific test data desired here were not obtained in Upshot-Knothole. Moreover, records of observed damage to storage tanks from industrial explosions and windstorms do not permit prediction of plastic response of full or partially filled tanks subjected to atomic blast. Hence, reliable prediction of plastic response of petroleum-products storage tanks depends largely upon the successful completion of full-scale investigations. While it was realized that the observed response of the types of tanks tested could not be used directly to guide analytical procedures for predicting damage to tanks of other types and sizes, it was believed worthwhile to attempt to obtain some useful ad hoc data by re-exposing the four available tanks to blast forces arising under full-scale test conditions.

Knowledge of factors governing rigid-body motion of small storage tanks is admittedly limited. No data exist for the static or kinetic coefficient of friction of steel upon Nevada desert soil. There is very little knowledge of the proper drag coefficients to use for small storage tanks exposed to precursor type loadings. Variation by a factor of two in the drag coefficient could effect large changes in displacement. Nevertheless, this type of response was the only one upon which pretest analysis could be based.

2.2 DAMAGE CRITERIA

The minimum damage objective for petroleum storage tanks usually is to cause loss of contents. Hence, damage to petroleum storage tanks can be measured by the amount of structural failure of walls and wall-to-base connections required to cause rupture and loss of contents. Rupture may occur with or without sliding and/or overturning. Loss of contents may also result from sliding which is sufficient to rupture pipe connections. Damage may range from light to severe depending upon the extent of rupture of the shell and the resultant loss of contents. Damage in this test was expected to range from light to severe with possibly an example of moderate damage between the extremes.

For purposes of this test of small tanks, light damage is defined as damage sufficient to cause slow or small leakage, while severe damage is associated with rupture which causes immediate, complete loss of contents. Moderate damage lies between these two extremes. It should be noted that even light damage, as defined, may be associated with very-large distortion of the shell. It was believed, prior to this test, that severe damage could occur without overturning; now it is believed this will apply only to large tanks. Small tanks may overturn, spill contents and be severely damaged. For the purpose of this test, it was intended to limit extreme damage to that resulting from failure of structural components and rigid-body translation. An attempt was made

to avoid overturning in locating the tanks, since it was felt that the damage associated with overturning would mask the modes of failure caused by the other types of failure. For the filled tanks tested, it was anticipated that severe damage could be achieved at loadings less than those associated with overturning. For the purpose of this test, three welded tanks were located where severe, moderate, and light damage were anticipated. In addition one filled, bolted tank of standard Army design was located so as to receive severe damage.

2.3 LOADING CONSIDERATIONS

All loading calculations were based on the specified pretest conditions for Shot 12 of Teapot, i. e. a height of burst of 400 feet and a yield of 28 KT. For the damage desired, all of the tanks were located in a region of strong precursor action. The placement of the tanks was seriously hampered by the paucity of information on the forces in the precursor region. However, the horizontal loadings were predicted by a method developed for precursor loading by the Armour Research Foundation in Reference 2. Essentially, the net horizontal loads which are based on the results obtained from Structure 3.1t in Shot 10 of Upshot-Knothole are given in terms of the drag coefficient, C_d , and idealized surface dynamic pressure, P_d . The loading is shown schematically in Figure 2.1. It should be pointed out that this loading scheme was at best an approximation based on the Upshot-Knothole results, but that it represented, at the time, the best available estimate. For the net horizontal loading on the tanks, a drag coefficient of 0.35 was used and the idealized surface peak dynamic pressures were obtained from Reference 3.

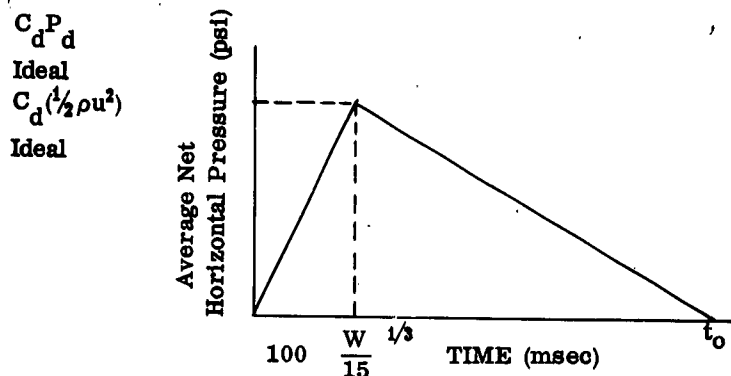


Figure 2.1 Schematic loading scheme in a precursor.

The vertical loadings in precursor regions are equally uncertain. For these computations, the ratio of the maximum vertical pressure to the peak free stream pressure was assumed to be constant. This assumption was based on rather inconclusive evidence from Project 3.1 in Shot 10 of Upshot-Knothole. This ratio varied from approximately 0.38 (for an overpressure of 50 psi) to 0.72 (for an overpressure of 8 psi). For lack of more detailed information, the vertical pressures were assumed to be approximately 50 percent of the free-stream pressure.

Both the net horizontal and the vertical loadings were believed to be the best available load predictions. Subsequently, alternate values for the dynamic pressure which

were significantly different became available. Reference is made to those included in Reference 4. The values suggested by this source for dynamic pressures over the desert were twice the ideal values as used in the load prediction scheme discussed above. It was felt that on the basis of the data available at the time that there was not sufficient justification for modifying the ideal dynamic pressures by a factor of two instead of using the ideal dynamic pressures directly.

The estimation of dynamic pressures in a precursor region under ideal conditions, i. e. for a rigid reflecting surface, has theoretical justification (see Reference 5). The data on dynamic pressures from Upshot-Knothole for a dusty precursor were quite fragmentary, with a number of questions involved in their interpretation. This experimental information indicated that the dynamic pressures were, if anything, higher than ideal values. However, experience in several past tests has indicated many variances between preshot effects estimates and actual test results. Thus, in order to assure at least the desired response, it was decided not to use the dusty precursor predictions but to use the curves of Reference 5 instead. If dynamic pressures were to depart from ideal, it was desired that the damage sustained by the tanks be greater than predicted.

This situation, regarding dynamic pressures, illustrates the inaccuracies involved in the horizontal loading calculations. Large inaccuracies could also be introduced by the assumption regarding the drag coefficient since very little data were available on drag coefficient for cylinders of short length. The highly approximate nature of the vertical loading considered was discussed earlier. It was not possible to determine the accuracy of the method of load calculations used, but it is apparent that very-large errors are possible for the various reasons cited above.

2.4 RESPONSE CONSIDERATIONS

2.4.1 Introduction. Based on the load predictions given in the previous section, studies were undertaken to determine locations for the tanks. One approach in designing a tank test is to place the tanks in accordance with the extreme variations possible in the load-prediction scheme and in the method of analysis, i. e. one tank would be located so that severe damage would be guaranteed for any possible variations in loading, a second tank would be located so that no more than light damage would occur, and additional tanks would be located at intermediate positions. For an unlimited number of tanks, this approach would certainly be used, since it would provide a bracket for any type of damage of interest as well as data for the full range of possible damage. This system may result, of course, in a large portion of the tanks being either undamaged or totally destroyed. With only one tank available for intermediate location as in this test, it appeared doubtful if useful data could be expected using the above described method of positioning.

It was decided, therefore, to try to bracket the ranges where one would achieve the type of damage of greatest interest. The greatest target interest is in the region of severe damage in order to attain complete loss of contents. This required the placing of the available tanks in a pressure region where the loading was sufficient to cause sliding and associated severe damage.

Because of the limited number of tanks available, it was decided to locate the test tanks in accordance with the specific loading scheme previously described. Assuming that the loading scheme is correct, this approach should yield the desired bracket of substantial damage. Even if errors were present in this loading scheme, it was believed that at least some useful information would still be obtained from the test. The loadings selected had the advantage of representing what was believed to be a minimum if the loadings differ from those predicted. This particular situation insured that, if

the predicted loadings were not realized, the damage would exceed that anticipated. If the desired bracket of damage were not achieved because of errors in load prediction, this would guarantee that useful test data relating to extreme damage, where interest is paramount, would still be obtained.

2.4.2 Tank Response. Since analytical means of treating plastic failure of tank shells are not available or at least are not realistic, no attempt was made to study failure related to this manner of response. Instead, failure resulting from movement of the tank and contents, treated as a rigid body, was studied. It was expected that calculations of response of this type, combined with consideration of the results of the previous test of tanks in Project 3.26.1 of Upshot-Knothole (Reference 1), would provide realistic distances for locating the tanks in this test. All calculations of response were based on tanks 80-percent filled with water.

The first mode of failure considered was that at which the tank would start to overturn as a rigid body about one edge (see Figure 2.2). When considering overturning, it was felt that only the initiation of overturning was of interest, since failure of the tank bottom would be expected with very small movements. Computations showed that a slight uplift of the ground-zero side of the tanks would occur if the filled tanks were placed at approximately 1,000 feet from ground zero. This calculation of the incipient uplift was based on the resistance to overturning provided by the weight of the tank, the weight of water, and the assumed vertical loading. Incipient overturning would be associated with the predicted peak horizontal loading.

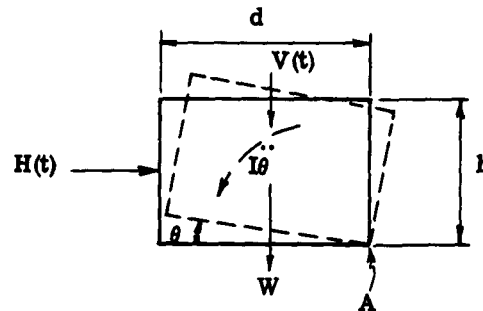


Figure 2.2 Overturning of tank about A.

The equation of motion is: $\frac{h}{2} H(t) = I\ddot{\theta} + \frac{[V(t) + W]d}{2}$

Where: h = height of tank.

H(t) = net horizontal force acting on tank as a function of the time.

t = time.

I = moment of inertia of tank and contents about A.

θ = angular displacement as shown.

$\ddot{\theta} = \frac{d^2\theta}{dt^2}$, angular acceleration.

V(t) = net vertical forces acting on tank and contents as a function of time.

W = weight of tank and contents.

d = diameter of tank.

The second type of rigid-body motion considered was sliding due to the horizontal forces (see Figure 2.3). Sliding is resisted by frictional forces developed between the bottom of the tanks and the sand. This resistance is dependent upon the coefficient of friction and on the vertical forces between the tank and sand. The vertical forces consist of weight of the tank, the weight of the water, and the vertical blast loading. Incipient sliding would be associated with the peak horizontal loading. For any test, the frictional resistance between the tank and sand is highly uncertain. If movement occurs, the tank might dig into the sand and thereby be restrained from further sliding; in effect, the coefficient of friction would be increased. If the coefficient of friction is assumed to be unity, sliding would occur at distances from ground zero of less than 1,300 feet. If the coefficient of friction is 0.5, the distance increases to approximately 1,600 feet. There is no practical method for prediction of sliding, plowing up of a ridge, and overturning about the ridge as a fulcrum.

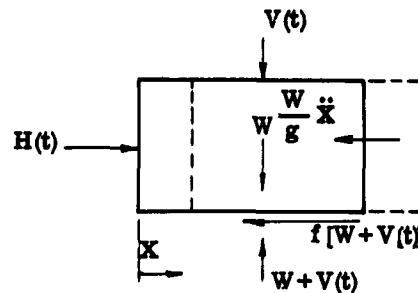


Figure 2.3 Sliding of tank.

The equation of motion is: $\frac{W}{g} \ddot{X} + f [W + V(t)] = H(t)$

Where: $H(t)$ = net horizontal force acting on tank as a function of the time.

W = weight of tank and contents.

$V(t)$ = net vertical forces acting on tank and contents as a function of time.

g = acceleration due to gravity.

X = horizontal displacement as shown.

$\ddot{X} = \frac{d^2 X}{dt^2}$, horizontal acceleration.

f = coefficient of friction, horizontal resistance per unit of contact pressure.

t = time.

Let us consider the factors governing one type of rigid-body motion, i.e., sliding. Assume two identical tanks, one filled of mass M_f , and one empty of mass M_e . Displacement, Δ , is a function of the applied force, F , and the mass, or:

$$\Delta_e \sim \frac{F}{M_e} \qquad \Delta_f \sim \frac{F}{M_f} \qquad (2.1)$$

Therefore, under the same loading force, Δ_e will be greater than Δ_f since M_f is greater than M_e , and thus, the degree of filling has a profound effect upon the response.

In Project 3.26.1, Upshot-Knothole, a number of petroleum storage tanks were tested in Shots 9 and 10. It is difficult on the basis of these tests to arrive at quantitative data, but they do provide some qualitative information for guidance on tank location. In Table 2.1, the location, overpressures, and damage to the tanks tested in Upshot-Knothole are given.

TABLE 2.1 TANK DAMAGE; PROJECT 3.26.1, UPSHOT-KNOTHOLE

Shot	Tank Construction	Range	Overpressure	Wall Damage
		feet	psi	
9*	Welded	1,995	13	No damage
		6,555	4	No damage
		9,210	3	No damage
		15,000	1	No damage
	Bolted	3,560	9	Light damage
		9,220	3	No damage
10†	Welded	1,540 ‡	12	Completely demolished
		6,500	2	Signs that overturning had started
		9,105	1	No damage
		14,920	0.7	No damage
	Bolted	4,010	5	Increase in damage resulting from Shot 9
		9,110	1	No damage

* All tanks in Shot 9 were filled with water to a depth of 7 feet.

† All tanks in Shot 10 were empty.

‡ Located in region of precursor action.

For purposes of the present test, it was desired to locate one welded tank in a region where light damage was anticipated. In Shot 9, no damage to a 70-percent filled tank was observed at a minimum distance of 1,995 feet, so it was apparent that heavier loading conditions are required for light damage. It is, of course, not possible to determine the precise increase in loading required to produce light damage. In this test assuming no precursor, similar loading conditions for which no damage should occur would be expected at approximately 2,300 feet. Damage to empty tanks is not indicative of damage to be expected for filled tanks; therefore, the Upshot-Knothole Shot 10 results are not applicable. One of the two filled bolted tanks tested in Upshot-Knothole Shot 9 received light damage at 3,560 feet; the other tank at a greater distance was undamaged. These observations provide a limiting distance for light damage to a filled bolted tank in the absence of a precursor, but furnish little guidance for locating such a tank for the severe damage desired in the present test.

Chapter 3

PROCEDURE

Four petroleum storage tanks which had remained substantially undamaged during Project 3.26.1, Upshot-Knothole, were used for this test. The tanks, which remained at the Nevada Test Site, were simply relocated for this project. Since only the response of the tank shells was of interest, it was not considered essential to restore the roofs of the tanks. All the tanks for this test were 80-percent filled with water. During Upshot-Knothole, a total of six tanks, four welded steel tanks and two bolted steel tanks of standard Army design, were tested on both Shots 9 and 10. On Shot 9 the tanks contained 7 feet of water; on Shot 10 the tanks were empty. The results of these tests were discussed briefly in Section 2.4.2. For details of these tests, see Reference 1. It was decided to make use of the existing undamaged tanks to obtain as much information as possible with minimum expense. Obviously, more-complete response data could be obtained by testing tanks of different sizes and wall thicknesses, but such tanks were not readily available.

3.1 GROUND RANGES

In locating the four tanks for this project, it was necessary to consider the damage desired for each tank. As previously stated in Section 2.4.1, it was desired to place all the tanks at ranges where damage would occur. Since light damage to a filled bolted tank had been obtained in Upshot-Knothole, it was desired in this test to obtain information about severe damage to such a tank. For the three filled welded tanks, it was desired to obtain a gradation of damage, with certainty of severe damage to at least one.

Using the results of the prior tests and the analytical approximations, it was possible to designate locations for the tanks in this test. It should be understood that this positioning represents only an estimate based on the approximate methods of analysis, limited experimental results, and an estimate of the anticipated loading. These studies furnished the information by means of which the tank locations were selected. Details of these considerations are given in Section 2.4.2. It was estimated that the inception of overturning would occur at a distance of approximately 1,000 feet from ground zero. Since the nearest filled tank to ground zero in Operation Upshot-Knothole, located at 1,995 feet, sustained no damage from a high-burst device, and since the empty tank, located at 1,640 feet, was completely demolished from the effects associated with the precursor of a low-burst device, it seemed logical to expect that a filled tank would sustain no damage at a distance of 2,300 feet from the proposed low-burst weapon, at which range the precursor effects would have terminated. It was expected that initiation of rigid-body sliding of the tanks would occur at distances less than 1,300 to 1,600 feet from ground zero.

Based on these estimates of limiting ranges, it was possible to locate the tanks where the desired damage was expected. For the bolted tank, where severe damage was desired, a range of 1,200 feet was selected. At this location several feet of rigid-body sliding without or prior to overturning was anticipated. Severe distortion and rupture of the tank shell also were expected. The locations selected for the three

welded tanks were at ranges of 1,350, 1,500, and 2,100 feet. The two closest locations were selected for the purpose of obtaining severe damage or at least moderate damage. In these locations a small amount of rigid-body sliding, without overturning was anticipated. Severe distortion and rupture of these tanks also were expected. The location of the third welded tank at 2,100-foot range was selected to obtain light damage. It was anticipated that light damage would occur at 200 feet less than the 2,300-foot range at which no damage would be expected. Table 3.1 shows these distances together with an identification symbol for the tank at each ground range.

TABLE 3.1 SUMMARY OF TANK DIMENSIONS, LOCATIONS, AND DYNAMIC PRESSURE, TEAPOT

Item	Identification	Height*	Diameter	Ground Range †	AFSWP‡ Predicted Dynamic Pressure	Observed Peak Dynamic Pressure
		feet	feet	feet		
3.9a-1	Bolted Steel Tank	8	15.5	1,200	190	200
3.9b-1	Welded Steel Tank	10	15.0	1,350	115	125
3.9b-2	Welded Steel Tank	10	15.0	1,500	75	90
3.9b-3	Welded Steel Tank	10	15.0	2,100	20	30

* All tanks were 80 percent filled with water.

† Tanks were located on the desert sector only.

‡ Taken from letter, "Estimated Free Field Effects Parameters for Met Shot", 26 October 1954, Headquarters, Field Command, Armed Forces Special Weapons Project.

§ Taken from Summary Report of the Technical Director, Programs 1-9, ITR-1153.

3.2 CONSTRUCTION

3.2.1 Welded Tanks. The tanks were originally completed with roofs. They measured 15 feet in diameter by 10 feet in height. For this project, only the sides and bottom were used. Both the sides and bottom were of $\frac{1}{4}$ -inch welded steel plate. All joints were butt-welded. No special foundations were used; the sites were graded smooth and the tanks were placed on the desert surface. No restraints were used. A preshot photograph of one of these tanks is given in Figure 3.1. These tanks were filled with water up to a height of 8 feet.

3.2.2 Bolted Tank. This tank was a standard Army storage tank, of bolted construction, 15.5 feet in diameter and 8 feet high. The tank was set in place without special foundations in the same way as the welded tanks, and was filled with water up to a height of approximately $6\frac{1}{2}$ feet. A preshot photograph of this tank is given in Figure 3.2.

3.3 PHOTOGRAPHY

No motion-picture photography was employed during the tests. Photographic observations were limited to still photographs before and after the tests.

3.4 INSTRUMENTATION

No instrumentation was used on the tanks themselves. It was expected that the actual overpressures and dynamic pressures with directional components would be available from Program 1 basic blast measurements.

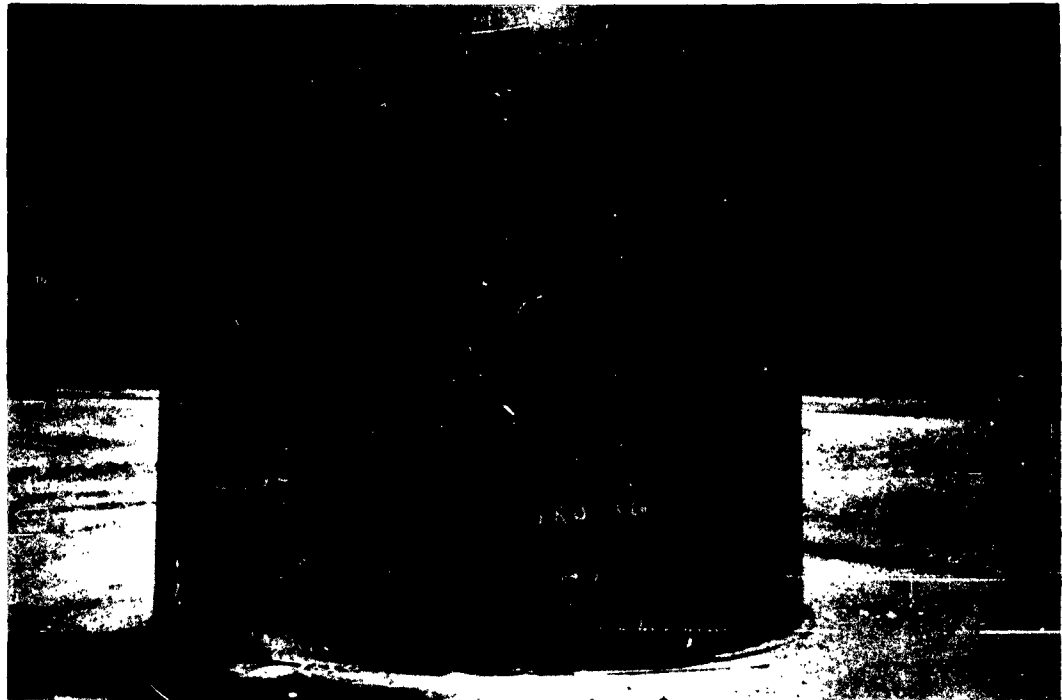


Figure 3.1 Typical view of 3.9b tank, preshot.

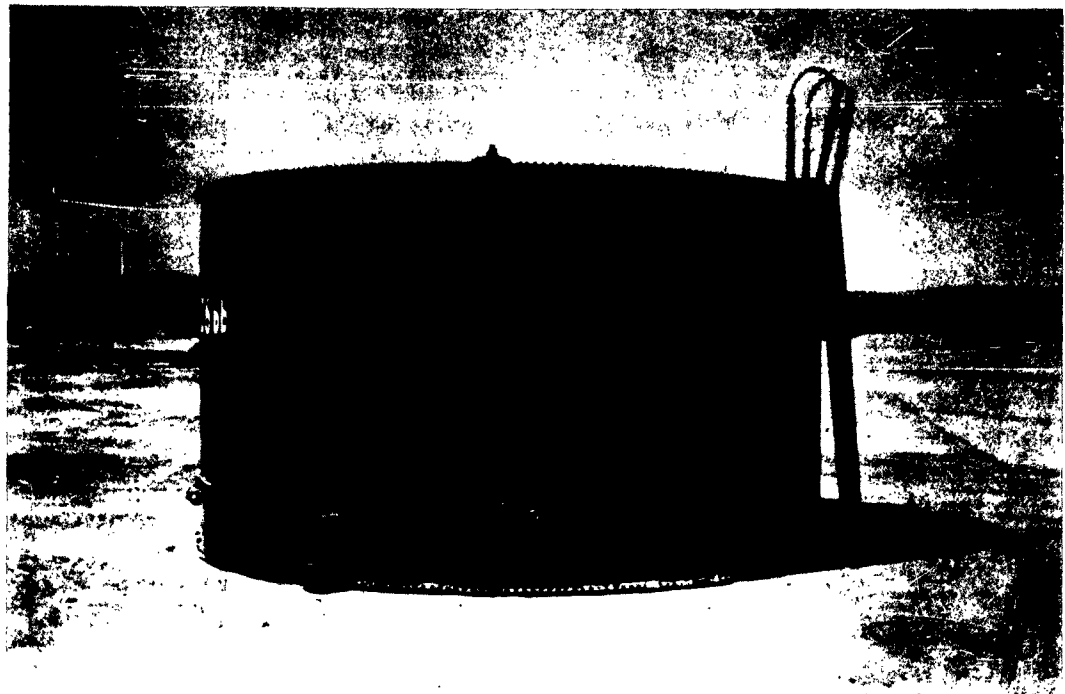


Figure 3.2 Typical view of 3.9a-1 tank, preshot.

Chapter 4

RESULTS

All four tanks received extensive damage in this test. A detailed description of the damage to each tank is contained in the following sections. As a result of Shot 9, Upshot-Knothole, the model roofs on the three welded tanks collapsed into the tanks in the form of debris. This debris was not removed but remained within these tanks during the re-test at Teapot. By observing the locations where the ground furrowed, where the roof debris landed, and where the water puddled, the order and manner of tank response could be traced. The roof debris provided corroborative evidence for ascertaining where, during the tank motion, the loss of contents occurred.

4.1 BOLTED TANK, 3.9a-1

One bolted tank, with roof intact, was located at a distance of 1,200 feet from ground zero in a predicted high-pressure region where severe damage was expected. The blast force tore out the base-ring bolts at about the same time that the siding bolts failed. This released the water; the roof tore loose at the fastenings and was carried 390 feet downrange from ground zero. The tank bottom remained in place; the wall was flattened on the ground immediately adjacent to the bottom with a minor portion of it still attached. In this instance, structural failure occurred before the tank could respond as a rigid body (see Figure 4.1).

This is an example of the type of failure sought in the second objective—failure of shell without rigid-body motion. The tank was demolished. It is not possible from this test alone to estimate the maximum distance at which severe damage to bolted tanks would have been obtained.

4.2 WELDED TANK, 3.9b-1

The nearest of the three welded tanks was located at 1,350 feet from ground zero in a region where severe damage was expected. The blast force tore the wall loose from the base and folded up the sides of the tank bottom. The wall of the tank although severely distorted, remained in one piece and was blown approximately 165 feet downrange from ground zero. The tank may have slid a few feet before the walls were torn loose; the tank bottom and old roof debris were found 20 feet obliquely from the original location. The contents were released on or near the original location (see Figure 4.2).

This constitutes another example of the second objective, failure of the shell without rigid-body motion. Moreover, this experience probably demonstrates the onset of the third objective, the region for sliding and possible overturning.

4.3 WELDED TANK, 3.9b-2

The second welded tank was located at a distance of 1,500 feet from ground zero in a region where severe or at least moderate damage was expected. The tank slid about 10 feet as a rigid body, pushed up a pile of dirt, and overturned; the wall-to-base connection was partially torn. The water and old roof debris were released over a



Figure 4.1 Postshot view of 3.9a-1, 1,200 feet (looking away from ground zero).



Figure 4.2 Postshot view of 3.9b-1, 1,350 feet (looking toward ground zero).

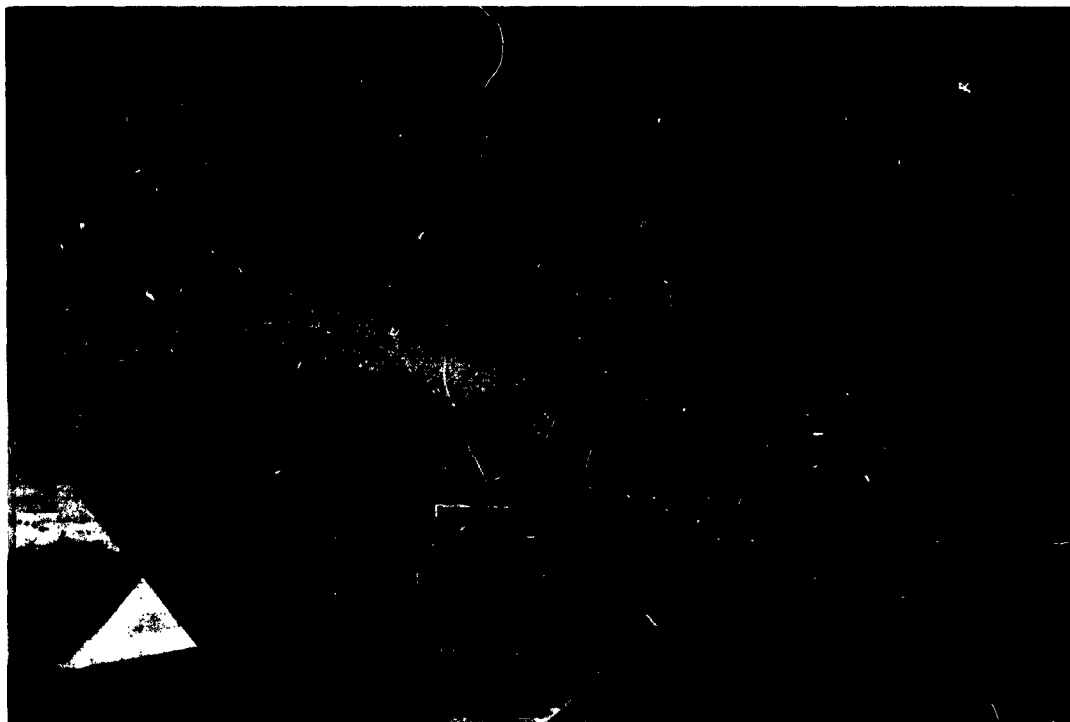


Figure 4.3 Postshot view of 3.9b-2, 1,500 feet (looking away from ground zero).

50-foot distance where the tank struck the ground. The empty shell (wall and bottom) was then carried approximately 160 feet downrange from ground zero. The shell was severely distorted and the metal was torn throughout a large portion of the wall-to-base connection (see Figure 4.3).

This is an incident illustrative of the type of damage sought in the third objective, to determine in what pressure region these tanks would slide, possibly overturn, and rupture.

4.4 WELDED TANK, 3.9b-3

The third welded tank was located at a distance of 2,100 feet from ground zero in a region where light damage was expected. The tank slid about 7 feet, pushed up a pile of dirt, and overturned about this point, rotating about three-quarters of a revolution. Marks on the ground indicated that the top portion of the side away from ground zero struck the ground during rotation. The tank came to rest 45 feet from its original position, and was resting on that side which originally faced ground zero. Damage to the tank consisted of crushing of the side which faced ground zero, with minor distortion of the remainder of the wall. The bottom of the tank was slightly bulged outward. It appeared that the tank, despite the distortion, would be water tight. Contents of the tank were lost during the rotation of the tank (see Figure 4.4).

At this 2,100-foot position, it was anticipated that the fourth objective would be demonstrated, i. e. tank sliding without either overturning or rupture, but with sufficient force to rupture pipe connections and thereby cause loss of contents. While the rigid-body response obtained was greater than sought, a check point of considerable

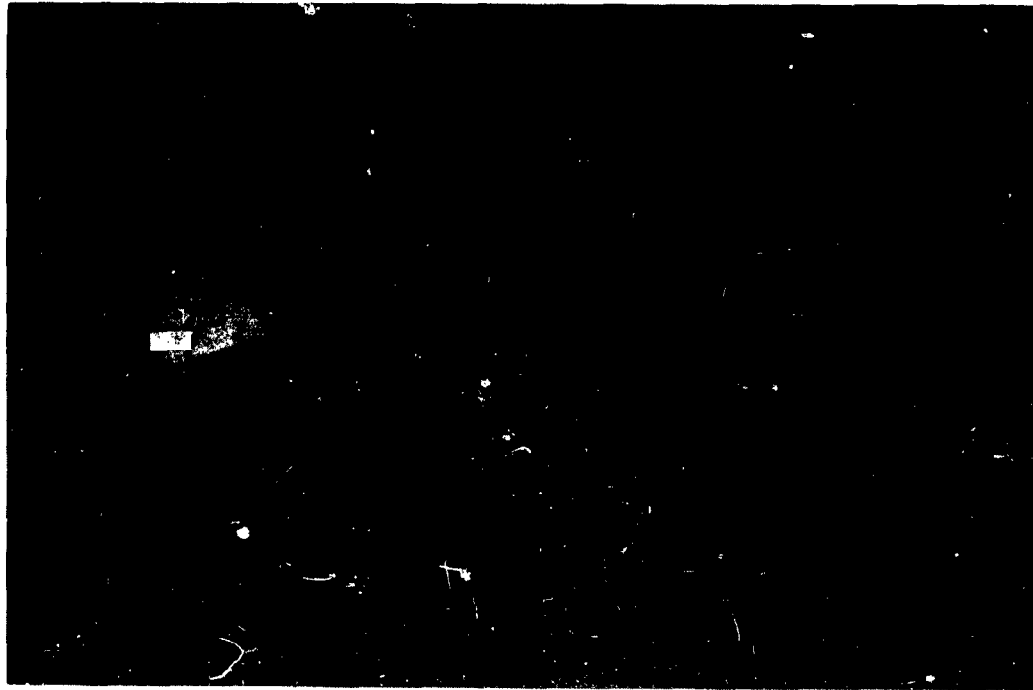


Figure 4.4 Postshot view of 3.9b-3, 2,100 feet (ground zero to right).

value was established for target analysis of small tanks. This damage incident disclosed that it is possible to overturn a small tank and spill the entire contents without destroying the utility of the tank. This is believed to be impossible in the case of large tanks. In this test there were no pipe connections. Had the tank tested been realistically connected with piping, additional restraint would have been provided, tending to reduce sliding and, therefore, overturning.

Chapter 5

DISCUSSION

Although damage at all ranges was generally more extensive than expected, a considerable amount of useful information has been obtained from this test for target analysis purposes. In fact, the tanks at the two closer ranges (1,200 and 1,350 feet) demonstrated the type of damage one would expect in large tanks, i. e. rupture of the shell directly by blast rather than by rigid-body motion.

The welded tank at 1,500 feet provided a pattern of response for that region in which rigid-body motion of small tanks, with associated rupturing, can be expected to occur. Fundamentally, such response holds considerable target interest for small storage tanks because the usefulness of the tanks, as well as the contents, is destroyed.

The response of the welded tank at 2,100 feet indicated that it was a little closer to ground zero than the region in which simple sliding without overturning or rupturing would have occurred. Since the precursor effect probably did not exist much beyond 2,500 feet from ground zero, the pressures there probably were less than those required for simple sliding. Small tanks probably would have been overturned, or at least would have slid sufficiently to break pipe connections and cause complete loss of contents to a distance of about 2,300 feet. The tanks at 1,500 and 2,100 feet bracketed the region where a small filled tank would be overturned and destroyed under the test conditions.

As previously indicated, almost nothing was known prior to this test about the kind of response one could expect at any given distance. There were, moreover, no data available which could serve as a basis for predicting rupture of the shells of small tanks. Finally, there were no data available upon which to base a prediction of sliding and overturning, with or without rupture occurring. In the light of these facts, it is believed that the test was of some success and will be useful as a source of data on small tanks.

Recent calculations have shown that the pressure ranges at which overturning and sliding would be predicted will vary considerably depending upon the assumed values for coefficients of drag and friction. The loading and response considerations which led to the placement of the tanks in this test were based upon values for drag and dynamic friction coefficients which have been assumed, due to the small amount of guidance which was available to permit accurate choice of these values.

It is of interest to note that overturning analyses carried out on the welded tank at 2,100 feet employing the post-test value of the dynamic pressure (42 psi) obtained from the 10-foot high q-gage, indicate that no overturning should be expected from a drag coefficient of 0.35 and for the same approximations as to the magnitude of the vertical loads. Actually, a dynamic pressure of approximately 60 psi would have been required to cause incipient overturning under the conditions cited.

Chapter 6

CONCLUSIONS

Although a paucity of data on large tanks still exists, there is now available a limited test of damage to small filled tanks. At least under Nevada soil conditions and the weapon size and height of burst employed, the following are known: (1) a combination of overpressure and drag pressure which will rupture filled tanks of this size and shell thickness, without rigid-body motion; (2) a combination of overpressure and drag pressure which will cause sliding, overturning, and rupturing of such tanks; and (3) the region in which such tanks would slide without overturning or rupturing but with sufficient force to break pipe connections and cause loss of contents. It should be possible to correlate the observed damage and basic field data with such theories of plastic response as may be developed in the future and to design a successful test experiment of large tanks, using thorough instrumentation and motion picture photography.

Pending results of tests of large tanks, it will be possible to make only rough estimates of pressures required for rupturing the walls of such tanks. The desired objectives on response of liquid storage tanks only partially attained in Project 3.26.1, Upshot-Knothole have now been explored to the limited extent possible using small tanks.

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