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WT-1631 W)/21 / 1 OPERATION HARDTACK-PROJECT 37

DAMAGE 10 EXISTING EPG STRUCTURES (U)

W.J. Flathau, Project Officer and R.A. Cameron,

> (b) U.S. Army Engineer Waterways Experiment Station, Vicksburg, Missinghai

> > and

Holmes and Navver, Incorporated Los Angeles, California

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FOREWORD

This report presents the final results of one of the projects participating in the military-effects programs of Operation Hardtack. Overall information about this and the other military-effects projects can be obtained from ITR-1660, the "Summary Report of the Commander, Task Unit 3." This technical summary includes: (1) tables listing each detonation with its yield, type, environment, meteorological conditions, etc.; (2) maps showing shot locations; (3) discussion of results by programs; (4) summaries of objectives, procedures, results, etc., for all projects; and (5) a listing of project reports for the military-effects programs.

ABSTRACT

The purpose of this project was to document indevaluate the effects of blast forces, radiation, and water waves resulting from nuclear explosions on various support-type structures and previously exposed test structures located on the various islands of the Eniwetok Proving Ground. The major effort of the project, a joint Waterways Experiment Station and Hornes and Narver, Inc., effort, was concentrated on the early shots which were expected to yield the most significant information for this project. To cover any supplementary information from the later shots, because the project was to be a minimum effort of funds and personnel, arrangements were made with Holmes and Narver, Inc., for the project to receive appropriate additional data from the later shots from the damage survey normally conducted by that organization in the field. This report contains the general effects data for the stations investigated from all the shots of concern to this project.

No electronic recording was utilized; however, self-recording measurements of air overpressure and acceleration were made at several stations, along with some measurements of erosion due to water waves. The damage surveys were performed by visual inspection, photographs, and level surveys.

The curve used for predicting air overpressure, the most important parameter in determining blast damage, proved to be reliable. Observed pressure data obtained during this operation correlated well with the prediction curve, which was based on data obtained from previous operations.

The curve used for predicting acceleration for floor slabs of structures appears to give reasonable values. However, limited data was obtained, and the over-all reliability of the prediction curve is uncertain.

It was found that the path-of-least-resistance method for predicting radiation within structures proved adequate. The slant-thickness method did not give realistic values.

No structural damage was observed which was attributable to thermal radiation. Steel was observed for exposures up to 1,400 cal/cm²; concrete surfaces showed minor spalling at 650 cal/cm².

Structural damage, due to water waves, may be neglected for close-in structures designed to withstand air blast. At greater distances, where air blast is of no great consequence, water waves must be considered in structural planning.

Damage to camps (light, wood-frame type construction) was investigated. The damage data compared with and amplified the data contained in TM 23-200 (Reference 8) pertaining to wood-frame structures. Damage to antennas and radar reflectors correlated well with data in the referenced manual also. The curve of Reference 8 for predicting damage to three-story, blast-resistant buildings is also adequate.

Reinforcing steel in roofs of biast-resistant structures should be designed to provide more uniformity of strength. Positive reinforcement should be continuous extending over supports; at least one-half of the negative steel should be carried beyond the point of inflection a sufficient distance to develop the allowable stress in such bars or a distance equal to the depth of the member, whichever distance is greater.

A ground-surface 21,060-galion water tank of $\frac{1}{6}$ -inch bolted steel plate, 3 feet high and 22 feet in diameter, suffered only light damage when exposed to pressures of 6.5 and 7.0 psi.

Heavily reinforced-concrete, earth-mounded structures (walls and roofs 5 to 6 feet thick with spans up to 5 feet) survived air overpressures up to 1,000 psi.

Objects located close behind earth mounds within a distance approximately equal to the height

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of the mound received considerable protection from dynamic pressures at overpressures of 35 psi and lower.

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Exposed standard 2-inch and 4-inch water pipes, including standard rising-stem valves, survived pressures up to 8 psi without any sign of damage.

The method used for predicting pressures at a zero angle of incidence on the front and rear faces of diffraction-type targets is satisfactory for both design and analysis purposes. At angles of incidence greater than zero however, the method is satisfactory for design purposes only. The predicted shape of overpressure-time curves for the roof of diffraction-type targets was not in close agreement with measured results.



PREFACE

This project was a joint, coordinated effort between the U.S. Army Ergineer Watei ways Experiment Station (WES), Vicksburg, Mississippi, and Holmes and Narver, Inc. (H&N), Engineers and Constructors, Los Angeles, Catuornia. This joint venture was made possible by the efforts of personnel from both the Armed Forces Special Weapons Project (AFSWP), and the Atomic Energy Commission (AEC). For WES, the project was under the general direction of E. P. Fortson, Jr., F.R. Brown, and G.L. Arbuthnot, Jr., with W.J. Flathau designated as the project officer. For H&N, the project was under the general direction of R. R. Alvy and S. B. Smith, with R.A. Cameron designated as the assistant project officer. Special recognition is given to Cupt. E.S. Townsley, of WES, who prepared the appendix on radiation. Also contributing to this project were Sp2 R. P. Andrew, Pfc. C. W. Denzel, and Pfc. D. G. Brown, of WES. The cooperation received from personnel of the Los Alamos Scientific Laboratory (LASL), the University of California Radiation Laboratory (UCRL), the Stanford Research Institute (SRI), and the Ballistic Research Laborator-ies (BRL) greatly assisted this project in meeting its objective.

CONTENTS

FOREWORD	4
ABSTRACT	5
DEFACE	
PREFACT STATES	7
CHAPTER 1 INTRODUCTION	19
1.1 Objective	10
1.2 Background	19
1.2.1 Previous Damage Surveys	19
1.2.2 Conclusions from ivy Damage Survey (1952)	21
1.2.3 Conclusions from Castle Damage Survey (1954)	27
CHAPTER 2 PROCEDURE	28
2.1 Shot Participation	28
2.2 Instrumentation	28
2.3 Data Requirements	30
	•••
CHAPTER 3 RESULTS: BIKINI ATOLL	33
3.1 Site Able	
3.1.1 Item 1. Station 1341. Castle	33
3.1.2 Item 2. Station #80.01. Redwing	20
3.1.3 Item 3, Stations 152.01 and 153.01, Redwing	90
3.1.4 Item 4, Station 1519, Redwing	44
3.2 Site Charlie	44
3.2.1 Item 5, Station 78.01, 1319 Redwing	44
3.2.2 Item 6, Station 1200, Castle	44
3.3 Sites Fux and George	44
3.3.1 Items 7, 8, and 9, Stations 2410.01,02, and03	48
3.3.2 Item 10, Stations 50.01,02,03,04,05, and06	48
3.3.3 Item 11, Station 1810, 1830 Redwing	54
3.4 Sites Sugar and Tare	54
3.4.1 Item 12, Stations 2200 and 2250	55
3.4.2 Rem 13, Station 2210	57
9.4.4 Year 15 Settion 0090 01	57
3.4.5 Here 16 Station 2230.02	64
3 4 6 Iten 17 Station 630 01	64
	64
CHAPTER 4 RESULTS: ENIWETOK ATOLL	65
4.1 Sites Gene, Helen, and Irene	85
4.1.1 Item 18, Station Complex	85
4.1.2 Item 19, Station 1525	65
4 ?. Item 20, Station 1311	75
4.1.4 Item 21, Stations 1211 and 1410	76

9

4.1.5 Item 22, Station 3.4, Castle 83
4.1.6 Itom 23, Generators 83
4.1.7 Item 24, Helicopter Pad 86
4.2 Site Janet
4.2.1 Item 25, Station 1312 86
4.2.2 Item 26, Station 3.1.1, Greenhouse 88
4.2.3 Item 27, Station 3.1.3, Greenhouse 101
4.2.4 Item 28, Stations 20A, B, C, D, E and F, Greenhouse
4.2.5 Item 29, Station 77.02 110
4.2.6 Item 30, Landing Pier 110
4.2.7 Camp 110
4.3 Site Yvonne 114
4.3.1 Item 31, Station 1130 114
4.3.2 Item 32, Station 1220.01 119
4.3.3 Item 33, Station 1216 119
4.3.4 Item 34, Station 1612 119
4.3.5 Item 35, Stations 1523.01 to 1523.04
4.3.6 Item 36, Station 1310 119
4.3.7 Item 37, Water Tank 119
4.3.8 Yvonne Camp 128
CHAPTER 5 DISCUSSION133
5.1 Prediction Curves 133
5.1.1 Air Overpressure 133
5.1.2 Floor-Slab Acceleration 133
5.2 Radiation and Water Waves 133
5.2.1 Nuclear Radiation 133
5.2.2 Thermal Radiation Damage 133
5.2.3 Water Waves 135
5.3 Damage-Distance Relationships 135
5.3.1 Camp and Wood-Frame Structures 135
5.3.2 Storage Tanks 135
5.3.3 Station 3.1.1 (Item 26, Three-story Blast-Resistant Buildings) 137
5.3.4 Station 1312 (Item 25, One-slory, Reinforced-Concrete Building)138
5.3.5 Gage Piers (Item 28) 138
5.3.6 Miscellaneous Damage138
CHAPTER 8 CONCLUSIONS AND RECOMMENDATIONS 139
6.1 Conclusions139
6.2 Recommendations140
APPENDIX A NUCLEAR RADIATION
A.1 Introduction141
A.2 Theory of Radiation141
A.3 Structural Shielding141
A.4 Prediction Methods142
A.4.1 Slant Thickness142
A.4.2 Path of Least Resistance142
A.5 Results
A.5.1 Station 560.01 (Item 2)142
A.5.2 Station To.01
A 5.3 Statio Complex and a second sec

1

SECRET

A.5.4 Station 3.4
A.7 Recommendations
APPENDIX B DIFFRACTION LOADING OF STATION 1312146
B.1 Prediction Methods
B.2 Results and Discussion 146
B.3 Conclusions146
APPENDIX C RESPONSE OF GAGE PIERS TO BLAST LOADS 152
C.1 Structural Analysis Using Design Strengths
C.2 Behavior of Concrete Section Under Dynamic Loads
C.2.1 Flexural Behavior at Yield
C.3.2 Flexural Behavior at Ultimate
C.4.3 Moment-Curvature Relation
C.4.1 Shear-Compression mode
C.5 Dynamic Analysis
C.3.2 Natural Pariod of Vibration
C 3 3 Durami C 1104 01 Viola (14)
C 4 Discussion and Conclusions
C.5 Notations
APPENDIX D WATER-WAVE DAMAGE165
D.1 Introduction
D.2 Dackground165
D.2.1 Operation Castlesson 165
D.2.2 Operation Redwing165
D.3 Theory.
D.4 wave Damage in Operation Hardlack
D.S. Discussion and Recommendations
REFERENCES
FIGURES
1.1 Shot geometry with pressure contours for Bikini Atoli,
Operation Castle 20
1.2 Shot geometry with pressure contours for Eniwetok Atoll,
Operation Castle 20
1.3 Shot geometry with pressure contours for Bikini Atoll,
Operation Heaving
1.4 Shot geometry with pressure contours for Entwetok Atoli,
Uperation Kedwing
2.1 General plan and shot geometry for Sukini Atoli
2.2 General plan and shot geometry for Entwetok Atoli
4.0 Frank air Ovyrpressure for surface bursts
2.5. Positive-plase utration for a t-st outrat burst
envioue tor a left surface hurst store with a surface for a left surface hurst 31
3.1 Control of a serie contours for Site Able 36
3.2 Extent of inundation on Site Able after Shot Sycamore 37

* -

ALL ALL MARTIN A

11

3.3 Post-FirSycamoreAspen. and -tledar. (Item 1)
Station 1341 on Site Able, no additional damage 37
3.4 Post-Poular. (Item 1) Station 1341
3.5 Plan and elevation including film badge locations for
(Ite., 2) Station 560.01, Site Able
3.6 Preshot, (Item 2) Station 560.01, Site Able 40
3.7 Preshot, (Item 2) Station 560.01 including parth berm, Site Able 40
3.8 Post-Fir, (Item 2) Station 560.01 41
3.9 Post-Fir, (Item 2) Station 560.01 including earth berm 41
3.10 Ground-surface profile between (Item 2) Station 560.01 and
(Item 4) Station 1519 42
3.11 Post-Poplar, (Item 2) Station 560.01, complete destruction of station 43
3.12 Post-Fir, (Item 3) Stations 152.01 and 153.01 43
3.13 Post-Poplar, (Item 3) Stations 152.01 and 153.01
3.14 Post-Fir, (Item 4) Station 1519 45
3.15 Shot geometry with pressure contours for Site Charlie 46
3.16 Post-Fir, Site Charlie, extent of inundation 47
3.17 Preshot, steel tower on Site Charlie 47
3.18 Plan including accelerometer and film badge locations
for (Item 5) Station 78.01, Site Charlie, Redwing
Station 1319 48
3.19 Preshot, (Rem 5) Station 78.01, Site Charite
3.20 Post-Fir, (Rem 5) Station 75.1
3.21 Post-Poplar, (Rem 5) Station 78.01
3.42 Presnot, (item 6) Station 1200, Site Charite looking
IOWARG SUFIECE SSTO
3.43 Post-Fir, (item 0) Station 1600
and Geowre and a second and a second and a second and a second a s
3 25 Dreshot (Item 8) Station 2410.02 Site For
3.26 Post Manie (Item 8) Station 2410 02
3.27 Plan and elevation for wave stations (Item 10)
Stations 50.01 through 50.05
3.28 Preshot. (Item 10) Stations 50.0102. and03. Site Fox 54
5.29(a) Post-Maple. (Item 10) Stations 50.0102. and0354
3.29(b) Post-Maple, (liem 10) Station 50.03
3.29(c) Post-Redwood, (Item 10) Station 50.03 55
3.30 Preshot, (Item 11) Station 1810, Site George 57
3.31 Post-Maple, (Item 11) Station 1810 57
3.32 Shot geometry with pressure contours for Sites Tare and Sugar 58
3.33 Post-Nutmeg, general view of Sites Sugar and Tare 59
3.34 Freshot view of timber bulkhead and sand bags at west end of
Site Tare 60
3.35 Post-Nutmeg view of timber bulkhead and bags at west
end of Site Tare 60
3.36 Fost-Juniper view of east end of Site Tare looking toward
surface zero 61
3.37 Post-Nutmeg, (Item 12) Stations 2200 and 2250 61
3.38 Presnot, (Item 13) Station 2210, Site Tare, prior to being
covered with sand
J.J. Fresnot, (Rems 14, 15, and 16) Stations 2270, 2230.01,
4450.12, Site Tare, prior to being covered with sand 62
o.no Posters. meg, (items 15 and 16) Stations 2230.01 and 2230.02 63

「大学に、大学に理事」といいたというなど、してなない、どれなど、「たちない」であるというであるとなっていましょう。

.

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÷

.

12

3.41	Plan and elevation including the location of self-recording	
••••	acc competents for (Item 16) Station 2230 02 Site Tare	63
3 42	Dost- 'strager (Item 16) Station 2230 02, aloge-up of demaged	
0,12	42 inche sommented metal nine	R 4
A 1 6	the mean with mean pipe and station locations for	01
7.1 0	Sites Owner Malay and Isone	70
4.9. 1	Sites Gene, Helen, and Irene	71
4.2 1	Ost-Koa, typical impact crater, 4,800 feet from ground z'.ro	11
4.3 1	lan of station complex on Site Irene	14
4.4 1	reshot, (Item 18) station complex, close-up of entrance and	
	crack in wing wall, Site Irene	72
4.5 E	ost-Yellowwood, (Item 18) station complex, close-up of	
	entrance and cracked wing wall	73
4.6 I	Post-Walnut, (Item 18) station complex, close-up of wing	
	wall failure	73
4.7 I	Plan and elevations for (Item 19) Station 1525, Site Irene	74
4.8 I	Preshot, (Item 19) Station 1525, Site Irene	75
4.9 1	Post-Koa, (Item 19) Station 1525, face-on view	75
4.10	Post-Koa, (Item 19) Station 1525, side-on view	76
4.11	Post-Walnut, (Item 19) Station 1525, retaining wall failure	76
4.12	Pian and elevations for (Item 20) Station 1311, Site Irene	77
4.13	Preshot. (Item 20) Station 1311, face-on view of retaining wall.	
	Site Irene	78
4.14	Post-Koa. (Item 20) Station 1311, face-on view of retaining wall	78
4.15	Post-Walnut, (Item 20) Station 1311, face-on view of retaining	
		79
4 16	Dreshot (Item 20) Station 1311 entrance Site Irene	79
4 17	Poet-Kog (Item 20) Station 1311 entrance, Site Hene Cooperstance	80
4 19	Dost-Kon (itom 20) Station 1911, 24 inch steel nings nushed	00
1.10	invest 2 ¹ / inches	80
4 10	Deck Kee (New 20) Station 1211 erect wattons in floor	01
4.19	Post-Kos, (item 20) Station 1311, Crack pattern in Hoor	01
4.40	Freshol, (Item 21) Stations 1211 and 1410, view of side wall	01
4 01	Tacing surface zero, Sile frene	01
4.21	Post-walnut, (item 21) Stations 1211 and 1410, view of exposed	0.0
	Side wall	82
4.22	Preshot, pipeline to ground zero, Site Irene	82
4.23	Post-Koa, pipeline to ground zero	82
4.24	Plan including film badge locations for (Item 22) Station 3.4,	
	Site Irene	84
4.25	Preshot, (Item 22) Station 3.4, side view, Site Irene	85
4.26	Post-Walnut, (Item 22) Station 3.4, side view showing scouring	
	action of water wave; dark area represents original earth	
	cover contact area	85
4.27	Preshot, (Item 25) generators, Sile Irene	85
4.28	Post-Koa (Item 23) generators	87
4.29	Post-Koa, (Item 23) close-up of damaged generator	87
4.30	Post-Koa, (Item 24) helicopter pad	88
4.31	Shot geometry with pressure contours for Site Janet	89
4.32	Plan including locations for air-overpressure gages and	
	accelerometers for (Item 25) Station 1312, Site Janet	90
4.33	Post-Walnut. (Item 25) Station 1312, erosion adjacent to	
	foundation	91
4.34	Over-all perspective for (Item 26) Station 3.1.1. Site Janet	91
4.35	Preshot. (Item 26) Station 3.1.1. Site Janet	92
		_

LAND THE REAL

「「「「ない」という。

13

4.36	Preshot, (Item 26) Station 3.1.1, Column 13C, concrete
4 37	Preshot (Item 26) Station 3.1.1. crack in calling adjacent to
4.07	Column Line 10 of the shear wall building looking away
	from surface zero. Site Janet 93
4.38	Preshot. (Item 26) Station 3.1.1. crack in ceiling adjacent to
	north wall of the shear-wall building looking away from
	from surface zero, Site Janet 93
4.39	Post-Yellowwood, (Item 26) Station 3.1.1 93
4.40	Post-Walnut, (Item 26) Station 3.1.1 95
4,41	Post-Walnut, (Item 26) Station 3.1.1, aerial view 95
4.42	Post-Walnut, (Item 26) Station 3.1.1, close-up of Building 5,
	a reinforced-concrete frame structure 95
4.43	Post-Walnut, (Item 26) Station 3.1.1, front column of Building 5 96
4.44	Post-Walnut, (Item 26) Station 3.1.1, second row of columns of
	Building 5
4.45	Post-Walnut, (Item 26) Station 3.1.1, third row of columns of
	Building 5
4,46	Post-Walnut, (Item 26) Station 3.1.1, Column 13C, second
	floor of Building 5 98
4,47	Post-walnut, (Item 26) Station 3.1.1, Column 8A, Inird
4 40	1100F OI Building 3
4.40	floor of Building 3
4 49	Poet-Walnut (Itam 26) Station 3.1.1 Column 5C first
1.10	floor of Building 2
4.50	Post-Walnut, (Item 26) Station 3.1.1, roof slab damage,
	Building 6 100
4.51	Post-Walnut, (Item 26) Station 3.1.1, crack in ceiling adjacent
	to Column Line 10 of the shear-wall building looking away
	from surface zero100
4.52	Post-Walnut, (Item 26) Station 3.1.1, crack in ceiling adjacent
	to north wall of shear-wall building looking away from
	surface zero102
4.53	Post-Elder, (Item 26) Station 3.1.1, front view
4.54	Post-Elder, (Item 26) Station 3.1.1, rear view
4.00	Post-Elder, (item 20) Station 3.1.1, close-up of Building 5,
4 58	Dest Elder (Item 28) Station 3.1.1. close_up of Buildings 1
4.50	2 and 3104
4.57	Post-Elder. (Item 26) Station 3.1.1. Columns 7 and 8B. first
1.01	floor of Building 3104
4.58	Post-Elder. (Item 26) Station 3.1.1. Columns 7 and 8B,
	second floor of Building 3
4.59	Post-Elder, (Ilem 26) Station 3.1.1, Columns 7 and 8B,
	third floor of Building 3105
4.60	Post-Elder, (Item 26) Station 3.1.1. Column 8D and crack
	in rear wall, first floor of Building 3 106
4.61	Post-Elder, (Item 26) Station 3.1.1, destroyed roof section
	of Building 6 and damaged area to roof at south end of
4 00	Building 4
4,62	Post-Elder, (Rom 20) Station 3.1.1, outside view of punched-in
	Tool Becare at north end of Building 4

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第二十二

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「「「「「「「「」」」」」

4.63	Post-Elder, (Item 26) Station 3.1.1, inside view of punched-in	
	roof section, north end of Building 4	- 107
4.64	Post-Elder, (Item 26) Station 3.1.1, close-up of punched-in	
	roof section, north end of Building 4	- 107
4.65	Post-Dogwood, -Olive, and -Pine, (Item 26) Station 3.1.1,	
	aerial view	- 108
4.66	Post-Dogwood, -Olive, and -Pine, (Item 26) Station 3.1.1,	
	underside of third floor along Column Line 11, and the	
	front wall facing surface zero	- 108
4.67	Post-Dogwood, -Olive, and -Pine, (Item 26) Station 3.1.1,	
	crack in third floor at intersection of front wall between	
	Column Line 11 and south shear wall	- 109
4.68	Post-Walnut, (Item 27) Station 3.1.3, entrance filled with mud	- 109
4.69	Structural details and elevation views of (Item 28) Stations 20A,	
	B, C, D, E, and F, Site Janet	- 110
4.70	Preshot, (Item 28) Station 20B, view of gage pier facing	
	surface zero, Site Janet	- 111
4.71	Post-Walnut, (Item 28) Station 20B, view of toppled gage pier	- 111
4.72	Postshot, (Item 29) Station 77.02, recording station	- 112
4.73	Preshot, (Item 30) landing pier, Site Janet	- 112
4.74	Post-Walnut, (Item 30) landing pier	- 112
4.75	Post-Elder, (Item 30) londing pier	- 113
4.76	Postshot, Janet Camp	- 114
4.77	Shot geometry with pressure contours and test stations	
	for Site Yvonne	- 115
4.78	Plan and elevation for (Item 31) Station 1130, reinforced-	
	concrete bunker, Site Yvonne	- 116
4.79	Preshot, (Item 31) Station 1130, entrance, Site Yvonne	- 117
4.80	Postshot, (Item 31) Station 1130, entrance	- 117
4.81	Preshot, (Item 31) Ttation 1130, side-tunnel entrance,	
	Site Yvonne	- 118
4.82	Post-Cactus, (Item 31) Station 1130, side-tunnel entrance	- 118
4.83	Post-Cactus, (Item 31) Station 1130, crack at intersection	
	of tunnel and main structure	- 120
4.84	Preshot, (Item 32) Station 1220.01, cubicle, Site Yvonne	- 120
4.85	Preshot, (Item 33) Station 1216, Site Yvonne	- 121
4.86	Post-Cactus, (Items 32 and 33) Stations 1220.01 and 1216	- 121
4.87	Plan and elevation for (Item 34) Station 1612, Site Yvonne	- 122
4.88	Preshot, (Item 34) Station 1612, retaining wall, Site Yvonne	- 123
4.89	Post-Cactus, (Item 34) Station 1612, retaining wall and	
	entrance to station	- 123
4.90	Post-Cactus, (Item 34) Station 1612, interior view	- 124
4.91	Preshot, (Ilem 35) Stations 1520.01 to 1523.04, Site Yvonne	- 124
4.92	Post-Cacius, (Item 35) Stations 1523.01 to 1523.04, foundation	
	pit for towers	- 125
4.93	Post-Cactus, (Item 35) Stations 1523.01 to 1523.04, 48-unch	
	metal corrugated pipe leading to ground zero	- 125
4.94	Preshot, (Item 36) Station 1310, concrete, earth-covered	
	station, Site Yvonne	- 126
4.95	Post-Rose, (Item 36) Station 1310, concrete, earth-covered	
	station	- 126
4.96	Post-Butterrut, (Item 37) 21,000-gallon water tank	- 127

15

SECRET

¥. †

1.1

4.97 Post-Magnolia, (Item 37) 21,000-gailon water tank and
Yvonne Camp arga 127
4.98 Post-Cactus, camp damage, tents
4.99 Post-Cactus, camp damage, light timber construction
4,100 Post-vactus, camp damage, latrine 129
4.101 Post-Butternut, telephone poles130
4.102 Post-Butternut, radar reflector130
4.103 Post-Butternut, helium bottles
4.104 Post- Magnolia, helium bottles 131
4.105 Postsnot, fire hydrant 132
5.1 Peak air overpressure for a 1 -kt surface burst, with observed
points
5.2 Reduced vertical ground acceleration 10 feet below ground
surface for a 1-kt surface burst, with observed points 136
5.3 Damage to wood-frame camp structures for a surface burst 136
5.4 Data for Structure 3.1.1 plotted on curves
B.1 Plan, elevation, and gage geometry for Station 1312, Site Janet147
B.2 Measured and predicted pressures for Station 1312, Shot
Yellowwcod 148
B.3 Measured and predicted pressures for Ciation 1312, Shot Tobacco 149
B.4 Measured and predicted pressures for Station 1312, Shot Walaut 150
B.5 Measured and predicted pressures for Station 1312, Shot Elder 151
C.1 Stress-strain curve for reinforcing stepl153
C.2 Stress-strain curve for concrete153
C.3 Assumed loading geometry for typical pier 154
C.4 Stress relationship for concrete section at design strength 155
C.5 Stress and strain relationships for concrete section at yield
strength 156
C.6 Stress and strain relationships for concrete section at ultimate
strength
C.7 Determination of deflection at ultimate capacity 159
C.8 Moment-curvature diagram for beam 159
C.9 Effective blast pressure on Station 20-D
C.10 Effective blast pressure on Station 20-F
C.11 Reflected pressures for Stations 20-D and 20-F 162
D.1 Wave action at the personnel pier from Shot Oak, Site Elmer 168
D.2 Transformer station prior to wave arrival 168
D.3 Transformer station, first wave striking the lagoon shore 168
D.4 Transformer station, first wave moving onshore; the start
of inundation 168
D.5 Transformer station after wave action ceased and water
subsided

.

.

2

TABLES

1.1	Ouscryations of Gross Damage: Operation Castle, Bikini and	
	Eniwetok Atolis 2	21
1.2	Observations of Gross Damage: Operation Redwing, Bikini Atoll 2	23
1.3	Observations of Gross Damage: Operation Redwing, Eniwetok Atoll 2	24
1.4	Damage Summary, Operation Hardtack 2	26
2.1	Schedule of Data Collection During and After Operation Hardtack 3	30
2.2	Summary of Solf-Recording Instrumentation 3	32
3.1	Summary of Vesults at Bikini Atoll 3	34
3.2	Recorded Hadiation Within Station 560.01 (Item 2) 5	50

3.3	Recorded Radiation Within Station 78.01 (Item 5) 56
3.4	Free-Field Air-Overpressure Measurements, Sites Charlie and
	Tare 56
4.1	Summary of Results at Eniwetok Atoll 66
4.2	Recorded Radiation Within Station Complex (Item 18) 71
4.3	Recorded Radiation Within Station 3.4 (Item 22) 83
4.4	Free-Field Air-Overpressure Measurements, Site Janet 88
4.5	Comparative Displacement of Columns 94
A.1	Predicted and Recorded Radiation Values for Station 560.01 143
A.2	Predicted and Recorded Radiation Values for Station 78.01
A. 3	Predicted and Recorded Radiation Values for Station Complex
A.4	Predicted and Recorded Radiation Values for Station 3.4
C.1	Predicted Pressures and Durations for Stations 20-A to 20-F
D.1	Observations of Wave Damage, Operation Castle166

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Chapter | INTRODUCTION

1.1 OBJECTIVE

The objective of this project was to record and evaluate damage from blast, radiation, and water waves to selected pre-existent and new structures at the Eniwetok Proving Ground by examination and measurement before and after certain test detonations. The damage properly associated with shot geometries can provide valuable information to designers and planners of structures to resist the effects of nuclear weapons.

1.2 BACKGROUND

Many structures have been built at prior tests at the Eniwetok Proving Ground for the purpose of housing scientific instruments in extreme environments. Damage to these structures was reported, but their exposure to nuclear effects was only incidental to their function, and the opportunity to gain useful information from their behavior was not exploited. In addition, considerable effort and funds have been invested in prior operations for structural tests, per se. Some of these structures still exist in an undamaged or partially damaged condition. Since a number of these structures were supposed to be subjected to partially damaged conditions during Operation Hardtack, an opportunity was afforded to obtain valuable information on structural response and damage with minimum additional effort. Therefore, this project was planned to exploit the opportunity to gain general information that would amplify and supplement existing design criteria and concepts.

The selection of pre-existent stations that were investigated was based upon an on-site survey of structures made in November 1957. Certain $n \Rightarrow w$ test structures were also included where it was predicted that they would be subject to high pressure and temperature or destructive waterwave action.

1.2.1 Previous Damage Surveys. Damage surveys were performed for Operation Ivy (Reference 1), conducted in 1952, and for Shot 1 of Operation Castle (Reference 2), conducted in 1954. These surveys described damage from a total of three shots; for this reason, no overall discussion of damage-distance relationships as a function of shot yield was made in either report. In addition to the published reports (References 1 and 2), Holmes and Narver, Inc. (H&N) made damage observations and took numerous photographs of scientific stations during operation Castle (1954) and Operation Redwing (1956). The postshot damage reports prepared by H&N were given only limited distribution within the $I \oplus C$. Since no complete damage Jurveys are available for Operations Castle and Redwing. the H&N reports were reviewed, and a summary of the iniscellaneous damage observations are tabulated in this report for the first time for a more general distribution.

Shot geometries with pressure contours for Operation Castle are shown in Figures 1.1 and 1.2 for Bikini and Eniwetok, respectively. Table 1.1 summarizes the blast damage observations for Shots 2_i , 3_j , 4_j , 5_j , and 6_j . Damage due to Shot 1 is thoroughly presented in Reference 2; however, pertinent results are presented in Chapter 3 of this report.

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Figure 1.1 Shot geometry with pressure contours for Bikini Atoll, Operation Castle (1954).



Figure 1.2 Shot geometry with pressure contours for Eniwetok Atoll, Operation Castle (1954).

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Shot geometries with pressure contours for Operation Redwing are shown in Figures 1.3 and 1, 1, 3 and the summary of blast damage observations is shown in Tables 1.2 and 1.3.

The summary of blast damage observations for Operation Hardtack is shown in Table 1.4. Salient conclusions reported during previous surveys (References 1 and 2) are given below.

1.2.2 Conclusions from Ivy Damage Survey (1952). (1) Exposed steel beams and pipes attached to structures were damaged or destroyed by overpressures of 11 psi and greater. (2) Small Build-

TABLE 1.1 OBSERVATIONS OF GROSS DAMAGE: OPERATION CASTLE *, BIKINI AND ENIWETOK ATOLLS

Description	Site	Shot Number	Code Name	Damage	Ground	Pressure
					ñ	pei
Concrete Structure:						
Station 1341; reinforced concrete, 3 story instrument shelter, shove ground. Damaged and left in a weakmed condition by Shot Bravo (Reference 2).	Abie	2	Romeo	Severe damage; the third story was blown completely off.	7,500	9 5
Wood Fremed Structure:						
Station 1:dowless, 16 feet to eaves; $3\frac{1}{2}$ inch $\times 3\frac{1}{2}$ inch $\times \frac{1}{4}$ inch steel angle stude at 48 inches o. c.; $\frac{1}{4}$ -inch exterior plywood.	George	1	Bravo	Moderate damage; plywood µuneis howori in 1 to 2 feet; one panel ripped off.	56,400	2.4
Steel Framed Structure:						
Station 2210; steel framed with cor- rugated aluminum roofing and siding; exposed end-on to blast.	Sugar	3	Koon	Moderate damäge; frame un- damäged; roofing blown off; some siding blown off.	5,600	8.3
Storage Tanks:						
POL facility; four 1,000-barrel fuel storage tanks	Sugar	3	Koon	Severe damage; blast wave blew the top off one tank; all tanks damaged and leaked fuel; spilled fuel burned, severely damaging all tanks.	4,000	18
Towers;						
Timber water tower; 30 feet high; six 12-li;ch × 12-inch columns; guyed at the 30 foot level; 2 full 4,200 gallon water tanks in place.	Fox	1	Bravo	Undamaged	51,000	2.9
Station 80.01; antenna array of five 75-foot trylon towers; guyed at 3 levels; 3 suva at each suv level.	Nan	6	Yankee	Completely leveled	78,000	1.3
Station 1303.04; 75-foot, square, steel photo tower.	Janet	6	Nectar	Moderate damage; tower undam- aged; oab frame was twisted and members bent; oab siding and rollup doors damaged beyond practical repair.	19,460	4.8
Field Generators and Fuel	Tanks:					
Building DO-500; five 75-KW gen- erators, 3 pontoon fuel tanks pro- tected by high surrounding berm.	Dog	1	Bravo	Undamaged	40,000	4.3
Station 110.03; exposed generators.	Dog	1	Bravo	Damaged; extent unreported.	41,000	4.1
Utilities:						
Station 2221-02; exposed vacuum	Sugar	3	Noon	Moderate damage	6,500	8.3

*Covers obsetvations made subsequent to the Shot 1 damage survey reported in Reference 2

ings covered with thin sheet metal over diagonal wood sheathing generally withstood overpressures up to 5 and 5 psi. However, one structure of this type was badly damaged by an overpressure of 4.5 psi. (3) Lightly constructed wood-frame shacks sheathed with corrugated metal and located in regional with overpressures greater than 4 psi were completely destroyed. No structures of this type were located in regions subjected to less than 4-psi overpressure. (4) Palm trees were

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TABLE 1.2 OBSERVATIONS OF GROSS DAMAGE: OPERATION REDWING, BIKINI ATOLL

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Description.	Bite	Shot	Damage	Range	Pressire
Construction Camps: (8-man tents of typical construction over concrete slabs; light wood frame structures framed with 3 inch × 4 inch studs and truesed rafters 3 foot on contentre, % inch exterior plyhoud siding, and corrugated aluminum; rocfing.)				11	pe:
Tests, and light wood frame structures.	Fox	Charokee	Complete destruction exuept for concrete floor slabs and some telephone poles, exposed wood surfaces were charred; there was evidence of several fires which apparently were extinguish- of by the evidence of the stat.	33,600	3.3
Tente, light wood frame structures, shop buildings, and hasgurs.	Nab	Zuni	Light damage was sustained; win- dow soreans broken; shutters broken; builting walls; roof sheet- ing damaged at joints; a few raf- ters partially fractured; 2 inch × 10 inch stude is hangar building partially fractured and wall knoched inward 4 feet; carpenter shup shifted 5 inches.	70,600	0.8
Storage Tanks:	_				
Building 37: 21,000 gallon ground stor- age tunk; 22 foot diameter; 8 foot high; % inch stoel plate.	Fex	Cherokse Fisthead	Apparently undamaged; tank was full at shot time. Top of tank slightly dished in; no other apparent damages; water	33,600 12,200	3.3 3.9
		Dakota	level in tank unknown. Destroyed: the tank, probably empty, was blown 400 feet.	13,209	7.5
Towers:					
Station 1515: 75-foot, square, stael, photo tower-	William	Zuai	Tower undemaged; the cab situitiers were moderately damaged.	32,080	2.8
Antennas:					
S' .ion 312.02; TV antenna.	Man-Made Island No. 2	Cherokee	Broken off at the base.	20,750	7.0
Station 312.03: TV antenna.	Man-Made Island No. 3	Cherokee	Broken off at the base.	23,550	6.0
Station 74: Radio antenna.	Oboe	Zuni	Beat over; top broken off.	14,830	11.0
Field Generators and Fuel Tr	anke:				
Station 1519: 3 generators, aids-on to blast.	Able	Charoket	Generator nearer the blast was blown off its base and left leasing on the other; light charring of wood and maint.	30,350	3.7
Station 131.01: Generator; fuel tanks on wood rack.	Able	Charokee	Generator housing drives against gm- erator and best; fuel tanks knocked down, words Tack slickly showed	31,190	3.5
Station 1319: 3 generators, end-on to blast	Charlie	Cherokee	Generator searer the blast moved oue foot; side panels drives against the generator and best or broken of; maint obsumed on arrowed surfaces	19,640	8.0
Station 312.02: Generator.	Man-Made Island	Charokee	Undamaged; generator end-on in blast;	20,750	7.0
Batton 312.03: Generator, a. 45 degrees to blast.	Mon-Mada svik 1 No. 2	Cherokee	Generator income to generator charred Generator incoming slightly basis, genera- tor at 45 degree to blast with one side mended by and how	، دەكەرلىم	6.0
Custle Station 110: 2 generators behind & retaining wall.	Uncle	Zuni	Das generator blove on its eide; the other upside down.	10,270	21.0
Station 74: Generator, fuel task.	Obos	Z: *'	Undamaged.	14,830	11.0
ing wall; cylindrical Aol tank.	~8a	4.481	lapse of ar udjoining concrete divid- ing wall; fuel task was diabed in.	0,144	9 4 .0
Utilities and Ventilation Equi	lpment:				
Station 1319: Faterior debu: idifier and compr. Jor unit.	Charite	Cherokee	Debumidifier thrown against the com- pressor; the air intake fan was blast- ed against the intake.	19,569	8.0

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TABLE 1.3 OBSERVATIONS OF GROSS DAMAGE: OPERATION REDWING, ENIMETOR ATOLL

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Detoription	Site	Shot	Damage	Ground Range	Pressure
Concrete Structures.				ĸ	be r
Sintion 1911.04; mannive, semiburish; walls, reef and Scar 5 met thick; havily reinforced; earth rover 5	Yvone	LaCrosse	Undamagud; earth cover aimost completely blown away.	620	1,100
Notion 1310, shore ground; 5 × 3 fast blast data expected (son-on to blast wave; deer consolited of $\frac{1}{2}$ (such over- plate, 6 × $\frac{1}{2}$ (such horizontal stilleners at 13 inches o.e. with 0 × $\frac{1}{2}$ (such framms on the stilleners	Yvonne	Erie	Structurally undamaged; blast door severe- ly damaged; door looking handles shoared off; door hings wes bast on that it was impossible to span the door.	1,420	36
Section 7364: Above ground subical, 11 by 11 feet by 9 feet high, walls and reaf 1 feet 6 inches thinks 0.4 percent reinfortement sets with, each face, in walls and reaf.	(rene	3emincie	Completely destroyed; only the base slab remained.	1,680	18
$ \begin{array}{llllllllllllllllllllllllllllllllllll$					
Tents. Light wood frame structures.	Yvonne Yvonne	LaCrosso LaCrosso	wood frames failed; tests collapsed. Severe damage; aldes of buildings caved In; reads blows off; lower walled beller homes was undersamd.	8,200 8,200	2.3 2.3
Tests and light wood frame structures.	үүсөнө	26-3-34B	Complete destruction; the site was level-	2,300	13
Light wood frame structures.	Uroula	Kiekapoo	Light damaga; several plywood passis were farent off the rear wall of shode; aluminum read massi bloom off case read	5,600	0.75
Tests and light word frame structures.	Urmia	Mohawk	Complete destruction; anly electrical power poles and concrete liver slahe were remarkle.	8,600	7.0
Tests and light wood frame structures.	Gees	Seminole	Complete destruction except for concrete floor slabe.	3,900	4.1
Wood Framed Structure:					
Station 1836; essentially windowiene; 2 × 4 (anth stude 2 fluct e.e., and 2×6 (anth railers 2 fluct e.e.; $\frac{N}{2}$ inch exterior ply- wood siding.	Yvanne	LaCrosse	Moderate damage; and wall, facing blast was pushed inward; side walls ware pushed inward; several panels caved in compilety.	8,090	2.4
Station 1999; relabilitated to as-built condition after LaCrosso shot.	Yvonne	Erio	Completely destroyed; walls were caved in; reef fell in.	2,190	16
Storage Tanks:					
Sublicity 46, 21,000 gallen ground storage tank; 23 fast diameter, 8 feet high, $\frac{1}{4}$ inch steel plate; full at abat time.	Yvonne	Lachura	No damage.	6,130	24
Light Baffles: (Wead frame billhoards with ¹ / ₂ inch plywead soling; inclug blast; back rolys at 45 degree support brace top of beard; bottom of beard is support by a horisestal the to the back stays).					
Sintian 1884; 8 fost high by 44 fost wide; four 4 × 10 inch posts; four 4 × 8 inch back stars.	Yvonas	LaCross	Destroyed	7,690	8.7
Sintion 1863; 3 billhoards, each 8 foot high by 13 Sent wide; two 4 × 8 (ach peace; two 4 × 9 (ach bank stays.	Yvonae	LaCrosse Erie	ito apparent damage Dustreyed	7,840 1,860	2.5 18
Station 1802; 6 fost high by 28 fost wide; itur 4 × 8 inch posts; four 4 × 8 inch back stays	Yvonne	LaCrosse Erie	No apparent famage Destroyed	7,985 2,100	2.4 16
Sintion 1501; 2 billhoards, each 8 feet square; two 4 × 6 inch posts; two 4 × 6 inch bankstays.	Yvonne	LaCrosas Erie	No apparent damage Destroyed	8,843 3,150	2.4 15

24

TABLE 1.3 CONTINUED

Destription	Rite	Binut	Damiti	Oround RAnge	Presaure
Teware:				n	pei
Blation 7; 300 Syst shut tower, 30 Sect agains 6 Sech steel bat legs; guyed at 100 and 300 Sect Jovels.	Yvaan	Erie	Medarate datange; towar andranad a curved singe; middle parties best outward; hor- over, oub rémained is its original pacifice, directly over sowar base; obvation guide rails and extremer ware best and traited.	3,000	7.8
Building 83; timber weinr tower, 30 feet high; eix 13 × 12 iveb columns and deu- hie 2 × 6 imb breeine.	Yvano	LaCrosss	No apparent damage; water tinks were re- neved prior to the shet.	8,180	1.3
Building 101; timber water tower, 30 feet high; eight 12×12 inch columns and double 2×6 inch bracing.	Ureula	Mohawk	Overtained, estimate broken and fractured; water tanks were removed print to shat.	8,660	7.0
Wood Pile piers:					
Yvenne persennel pier	Yveen	LaCresse Erie	Undnungged Destroyed, many piles broken hi or near the under line.	5,400 808	4.6 130
Gene personne) pier	Clease	Semiaele Apaulie	Undamaged Completely destroyed.	8,900 1,408	2.7 >1,000
Redar Bolleotors:					
Station 7411.01	Sally	Yuma Kiokapee	Undamaged Knooled off its base.	1, 280 1,340	3.6 9.0
Field Generators and Fuel Ta	nko:				
Control Yvotne artes; 2 generators Station 1611; true 75-XW secondars	Yvene Im	LaCresse	Overtarmed; reased after major overhead	1,600	45
Station 1611; two 70-KW generators; 8 Novy periods funt tents	11400	Apache	Overtarmed; postcon task wells dished in.	7,760	24
Batica 1611; two 78-KW generators; 3 Navy perioes fuel tasks.	Ireas	Huren	Overtarend; recovered and salvaged; pentota tasks undemaged.	6,830	9.2
Vacuum Pipelines:					
Bation 1011; 1015; 10 inch OD steel varuum pipe line roller supported 20 feet c. c.; crissied approximately rollel to the blast.	Trunne	LaCreson	Completely dustruped at less thrm 1,300 foot; undamaged beyond 1,300 foot.	1,300 1,600	78 45
blast.	Thuns	Clackfoot	Undninsiged bayond 1,100 Sect.	1,100	40
Utilities and Ventilation Equi	pment :				
Building 75; Postshoute	Yvenn	LaCrosse	Air intain dust burst when initiarily valve failed to close.	8,199	8.4
Station 2211; powerhouse	Saily	Yuma	Pleasure chamber exploded when butterfly valve failed to close.	850	9 .12
Building 100; powerhouse	Urmin	Kichapon	Pleasa ohambar burst.	5,600	0.0
	Typene	Erte	Cutside tuel lines broken off leading into feel vierage tanks; feel lines leading (nie meethuses broken it entry.	2,300	13
Miscellanst us; whier closets, urinals, washbewls, underground utilities	Y vonne	LaCrosse	Plumbing Externs undermaps, underground utilities undermrised except that represed Extures moved by the blast severad pipping contactions to 'he main lines (unsp area)	8,386	1 3
Airport Rusway:					
Asphalt paved rukway	Yvoune	Erio	Moderate damage; asphait broks into small pieces; aspend word lagging is hithered source	300 to 500	1,000 ta 500

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TABLE 14 DAMAGE SUMMARY, OPERATION MARDTACK

Description	Maalmun Overpressure	Mazimum Damage	hem Number	Specia) Remarks
Review 1841 Castle Shate Suchas		la mara da mara	,	
Three stories high. Damaged from			•	
ghota Brave and Remov of Operation				
Castle. No damage from Cycrotion.				
Balies 500.01, Rodwing. Concrete shal-	1,200	Completely destroyed.	2	Interior radiation measurement.
ter. He damage from Operation				Wave action
Ruttring. Station 1819, Reducer, Beinforced-	1.700	Completely destroyed.	4	Wave action-
generets plate busier.				1-4
Baties 78.01. Concrete Himing station.	50	No damage.		Union rediction measurer.ont. Wave action.
No animago trom Operation Redwilly. Institus 1966, Cantin, Canarain militari	32	Light damage.		
structure. Damaged from that Brave;	••			
no additional damage from that Romes				
er uperation Chatte. Ne damágo IPem Concellos Induine.				
Station 1210. Contial connector pit.	439	No damage.	13	
Underground relaterced-ouncrote				
etruction 1970. Connector sit. on.croin	1,400	No damage.	14	
ben, earth .nounded.		··· •		
Station 2730.01. Concrete Junior-	1,050	Ne damage. Ne damage	18	
mation \$239.92. Controls builder. Mation \$26.61. Buriod concrete structure.		No damage.	17	
Instrumentation pit for rediction offices.		• • • •		
Station Complex. A comprete sheltor,	48	Retaining well failed.	18	Unwrige radiation hwanurement. Wave action.
addition to 1611 Redwing (vedalization of Stations 1634, 1636, and 1311). No				
damage to interior of station from Shote				
Seminole, Aperlie, or literen of Opera-				
tion poorving. matica 1825. A reinforced-secordia	43	Severe damage to retaining	19	Thermal radiation. Wave
Fiser station.		wall.		sction.
Station 1311. A constrole detector	43	Light damage.	10	Inslate Locate Con
Station 1410 and 1211. A reinforced-	43	No dessage.	81	
concrete structure and terminus of				
pipeline.	34	No damare.	22	Interior relation means ement.
signal terminal pit.				Wave action.
Station 1312. A reinforced-concrete	м	No damage.	25	Hisst diffraction study (Appendia
recording station.				active.
Station 3.1.1. Three-story, multi-	20	From light damage to	26	These structures were subjects
compariment test structure: costores		colleges, depending on		to repeated loadings in the 10
frame, staal frame, and concrete absar		the of environce.		lends' ber 20 1 - het (overstagenia)
Station 20-R. Reinforced-concrete gage	25	Severe damage, failure at	28	Structural response study
pior.		been of stem.		(Appendix C).
Station 77.02. A reinforced-concrete,	17			
Biation 1130. A reinfarued-ouncrete	460	Light damage to bunnel only.	31	Thermal radiation, 650 cal/cm
punker with a side tennel.		No demore	••	
Station 1316. A reinforced-concrete	460	10 GEINGER.	49	
diation 1612. A reinforced-merete,	1,000	Several discussion in retaining	34	
earth-mounded Triter Mation.		well. Light damage to		
mation 1310. A large, massive.	16	No damage.	34	
reinforond-concrute, sarth-		-		
nevended appropries				
Cool Structures:				
Stations 182.01 and 183.01, Redwing-	1,200	Completely destroyed.	3	
Steel beams and pressure-gage mounts.			10	Marimum total thermal
Stations 50.91 through 50.05. Water-	300	damaged.		radiation 5,000 cal/cm ³ .
Station 3.1.1. Three-story, multi-	20	From light damage to col-	26	3. pees at actures were subject
compartment test structure: craurete		lapse, depending on type		to repeated loadings in the
grame, steel ream, and connects		ot exception to:		brie 13566.

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TABLE 14 CONTINUED

theness intion	Maximum Overpressure	Maximum Damage	ltem Number	Spucial Homarka
Station 1220 (. Cubicle mounted on 4	150	Severe damage.	33	
RINGURAL-BASS platform. Stations 1833.01 to 0.04 Four steel- pips fowers encased by plywood covering.	450	Complete destruction.	18	
Wood Frame Structures:				
Station 2410-01. Wonden shelter earth-	8 8 L	Completely destroyed.	7	
Mounded. Station 2410.02. Wooden shelter earth-	148	Completely destroyed.	•	
Station 2418.03. Wroden shelter warth-	76	Completely destroyed.	•	
Station 1810. Plywood construction	21	Plywood room destroyed.	11	
Construction camp.	0. 1	No damage from any of the abeta.	Nan	
Construction camp.	1.1	Savere Jamage.	Ober	
Construction camp.	5.2	Complete destruction-	Janet	
Construction caup.	6.6	Complete destruction.	Yvoilue	
Miscellaneous Structures:				
Fution 2260. 139 % tower on top of	8.	No deman	12	
Generators, Four, 75-kvs, dissel-	34	Severe damage.	23	
Heliomies net Steel landing mals.		Complete destruction.	24	
Station 3.1.3. Underground test	29	No damage	<u>,</u>	
I andine mar.	30	Light damage.	30	Wave action.
Water task & \$1.000-railes task of	7	Light damage	37	
"A-inch steel plate, # feet high, and 10 feet 10 inches in radius.				

destroyed by air-blast ov :rpressures of 4 to 5 psi and greater; none were destroyed by overpressures less than 4 psi.

1.2.3 Conclusions from Castle Damage Survey (1954). (1) The blast wave of a 15.0-Mt surface burst caused considerable damage to light wood-frame structures out to a radius of about 16 miles from ground zero. (2) Trussing and knee bracing was effective in decreasing the severity of damage to light wood-frame buildings at grent distances. (3) Heavily reinforced-concrete, above-ground, shelter-type structures subjected directly to the blast wave received significant damage as far away as 1.5 miles. It was not known how much farther this damage would have extended. (4) Earth cover appeared to provide a considerable degree of protection from air slock to reinforced-concrete, shelter-type structures. The addition of the earth cover appeared to be beneficial, primarily due to decreasing the blast loading by improving the aerodynamic shape, which in turn reduced reflection factors. Also, there was a possibility of slight attenuation of pressure incident on the structure, depending on the depth and condition of the earth cover.

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Contraction - Child



Chapter 2 PROCEDURE

2.1 SHOT FARTICIPATION

The objective dictated that this project (a joint WES-H&N effort) adequately document information from nearly all the Operation Hardtack shots. The major effort of the project was concentrated on the early shots which were expected to yield the most significant information for this project. Some supplementary information of interest, however, was also expected from the later shots. Therefore, because this project was to be a minimum effort using limited funds and personnel, arrangements were made with H&N to receive the damage survey normally conducted by its field organization. In addition, it was planned to have a project representative visit the test site after the operation to obtain additional data regarding the later shots. The schedule of observation of effects from the various shots by the project during the operation and by the project representative after the operation. If additional the project during the operation and by the proj-

The general layout and planned shot geometry for Operation Hardtack events, including the code name of the shot, site (island), and stations investigated, are shown in Figures 2.1 and 2.2 for Bikini and Eniwetok, respectively.

2.2 INSTRUMENTATION

Eleven self-recording, air-overpressure gages and six self-recording accelerometers were located as shown in Table 2.2. The locations were selected to provide the most useful data, taking into account shot geometries with respect to structures, and the available instrumentation. The exact location, as well as the results obtained with these gages, appear in Chapters 3 and 4 under the section pertaining to the structure in which or near which the gage was actually located. The gages were furnished, calibrated, and read by personnel from the Ballistics Research Laboratory (BRL). The self-recording pressure gage consisted of a precisely govened, battery-operated motor that rotated a silvered-glass disk placed in operation by a fast-rising light pulse or thermal radiation from the detonation. A stylus attached to a compact metal-bellows element traced on the rotating disk a record of the dilations of the bellows produced by the pressure of the blast wave. In this way, a time-dopendent record of the blast pressure was impressed on the disk.

The self-recording accelerometer was similar to the self-recording pressure gage, except that the sensing element was a cantilever spring with a mass attached at the free end. A recording stylus was mounted on this mass. A second element was mounted at a right angle to the other so that the two styluses recorded acceleration in two planes on a single glass disk. For a more detailed description of these two types of self-recording gages, including methods of installation and calibration, see WT-1612.

Dosingeter Film Packets, Type 559 (manufactured by E.I. du Pont de Nemours and Co.) obtained from and processed by TU 7.1.6 were placed in various stations to determine total gamma radiation. The location of the film badges and the values obtained appear in Chapters 3 and 4 under the section pertaining to the appropriate structure in which the badges were placed. The film used had two ranges of sensitivity; one from 0 roentgens (r) to 10 r and the other from 2 r to 400 r.

Photographs were taken before and after the shots at each station so that a visual comparison of damage could be made.



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Figure 2.1 General plan and shot geometry for Bikini Atoll.



Figure 2.2 General plan and shot geometry for Eniwetok Atoil.



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2.3 DATA REQUIREMENTS

Air overpressure was measured to correlate damage with pressure. The curves shown in Figures 2.3 and 2.4 were used for predicting values of air overpressure and positive-phase duration, respectively. Both curves are based on data found in References 3 and 4.

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The geometry and position of Station 1312, a large, reinforced-concrete diagnostic station without earth cover (constructed for Operation Hardtack on Site Janet), offered the opportunity to obtain loading information for a large diffraction-type target. To obtain this information, two pressure gages were placed in the front face, two on the roof, and one on the back face of

	Shot	
Site	Effects Observed by Project During Operation	Effects Observed by Project Representative Postoperation
Bikini Atoll		
Abie	Fir	Certer
	Sycamore Aspen	Poplar
Charlie	ŀir	Cedar
	Sycamore Aspen	Poplar
Fox and George	Maple	Redwood
Tare and Sugar	Nutmeg	Hickory Juniper
Eniwetok Atoll		
Gene, Helen, and	Коа	Dogwood
Irene	Yellowwood	Olive
	Tobacco	Pine
	Walnut	
	Elder	
Janet	Koa	Dogwood
	Yellowwood	Olive
	Tobacco	Pine
	Walnut	
	Elder	
Yvonne	Cactus	Linden
	Butternut	Sequoia
	Holly	Fig
	Magno, a	Pisonia
	Rose	

TABLE 2.1	SCHEDULE OF DATA COLLECTION DURING A	AND
	AFTER OPERATION HARDTACK	

the station. The results of this work are presented to Appendix B.

Acceleration measurements were obtained to assist in relating the response of a structural system with pressure and, also, to determine whether or not the acceleration was of such magnitude as to possibly cause physiological damage to personnel. For the purpose of predicting accelerations, a curve (Figure 2.5) was drawn from data contained in References 5, 6, and 7. The reference data indicated that the vertical acceleration of the floor slab approximated the vertical acceleration of the soil mass at the same level. If it is assumed that the total weight of a buried structure is approximately the same as the weight of soil displaced, the acceleration

Figure 2.5 Reduced vertical grownd acceleration 10 feet below ground surface for a 1-kt . riace burst.

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of the floor slab (at least in the downward direction) should approach the free-field value.

Radiation measurements were obtained to evaluate and compare actual with predicted values. The TM 23-200 (Reference 8) was used as the guide in making predicted radiation values, as well as in determining the attenuation factors for the various structures. A discussion of the method and calculations used for predicting radiation within the four structures that were radiologically evaluated is given in Appendix A to this report.

Water-wave predictions and wave-crest-height measurements were made by Project 50.1 (Scripps Institution of Oceanography). The data were used to study the relationship between wave action and land erosion. The results of this work are presented in Appendix D.

Site	Ctation	Number of	Gages
alle	Station	Air Overpressure	Acceleration
		psi	g
Charlie	78.01	2	2
Tare	2230.02	2	2
Janet	1312	6	2
	3.1.1	1	0

TABLE 2.2 SUMMARY OF SELF-RECORDING INSTRUMENTATION

Level surveys were performed to determine the loss of earth cover over several mounded structures resulting from the effects of water waves and air blast.

The recorded damage from this operation and past operations, summarized in Chapter 1, was correlated with various curves of Reference 8. This project also utilized basic data from other Operation Hardtack projects to amplify the correlation.

An opportunity was afforded to compare predicted with observed response of reinforcedconcrete gage piers which were located on Site Janet. This work is described in Appendix C.

Chapter 3 RESULTS: BIKIN! ATOLL

For ease in interpretation of results and reference to various figures, the test results are presented in order according to atoll, then site (island), and then station. Where applicable to a particular station, a brief history relating effects from past operations is also included.

The general test results and descriptions of the stations investigated on Bikini are summarized in Table 3.1. Throughout this report, the terms severe, moderate, and light damage are used; for clarification the following definitions (Reference 8) are given:

Severe Damage. That degree of structural damage which precludes further use of a structure for the purpose for which it is intended without essentially complete reconstruction. Requires extensive repair effort before usable for any purpose.

Moderate Damage. That degree of structural damage to principal load-carrying members (trusses, columns, beams, and load-carrying walls) that precludes effective use of a structure for the purpose for which it is intended until major repairs are made.

Light Damage. That degree of damage which results in broken windows, slight damage to roofing and siding, blowing down of light interior partitions, and slight cracking of curtain walls in buildings.

3.1 SITE ABLE

The effects of Shots Fir (1.36 Mt), Sycamore (93 kt), Aspen (319 kt), Cedar (220 kt), and Poplar (9.3 Mt) were observed at Site Able. The shot geometry with pressure contours and test stations for this site is shown in Figure 3.1. The air blast and subsequent water wave from Shot Fir swept the island free of all vegetation. The extent of inundation from Shot Sycamore is shown in Figure 3.2. The effects from Shot Poplar which exposed the island to air blast pressures greater than 1,000 psi completely destroyed all man-made stations.

3.1.1 Item 1, Station 1341, Castle. A three-story, reinforced-concrete, photographic bunker, constructed during Operation Castle (1954), was designed for an incident air overpressure of 50 psi and a reflected pressure on the front face of 130 psi. A factor of safety of over 2 was used in the design; therefore structural failure at reflected pressures less than 260 psi would not be expected (Reference 2).

This station was severely damaged and left in a weakened condition as a result of Shot 1 (Bravo) of Operation Castle, which subjected it to about 130-psi air overpressure. A 95-psi overpressure from the Romeo shot (Operation Castle) caused additional damage, destroying nearly all of the previously damaged third story and making the station unsuitable for occupancy. No additional damage was inflicted during Operation Redwing (1956).

Figure 3.3 shows that blast effects from Shots Fir, Sycamore, Aspen, and Cedar inflicted no additional damage. However, the high overpressure level of 35: psi from Shot Poplar sheared the second floor from the structure, as shown in Figure 3.4.

3.1.2 Item 2, Station 560.01, Redwing. A reinforced-concrete shelter was constructed and not damaged during Operation Redwing (1956). The general plan and elevation for this siructure, including film-badge locations, are shown in Figure 3.5.

This station was located in an estimated 30-, 6-, 12-, 10-, and 1,200-psi air-overpressure range from Shots Fir, Sycamore, Aspea, Cedar, and Poplar.

Pre- and post-Fir photographs (Figures 3.6 through 3.9) show the effect of water waves and

33

TABLE 3.1 SUMMARY OF RESULTS AT BIKINI ATOLL

					Generad		Dead	held		
					Dance to			Initial		
	Item		;		m alimu				i i	
Site	Number	Station Description	Bhot	Vield	Ground Zero or Burface	Peak Overpressure	Duration	Free-Field Gamma	Floor Slab Acceleration	Remarks
					Zero			Radiation		
					ų	ja Bel	Jec.	r/br	54	
άb.	-	Station 1341. Castle. Photo	Fir	1.36 Mt	7,560	20	2.10	1,100	2.0	No additional damage
		bunter. Three stories high.	Svcamore	23 ha	7,560	4.2	1.39	8	0.04	No schitional damage
		Lanared from Shota Brave and	Aspen	319 M	7.560	8 .5	1.66	150	0.2	No additional damage
		Romeo of Coaratton Castle.	Cedar	220 ht	7,560	7.0	1.57	100	0.1	No additional damage
		No damage from Operation	Poplar	9.3 M(t	4,400	350	3.16	1,000,000	210	Severe damage
		Redwing.								
	21	Station 560.01, Hedwing. Con-	Pir	1.36 Mi	6,030	8	1.92	7,000	4.2	No additional damage
		crets shelter. No damage	Sycamore	93 kt	6,030	6.0	1.20	210	0.1	No additional damage
		from Operation Redwing.	Aspen	319 ht	6,030	12	1.47	1,000	0.5	No additional damage
		1	Cedar	220 kt	6,030	10	1.40	099	0.3	No additional damage
			Poplar	9.3 Mt	2,920	1,200	3.10	4,000,000	1,112	Completely destroyed
		Stations 152.01 and 153.01,	Fir	1.36 Mt	6,020	8	1.92	7,000	4.2	No damage
		Redwing. Star! brams and	Bycamore	93 kt	6,020	6.0	1.20	160	0.08	No damage
		pressure gage mounts.	Aspen	319 ht	6,020	12	1.48	906	6.5	No damage
			Cedar	220 kt	6,020	91	3.39	600	0.3	No damage
			Poplar	9.3 Mt	2,820	1,200	01.1	5,000,000	1,020	Completely destroyed
	-	Station 1518, F. iwing. Rein-	FIF	1.36 Mt	5,650	37	1.86	10,500	5.3	No damage, moved 11 feet
		forced concrete photo bunker.								horizontally
			Sycamore	93 kc	5,650	6.8	117	300	0.1	No datriage
			Aspen	319 ht	5,650	1	J.45	1,400	0.6	No damage
			Cedar	220 kt	5,650	11	1 35	800	0.4	No damage
			Poplar	9.3 Mt	2,620	1,700	3.10	7,000,000	1,245	Completely destroyed
Charlte	5	Station 78.01. Concrete thathe	Fir	1.36 Mt	5,720	35	1 39	10,000	5.3	No damage
	•	station. No damage from	Bycamore	93 kt	5,720	6.7	1.18	320	0.1	No damage
		Operation Redwing.	Aspen	319 kt	5,720	14	1.45	1,500	0.6	No damage
			Cedar	220 kt	5,720	п	1 35	800	0.3	No damage
			Poplar	9.3 Mt	9,190	8	3.42	10,600	11	No damage
	9	Station 1200, Cuatle. Concrete	Fir	1.36 Mt	7,550	20	2.10	1,150	2.0	Light damage
		support structure. Damaged	Sycamore	93 ht	7,550	4.2	8E-1	33	9-94	No additional damage
		from Shot Brave; no additional	Aspen	319 kt	7,550	63	1.66	150	0.2	No additional damage
		darnage from Shot Romeo of	Cedar	220 kt	7,550	7.0	1.57	8	0.1	No additional damage
		Operation Castle. No damage	Poplar	P.3 Mt	11,020	32	3.63	3,500	8.6	No additional damage
		from Operation Redwing.								
For.	7	Station 2410.01. Woodsn	Maple	230 kt	1,520	195	6.92	400,000	39	Completely destroyed
		shelter, new.	Redwood	412 kt	1,520	365	1.11	1,100,000	15	
	a 0	Station 2410.02. Wooden	Maple	230 kt	2,125	85	0.95	200,000	12	Completely destroyed
		shelter, metc.	Redwood	412 kt	2,125	145	114	350,000	26	

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TABLE 3.1 CONTINUED

						Crowd		Prec	Licked		
		i				Range to			Initial		
	Site		Station Nu:ober	Shot	Yield	Ground Zaro	Peak	Duration	Free-Field	Floor Slab	Remarks
						or Surface	Overpressure		Gamme	Acceleration	
						Zaro			Radiation		
						ų	ä	236	r/ar	5	
		6	Station 2410.55. Wooden	Maple	230 ht	2,735	2	1.00	45,000	1.1	Completely destroyed
			shelter, new	Radwood	412 kt	2,735	36	1.17	120,000	12	•
		10	Stations 50-01, 50 J2, 50.03,	Maple	230 ht	1	ł	!	ł	1	No damage, see Section 3.3
			50.04. 50.05. apr 50.06.	Redwood	412 ht	ł	ł	ļ	ł	ł	50.01 and 50.02 destroyed
			Water-wave gage a.								50.03 damaged
	George	11	Station 1810. Pivwood con-	Maple	230 kt	5.280	14	1.30	2.000	0.5	Plywood room destroyed
		1	struction between Platfors	Redwood	412 ht	5,260	21	1.46	4,000	11	No additional damage
			1830 and 1030.								•
	an N		Camp.	Maple	230 kt	62,500	0.1	5.8	÷0	0	No damage from any of
			1	Redwood	412 ht	32,500	0.2	6 4	₹0	0	the shots
	Oboe		Camp.	Nutmeg	24.0 ht	15,000	0.7	1.65	€ 0	0	No damage
			•	Hickory	13.4 ht	15,000	0.5	1.5	4 0	0	No demage
				Poplar	9.3 Mt	85,000	1.0	66	₹0	•	No damage
3!				Pisonia	265 kt	11,000	3.8	1.95	1	0.04	Lot known
5				Juniper	63.6 kt	15,000	1:1	19	0 ±	•	No damage
	Sugar	12	Station 2250. 150-foot tower	Nutmer	24.0 ht	4,510	4.5	0.82	280	0.03	No damage
	•		on top of concrete photo	Hickory	13.4 ht	4,510	3.5	0 76	170	0.01	No detonge
			burker.	Juniper	63.8 kt	4,510	8.2	1.0	950	0.08	Severe damagn
	Tare	51	Station 2210. Coaxial connector	Nutmer	24.0 kt	785	170	6.6	260,000	12	No damage
			pit. Underground reinforced	Hickory	13.4 ht	785	8	0.36	140,000	5.7	No damage
			concrete structure.	Juniper	63.8 kt	785	430	99 ")	700,000	8	No damage
		4 1	Sts.ion 2270. Connector pit,	Nutneg	24.0 kt	550	490	0.42	400,000	47	No damage
			concrete box, earth mounded.	Hickory	13.4 ht	550	260	0.35	320,000	11	No damage
				Juniper	63.8 kt	550	1,400	0.59	1,300,000	181	No damage
		15	Sturion 2230.01. Concrete	Nutioneg	M.O.M.	999	350	0.42	350,000	8	No damage
			bunker.	Hickory	13.4 kt	99	200	0.35	220,000	14	No damage
				Junper	63.8 ht	600	1,050	0.60	1,000,000	8	No damage
		16	Station 2230.02 Concrete	Nutimeg	24.C ht	635	320	0.42	300,000	72	No damage
			bunksr.	Hickory	13.4 kt	635	180	0.36	220,000	9	No damage
				Juniper	63.6 kt	635	1,000	3.61	1,000,000	106	No damage
		11	Station 630.01. Buried concrete	Nutrieg	24.0 kt	725	210	3 42	200,000	15	No damuge
			at ructure. Instrumentation pit	Hickory	13.4 kt	725	120	0.36	130,000	9-9	No damage
			for rediation effects.	Junipar	63.8 kt	725	560	0.60	700,000	3	No damige

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Figure 3.1 Shot reometry with pressure contours for Site Able.


Figure 3.2 Extent of inundation on Site Able after Shot Sycamore.



Print Contraction

Figure 3.3 Post-Fir, -Sycamore, -Aspen, and -Cedar, (Item 1) Station 1341 on Site Able, no additional damage. Pressure levels: Fir, 20 psi; Sycamore, 4.2 psi; Aspen, 8.5 psi; and Cedar, 7.0 psi.

37

air blast on the immediate area. The telephone pole adjacent to the structure was broken at the roof line. Although the door of this structure could not be sealed tightly due to faulty seating, it is assumed that the pressure build-up within the station was slight. Three one-hundred-watt light bulbs fartened to the ceiling did not break, indicating that the pressure within the station was very low. Three inches of mud covered the floor and high water mark was noted 1 foot 8 inches above the floor. The sand bags were strewn about the entire area, the top of the ber in was lowered 2 feet, and the earth mound in front of the station was reduced 7 feet in height. Indications were that at least 3 feet of water had been confined within the circular berm area. Pre-Fir, post-Fir, and post-Sycamore profiles of the island between Stations 560.01 and 1519 are shown in Figure 3.10.

Shots Sycamore, Aspen, and Cedar had no noticeable additional effects on this station as would be expected by observing the small overpressures resulting from these shots. It is also



Figure 3.4 Post-Poplar, (Item 1) Station 1341. Pressure level: Poplar, 350 psi.

evident from Figure 3.10 that Shot Sycamore caused very little, if any, additional erosion. The structure was completely destroyed from the effects of Shot Poplar. Figure 3.11 shows there was hardly a trace that the structure once existed and only a slight trace indicating the location of the circular earth berm that once surrounded the structure.

Radiation values within the structure for Shots Fir, Sycamore, and Aspen are listed in Table 3.2.

3.1.3 Item 3, Stations 152.01 and 153.01, Redwing. Two steel beams, one an 8-inch, 67-lb/ft, wide-flange beam, 10 feet 8 inches long, and the other an 8-by-8-inch, 56.9-lb/ft angle, \hat{v} feet 8 inches long, were erected as test drag-type structures and were undamaged during Operation Redwing (1956).

These stations received an estimated air pressure of 30, 6, 12, 10, and 1,200 psi from Shots Fir, Sycamore, Aspen, Cedar, and Poplar, respectively. The stations were undamaged from the first four thats except for slight erosion of the soil around the concrete foundations, (Figure 3.12); however, the force from Shot Poplar destroyed the steel drag members, leaving only the concrete bases (Figure 3.13).



SECTION A-A



PLAN

Figure 3.5 Plan and elevation including film badge locations for (Item 2) Station 560.01, Site Able.

39





Figure 3.7 Preshot, (Item 2) Station 560.01 including earth berm, Site Able.

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Figure 5.11 Post-Poplar, (Item 2) Station 560.01, complete destruction of station. Station 1341 can be seen in background. Pressure level: Poplar, 1,200 psi.



Figure 3.12 Post-Fir, (Item 3) Stations 152.01 and 153.01. Pressure level; Fir, 30 psi.

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3.1.4 Item 4, Station 1519, Redwing. A reinforced-concrete, photographic station approximately 24 feet long, 9 feet wide, and 7 feet high and weighing 50 tons was constructed and undamaged structurally during Operation Redwing (1956).

This station was located in an estimated 37-psi overpressure range from Shot Fir and was displaced 11 leet horizontally away from surface zero. A post-Fir view is shown in Figure 3.14. The pressures of 6.8, 14, and 11 psi from Shots Sycamore, Aspen, and Cedar, respectively, caused no further damage or movement. The very-high overpressure of 1,700 psi from Shot Poplar completely destroyed this station.

3.2 SITE CHARLIE

The effects of Shots Fir (1.36 Mt), Sycamore (93 kt), Aspen (319 kt), Cedar (220 kt), and Poplar (9.3 Mt) were observed at this site. The shot geometry, with pressure contours and test stations, is shown in Figure 3.15.

The air blast and water wave from Shot Fir swept nearly all vegetation from the island. Inundation caused from Shot Fir extended past Station 78.01 as can be seen in Figure 3.16. A light steel tower, shown in Figure 3.17, was located in the 25-psi air-overpressure range of Shot Fir and was completely destroyed, leaving no trace of the structure.

3.2.1 Item 5, Station 78.01, 1319 Redwing. A reinforced-concrete timing station, constructed and undamaged during Operation Redwing (1956) was modified for use in Operation Hardtack (1958) by adding a new entranceway and mounding earth over the old entrance and retaining wall.

This station was located in an estimated 35-, 6.7-, 14-, 11-, and 50-psi air-overpressure range for Shots Fir, Sycamore, Aspen, Cedar, and Poplar, respectively. However, the structure apparently received no structural damage from any of the shots. The general plan including locations for accelerometers and film badges is shown in Figure 3.18 while the data obtained from the radiation measurements are shown in Table 3.3. The data obtained from the airoverpressure gages shown in Figure 3.15 are presented in Table 3.4. No records were obtained from the self-recording accelerometers located in this structure.

The structure, including the earth mound over the structure and light steel structural members used for guiding a guillotine-type gate over the entrance, is shown in Figure 3.19 prior to Shot Fir, in Figure 3.20 after Shot Fir, and in Figure 3.21 after Shot Poplar. For Shot Fir it appeared that the water-wave run-up on the side of the mound facing surface zero was 5 to 6 feet vertically (see Figure 3.20) and that the passing wave reached a height of 1 to 2 feet as observed by the water marks on the earth mound. A heavy, interior steel door was knocked off its pin and socket hinge from the shock effects of Shot Poplar.

3.2.2 Item 6, Station 1200, Castle. A reinforced-concrete, earth-mounded structure was constructed during Operation Castle (1954). The structure, situated in the 130-psi airoverpressure range, was damaged from Shot 1 (Bravo) of Castle; portions of the parapet and retaining walls at the rear of the structure were torn off by the blast. No additional damage was received during Operation Redwing (1956). The earth cover around this station was removed after Operation Redwing.

This station was located in the 20-p.4 air-overpressure range for Snot Fir and received slight additional damage. A retaining wall previously damaged was forced over, leaving only the reinforcing steel holding the cracked portion to the main section (Figures 3.22 and 3.23).

No additional damage as the result of Shots Sycamore and Aspen was observed. The station appeared intact as observed by distant observation after Shots Cedar and Poplar which caused pressures of 7 and 32 psi, respectively.

3.3 SITES FOX AND GEORGE

These sites were exposed to Shots Maple (230 kt) and Redwood (412 kt); however, the destructiveness of Shot maple was such that no significant additional damage was inflicted by Shot Redwood. Site Fox was completely inundated by the water wave generated from Shot Maple while

44



Figure 3.13 Post-Poplar, (Nem 3) Stations 152.01 and 153.01. Pressure level: Poplar, 1.200 psi.



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Figure 3.14 Post-Fir, (Item 4) Station 1519. Pressure level: Fir, 37 psi.

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Figure 3.10 Tool: Fir, Site Charlie, extent of inundation.



Figure 3.17 Preshot, steel tower on Site Charlie; completely destroyed by Shot Fir, 25 psi.

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Figure 3.18 Plan including accelerometer and film badge locations for (Item 5) Station 78.01, Site Charlie, Redwing Station 1319.

Site George was partially washed over. The shot geometry with pressure contours and test staticus for the two sites are shown in Figure 3.24.

3.3.1 Items 7, 8, and 9, Stations 2410.01, -.02, and -.03. Three identical timber shelters mounded over with earth were constructed during Operation Hardtack (1958). A typical preshot



Figure 3.19 Preshot. (Item 5) Station 78.01, Site Charlie.

view is shown in Figure 3.25 and typical post-Maple view (pressure level, 85 psi) in Figure 3.26. All three structures were completely destroyed and the earth mounds over the structures were washed away by the blast and water-wave forces of Shot Maple.

3.3.2 Item 10. Stations 50.01, -.02, -.03, -.04, -.05, and -.06. Six water-wave gages were constructed and located as shown in Figure 3.24. The structural details of a typical gage are shown in Figure 3.27.





Figure 3.20 Post-Fir, (Item 5) Station 78.01. Pressure level: Fir, 35 psi. Arrows indicate extent of inundation.



Figure 3.21 Post-Poplar, (Item 5) Station 78.01. Pressure level: Poplar, 50 psi.



Figure 3.22 Preshot, (Item 6) Etstion 1200, Site Charlie looking toward surface zero.



TABLE 3.2 RECORDED RADIATION WITHIN STATION 560.01 (ITEM 2)

See Figure 3.5 for a detailed location of film badges.

Plan of Film-Badge Locations



• Film badge located 3 feet above floor ^{II} Film badge located on ceiling

					Radi	ation,	r, at F	ilm-B	adge Lo	catior	ទេ				
Shot	-			B	C		Γ	5		2		F		G	
·····	a*	bţ	a*	bt	2*	ht	8.*	bţ	R*	b†	a*	bt	a*	<u>c</u> ‡	dš
Fir	4.1	_	5.0		3.0	_	3.0	_	3.0		6.0	_		_	_
Sycamore	0.60		0.10	_	0.15		0.09		0.09		0.15	—			
Aspen	20.0	22.0	4.8	4.8	3.4		2.3		3.2		5.2	4.4	2.5	2.6	2.2

* Plane of badge on surface of wall or ceiling.

† Plane of badge normal to both wall and ceiling.

t Plane of badge normal to ceiling and parallel to short wall. S Plane of badge normal to ceiling and parallel to long wall.



Figure 3.23 Post-Fir, (Item 6) Station 1200. Pressure level: Fir, 20 psi.

50



All the wave stations survived the effects from air blast and water waves generated from Shot Maple; however, Station 50.04, which weighed about 10 tons, was thrown approximately 300 feet. The footing of Station 50.01 was cracked vertically. A preshot view of Stations 50.01, -.02, and -.03 is shown in Figure 3.28 and a post-Maple view in Figure 2.29(a). A large concrete block weighing approximately 15 tons (shown in the foreground of Figure 3.28) was thrown



Figure 3.25 Preshot, (Item 8) Station 2410.02, Site Fox.

approximately 150 feet by the force from the water wave generated by the shot. The final position can be seen in Figure 3.29(a). However, no structural damage was observed for this block which was located in the 340-psi range from Shot Maple.

These stations were subjected to thermal radiation with values ranging from 400 cal/cm² to 1,200 cal/cm² for Shot Maple without noticeable effects. Shot Redwood then subjected the stations to higher values of thermal radiation ranging from 800 cal/cm² to 2,000 cal/cm².



Figure 3.26 Post-Maple, (Item 8) Station 2410.02. Pressure level; Maple, 85 psi.

As a result of Shot Redwood, the two closest stations, 50.01 and 50.02, were destroyed. Station 50.03 was moderately damaged; the leeward pipe of the gage tower buckled laterally, leaving the whole tower tilting away from surface zero. Station 50.04, which had its base completely exposed (i.e., was not buried) was washed to the far side of the island. Stations 50.05 and 50.05 remained undamaged.



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Figure 3.27 Flan and elevation for wave stations, (Item 10) Stations 50.01 through 50.06, Site Fox.

53

Station 50.03 which survived both shots is shown in Figures 3.29(b) post-Maple and 3.29(c) post-Redwood.

3.3.3 Item 11, Station 1810, 1830 Redwing. A reinfor ed-concrete shelter was rehabilitated for use in Operation Hardtack and a large plywood room added to the station between the existing structure (Redwing 1830) and Station 1030 (Redwing 1528).

A pre- and post-Maple view of the structure is shown in Figures 3.30 and 3.31. The blast



Figure 3.28 Preshot, (item 10) Stations 50 01, -.02, and -.03, Site Fox.

effects (14 psi) destroyed the plywood room but caused no structural damage to the existing reinforced-concrete structures.

No additional damage was sustained as a result of Shot Redwood.

3.4 SITES SUGAR AND TARE

The effects of Shot Nutmeg (24 kt), Hickory (13.4 kt), and Juniper (63.8 kt) are reported



Figure 3.29(a) Post-Maple, (Item 10) Stations 50.01, -.02, and -.03. Pressure levels: Maple, 350 psi, 260 psi, and 190 psi, respectively.

herein. The shot geometry, with pressure contours and test stations for these sites, is shown in Figure 3.32. A post-Nutmeg picture, Figure 3.33, taken from above surface zero shows most of the test stations. A comparison of Figures 3.34 and 3.35 shows the damage to the timber bulkhead and sandbags located at the end of Tare before and after Shot Nutmeg. Severe shock from the first shot crubed the recording disks for both air-overpressure gages, the locations of which are shown in Figure 3.32. However, the records were pieced together and the recorded results for Stations 174.33A and B were 265 psi (estimated peak) and 310 psi, respectively, while

54

the predicted preasures for these two locations were 330 psi and 310 psi, respectively.

Shot Hickory had no appreciable effect on the island or any of the structures on the island. The east end of Site Tare was severely washed by the effects of Shot Juniper as can be observed in Figure 3.36 showing that Items 14, 15, and 16 are now located in water, while Item 17 is now located on the high tide line. No structural damage was imparted to any of the structures.



Figure 3.29(b) Post-Maple, (Item 10) Station 50.03. Pressure level: Maple, 190 psi; 800 cal/cm².

3.4.1 Item 12, Stations 2200 and 2250. Station 2200, a reinforced-concrete, photographic bunker was originally constructed and remained undamaged during Operation Castle (1954). The station was rehabilitated with additions for Operation Redwing (1956) and received damage only to several adjoining retaining walls. For Operation Hardtack (1958), the station was again re-



Pressure level: Redwood, 360 psi, 1,400 ca $\sqrt{\text{cm}^2}$.

habilitated with more additions. A 150-foot diagnostic tower designated as Station 2250 was erected atop Station 2200.

The stations were located in the 8.2-psi range from Shot Hickory and minor damage was received by the elevator cab of the tower. No damage was incurred from the other shots. A general postshot picture is shown in Figure 3.37.

55

TABI .. 3.3 RECORDED RADIATION WITHIN STATION 78.01 (ITEM 5)

See Fi, ure 3.18 for detailed location of film badges. All badges are located 3 feet above floor level.

Plan of Film-Badge Locations



	Í						Rad	istion	. r. et	Film-	Badge		lons						ŀ
Shot	ĺ	<			ľ			υ			Δ		шĮ	64	υŀ	≍Ì	-ŀ	- •	×ŀ
	* 8	1	탕	* C5	م	et t		÷	5	-	à	5	:	•					
Fir Sycariore Maple Aspen	3.7 0.9, 1.3	3.0 1.1 1.6	1135	3. 7 1. 1 1. 1	1133	27	0.01 0.1 0.8	1118		0 1.2 0.6	1123		0000	0 0 0	0 0 0	0 0 0	0 0 0		
* Plane of	bid	ns uo	ríace	llew Jo															

TABLE 3.4 FREE-FIELD AIR-OVERPRESSURE MEASUREMENTS, SITES CHARLIE AND TARE

Maximum See Figure 3.15 for location of Stations 174.22A and B and Figure 3.32 for location of Stations 174.33A and B. Ground d/W^{1/3} Positive Maximum Darves d/W^{1/3} Positive

Shot	Site	Range	ft/htt1/3	Duration	Overpressure	Hange (d)	ft/ht1/3	Duration	Overpressure
		<u>n</u>		80C	psí	1		Bec	psi
Fir Sycamore Aspan	Charlie	Station 5,715 5,715 5,715	174.32A 515 1,259 836	1.325 1.043 1.720	44.5 7.1 14.5	Station 5,826 5,826 5,826 5,826	174.32B 525 1,284 852	1.047	36.0 7.3 12.6
Nutmeg	art	Station 638	174.33A 221		310.0	Station 633	174.33B 221		265 *

* Partial record, peak overpressure was ustimated.

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56

3.4.2 Item 13, Station 2210. A reinforced-concrete, sand-mounded connector pit with the front wall sloping at $1/_2$ to 1 on the side facing the zero station was constructed during Operation Harcwck (1958). The walls (except the sloping front wall) were about the same size and configuration as those of the structure shown in Figure 3.41.

This structure was located in the estimated 170-, 90-, and 430-psi air-overpressure region



Figure 3.30 Preshot, (Item 11) Station 1810, Site George.

for Shots Nutmeg, Hickory, and Juniper, respectively, and was not damaged structurally by any of the shots. A view of this structure prior to being mounded with sand is shown in Figure 3.38. Sand was placed level with the roof of the structure.





Figure 3.31 Post-Maple, (Item 11) Station 1810. Pressure level: Maple, 14 psi.

cand was constructed during Operation Hardtack (1958). A preshot view of this station prior to being covered with sand is shown in Figure 3.39.

This station was located in the estimated 490-, 260-, and 1,400-psi overpressure range for Shots Nutmeg, Hickory, and Juniper, respectively. Even though the station was exposed to extremely high overpressures it was not damaged structurally. A post-Juniper view of this structure is shown in Figure 3.36.









Figure 3.33 Past-Nutmeg, general view of Sites Sugar and Tare.

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59



Figure 3.34 Preshot view of timber bulkhead and saud bags at west end of Site Tare.



Figure 3.35 Post-Nutmeg view of timber bulkhead and sand bags at word: end of Site Tare. Pressure level: Nutmeg, 650 psi.



Figure 3.30 Post-Juniper view of east end of Site Tare looking toward surface zero.



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Figure 3.37 Post-Nutmeg, (Item 12) Stations 2200 and 2250.





Figure 3.38 Preshot, (Item 13) Station 2210, Site Tare, prior to being covered with sand.



Figure 3.39 Preshot, (Items 14, 15, and 16) Stations 2270, 2220.01, and 2230.02, Site Tare, prior to being covered with sand.



Figure 3.40 Post-Nutmeg, (Items 15 and 16) Stations 2230.01 and 2230.02. Pressure levels: Nutmeg, 350 and 320 psi, respectively.



Figure 3.41 Plan and elevation including the location of self-recording accelerometers for (Item 16) Station 2236.02, Site Tare.

63

3.4.4 Item 15, Station 2230.01. A reinforced-concrete detector structure was constructed during Operation Hardtack (1958). For practical purposes the plans for this station were the same as those shown in Figure 3.41 for Station 2230.02 except that the walls were 6 inches greater in thickness.

This station was located in the estimated 350-, 200-, and 1,050-psi air-overpressure range for Shots Nutmeg, Hickory, and Juniper, respectively, and was undamaged. However, the structure settled 5 inches and moved 1.5 inches toward surface zero after Shot Nutmeg. Comparable measurements after the other two shots are not available. For a general preshot view of this structure prior to being mounded with sand, see Figure 3.39. A post-Nutmeg view, including the removed closure plugs, is shown in Figure 3.40.

3.4.5 Item 16, Station 2230.02. A reinforced-concrete detector structure was constructed during Operation Hardtack (1958). The plan and section for this structure, including the location



Figure 3.42 Post-Nutmeg, (Item 16) Station 2230.02, close-up of damaged 42-inch corrugated metal pipe. Pressure level: Nutmeg, 320 psi.

of self-recording accelerometers, are shown in Figure 3.41.

This station was located in the estimated 320-. 180-, and 1,000-psi air-overpressure range from Shots Nutney, Hickory, and Juniper, respectively, and was undamaged. However, see water that leaked past the closure plugs into the structure as a result of the water wave from Shot Nutmeg corroded the recording disks of the accelerometers, thus clusing a loss of the data. A general, preshoi view of the structure and the attached 42-inch, round, corrugated-metal pipe, prior to being mounded with sand, is shown in Figure 3.39. Damage to the pipe after Shot Nutmeg is shown in Figures 3.40 and 3.42.

3.4.6 Item 17, Station 630.01. A reinforced-concrete instrumentation pit was constructed during Operation Hardtack (1958).

The station v_{3k} situated in the estimated 210-, 120-, and 560-psi air-overgressure range from Shots Nutmeg, Hickory, and Juniper, respectively, and suffered no apparent damage.

64

Chopter 4 RESULTS: ENIWETOK ATOLL

This chapter pertains to the results obtained at the Eniwetok Atoll; however, the introductory remarks of Chapter 3 are applicable here as well.

The general test results and description of the stations investigated at Eniwetok, including estimated peak overpressure, duration, free-field gamma radiation, and floor-slab acceleration where applicable, are summarized in Table 4.1.

4.1 SITES GENE, HELEN, AND IRENE

The effects of Shots Koa (1.38 Mt), Yellowwood (340 kt), Tohacco (11.7 kt), Walnut (1.45 Mt), Elder (940 kt), Dogwood (397 kt), Olive (202 kt), and Pine (2.1 Mt), are reported at these sites. The shot geometry, with pressure contours and test stations, is shown in Figure 4.1. The detailed information concerning the effects on the various stations from each shot is presented in Table 4.1.

Small craters ranging from 30 to 60 feet in diameter and 6 to 10 feet deep dotted site Irene and were generally located near the long pipeline extending from Station 1410 to ground zero. It is believed that these craters were of the impact type (as indicated by wide, flat bottoms) and formed by missiles (possibly concrete blocks used for the pipeline foundation or pieces of coral) resulting from Shot Koa. A typical crater of this type is shown in Figure 4.2; the concrete block in the picture was one of the foundation blocks for the pipeline.

4.1.1 Item 18, Station Complex. A reinforced-concrete recording station was constructed during Operation Redwing (1956) and received no major damage during thet operation. This station was rehabilitated for use in Operation Hardtack (1958), and various parts of it designated as Stations 73.01, 1314, 1524, and 1611. The general plan for the station complex and other adjoining stations is shown in Figure 4.3.

The highest overpressure received by the complex was an estimated 42 psi from Shot Koa. The interior of the station was not damaged by any of the shots. The reinforced-concrete wing wall located at the entranceway (Figure 4.4) was slightly cracked prior to any of the shots. The wing wall was not keyed to the structure nor was reinforcing steel used to the two together. The wall was side-on to the blast wave from Koa (40-psi range) but received no additional damage. The same wall was face-on to the blast from Yellowwood (11.5-psi range) and was cracked loose from the main structure. The vertical crack was approximately $\frac{3}{4}$ inch wide and extended the entire height of the wall (Figure 4.5). The wall failed from the face-on blast effects of Walnut (28-psi range) and cracked loose at the intersection of the ground surface behind the wall (Figure 4.6). The results obtained from the film badges located as shown in Figure 4.3 are shown in Table 4.2.

4.1.2 Item 19, Station 1525. A reinforced-concrete diagnostic station was constructed during Operation Hawitack (1958). The general location of this station is shown in Figure 4.3 and the detailed plan and elevations are shown in Figure 4.7.

This z_{1}^{+} is non-received the highest estimated overpressure of 42 psi from Shot Koa. The retaining wall integral with the front wall of the structure was severely damaged by face-on air relast from Shot Koa but received no additional damage from Shots Yellowwood or Tobacco. However, one end of the wall was destroyed by Shot Walnut. A preshot view of the front wall with

65

					Ground		Pred	icted		
Bite	Item Number	Station Description	Shot	Yield	Range to Ground Zero or Burlace Zaro	Peak Overpresentre	Duration	Irteal Free-Field Gamma Rediation	Floor Stab Adceleration	Romarka
					đ	Z	2	1/I	•	
1	•	and a second second		1 10 10		57	1.05	13, 660	L .3	No deman
	9	claiter company A contrate	Vallorented			511	1.65			Light demons to
		Defution (combination of						ł		retaining wall
		Stations 15:4. 1326, and	Tobacco	11.7 M	6.140	1.9	0.89	8	•	No additional damage
		1311). We demans to interfer	Walnut	1.45 Mt	6.510	-	1.8	000	3.6	Retaining wall fuiled
		of station from those Anache.	Ekter	1976	6,140	1	1.80	4.100	2.3	No additional damage
		Seminola or Huran of Chart	Derwood		6.140	1	1.55	1,100	0.7	No additional damage
		ation Raducine.	Olim	202 H	6,140	9.5	1.30	7	0.2	No additional damage
			Pine	2.1 MC	7,720	28	2.30	1,400	7	No additional damage
	19	Station 1525. A reinforced	Kos	1.36 M	5,300	4	1.85	15,900	:	Bevere damage to
	l	cenerate Fluor station.								restated well
		+	/ Yaliowwood	340 14	6,700	11	1.67	9	9.4	No additional damage
			Tobacco	11.7 h	6,340	1.2	16.0	1	•	No additional damage
		¥ J	Walnut	1.45 Mt	6,700	21	8 8	3,040	3.2	Retaining vali fulled
		i.	Elder	19 PF	6,240	អ	1.82	2,000	2.C	No additional damage
		~ ~ `	Dogwood	194 HR	6,340	1	1.57	8	0.6	No additional damage
		~ ~	Olive	202 ki	. 6,340	•	1.40	- 280	0.2	No additional dumage
			Place	2.1 Mt	1,000	5 8	7.33	1, 1,100	3,2	No additional damage
	8	Statt ~ 1311. A concrete	New York	道 第 11	5,290	4	1.85	11 15,000	6.0	Light durings
		detyctor station mounded	Tallowcodd	19 H	6,400	11	1.55	9 9	0.4	No additional damage
		with earth.	Tobacco	11-7 ht	6,120	1.9	0.39		•	No selditional damage
		•	Walnut	1-46 MH	6,480	8	1.96	4,000	3.5	Additional light dam-
						,			4	•
			. Elder	1 91	6,120	ន	1.80	3,500	3	No selectional damage
			Dogwood	보니	6,120	21	1.55	1,100		No solitional damage
			Olin	202 ki	6,120	9-6	1.36	ŝ	0.2	No additional damage
			Plat	2.1 Mt	7,670	72	2.30	1,26 0		No additional damage
	21	Stations 1410 and 1211. A re-	No.	1.30 Mt	5,210	4	1.85	2,800	1.4	No dements
		inforce, concrete structure	Yellowwood	보이다	6,710	a	1.57	\$	0.8	No damage
		and terminus of pipeline	Tobacco	11.7 ht	6,380	1.6	0.91	*	•	No damage
			Walnut	1.45 Mt	6,710	58	7	3,000	3.2	No damage
			Elder	보유하	6,380	21	1.82	2,500	2.0	No damage
			Dogwood	Ř	6,380	51	1.57		9-9	No detraction
			Olive	202 hi	9,300	œ	1.40	270	C.2	No damage
			Place	2.1 Mt	7,870	8	2.32	1,000	. .	No damage

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ALC: NO ALC: NO ALC: NO

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TABLE 4.1 CONTINUEL

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							LIG			
	Item			:	Hange to				1	
Site	Number	Station Description	Staot	Yield	Ground Zero or Burface	Peak Overpressure	Duration	Vree-Field Gamma	Floor Stab Acceleration	Rer arks
				1	Zero			Rediation		
					¥	Ĩ	3ec	r/hr	•	
Irene	22	Station 3.4. A reinforced concrete	Koe	1.36 Mt	5,850	2	1.90	7,000	4.9	No damage
		signal terminal pit.	Yellowwood	340 kt	6,130	13	1.50	1,000	0.5	No damage
		,	Tobacco	11.7 kt	5,620	2.1	0.56	10	•	No demage
			Walnut	1.45 Mt	6,130	32	1.63	6,700	* *	No (amage
			Elder	940 kt	5,620	53	1.74	6,700	3.1	No damage
			Dogwood	397 kt	5,620	91	1.48	2,500	0.9	No damage
			Olive	202 H	5,420	11	1.32	7 6 0	0.3	No demage
			Pine	2.1 Mt	7,490	2	2.29	1,500	3.6	No damage
	23	Generators. Four, 75-kva, Masal-driven witte	Kon	1.36 Mt	5,610	R	1.86	10,000	5.3	Severe Damage
	24	Helicopter Pad. 8: wel landing mate	Koa	1.38 Mt	5,500	R	1.68	10,000	5.2	Complete destruction
Janet	25	Station 1312. A reinforced con-	Koe	1.38 Mt	12,100	9- 9	2.63	•	0.4	No damage
		crete recording tation.	Vellowrood	340 H	6,000	9	1.46	1,000	9.6	No damage
			Tobacco	11.7 kt	4,000	3.7	0.70	926	0.02	No damage
			Walnut	1.45 Mt	6,000	2	1.93	6,500	4.8	No damage
			Elder	년 96	4,000	3	1.56	46,000	8,6	No damage
			Dogwood	397 ist	4,000	31	1.29	19,000	2.9	No demage
			Olive	202 kt	4,000	21	1.12	7,500	1.0	No damage
			Pine	2.1 Mit	8,520	22	9 -1	280	2.3	No demagn
	26	Station 3.1.1. Three story	Kon	1.36 Mt	15,450	5.6	3.01		0.7	No damage
		test structure.	Yellowwood	340 년	8,460	-	1.79	3	0.2	No damage
			Tobacco	11.7 k	6,610	1.7	16.0	9	د ا	No damage
			Walnut	1.45 Mit	8,460	16	2.20	3	1.5	Severe changes to Bldg
										st, light dumage to Ride A
			e lider	1070	6 210	Ł	1.85	2 000	1.8	Bide 5 collement and
				ł		1				ersis dumant to Ride
										4 and 6, light damage
										to Eldgu 2 and 3.
			Dogwood	2 7 E	6,610	12	1.60	610	0.5	No additional damage
			Olive	202 kt	6,610	8.4	1.44	280	0.2	No additional damage
			rue	2.1 Mt	10,870	13	2.65	10 ±	1-1	No additional datange
	12	Station 3 1.3. La Jerground	Kos	1.36 ML	14,250	6.4	2.86	1*	0.3	No damage
		test structure.	Yellowwood	346 FL	7,450	8.6	1.55	190	3.3	No dum age
			Tobacco	11.7 kt	5,520	3.3	0.85	\$	0	No damage
			Wainst	2 2 1	7,450	21	2.09	1,400	2.2	No di: mage
			Elder	140 kt	5,520	R	1.73	7,400	32	No dam ega
			Dogwood		5,520	17	1.47	2,300	0.9	No damage
			Oliwe	202 H	5,520	11	1:31	1,100	0.3	No damage
			Pise		9,910	9	2.54	150	14	No damage

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TABLE 4.1 CONTINUED

					Grand		Pred	tetad		
					Paner to			laitial		
Site	ltem Number	Bration Description	Shot	Yield	Ground Zero or Burlace Zero	Peak Overpressure	Duration	Free-Field Gamma Radiation	Floor Slab Acceleration	Remarks
1				{	z	Ā	Pec	1/JFL	•	
Innet	12	Station 20-8. Stateforced	Kon	1.26 Mt	13,920	6.6	2-84	34	0.3	No damage
į	1	CONCINIE ERRY (ART.	Tellewood	340 14	6,890	10	1.60	370	6.3	No destruga
			Tobacco	11.7 ht	5,010	2.6	0.78	75	0.01	No deserves
			Wainut	1.45 ML	6,890	2	2-03	2,650	2.8	Severe damage, fall-
										ure at base of stam
			Ekter	Den Ist	5.010	35	1.67	14,000	9.4	*
			Dogwood	287 kt	5,010	20	1.40	4,500	1.3	ł
			Olive	파 202	5,010	1	1.24	2,100	0.5	ł
			Pine	2.1 Mit	007'6	55	2.49	8	1.8	1
	8	Stution 77.02. A relatorced	Kok	1.36 Mft	16,640	2.2	3.15	0.2	0.1	No diamage
		concrete, each mounded	Yellowwood	340 ht	6,790	9	1-61	ž	0.2	No damage
		timise stice.	Tobacco	11.7 ht	7,200	9:1 1	0.96	\$	•	No demage
			Wainst	1.45 Mt	8,790	۰,	2.24	280	1.3	No damage
			Eldar	14 0F6	7,200	11	1.8.1	1,000	1.4	No damage
			Dog' ood	397 kc	7,200	10	1.67	980	0.4	No damage
			olim	202 ht	7,200	7.2	1.53	110	0.1	No damage
			Pine	2.1 Mft	10,770	14	2.63	2	1.1	No damage
	2	Lar ding Pier.	Koa	1.36 Mft	14,670	6.2	2.90	9 .0	0.2	No damaga
		•	Yellowmood	340 ht	7,200	9.5	1.63	550	0.3	No damage
			Tobacco	11.7 kt	5,400	2.3	0.83	45	Q	No darrage
			Waltnut	1.45 Mt	7,200	ន	2.06	1,500	2.5	Light damage
			Elder	940 ht	5,400	8	11-71	9,400	3.7	Additional light damage
			Dogwood	397 kt	5,400	17	1.45	3,000	1.0	No additional damage
			Olive	202 ht	5,400	12	1.29	1,100	0.4	No additional damage
			Pine	2.1 Mt	9,470	18	94-i	220	1.8	No additional damage
		Janet Camp	Kot	1.38 Mt	16,200	52	3.10	0.7	0.1	Complete destruction
Yvame	31	Sta for 1130. A reinforced	Carcture	17 ka	895	450	0.36	300,000	32	Light damage to
		concrete bunker with a								tumpel only
		stde turnel.								
	32	Bts-ion 1220.01 Cubicle	Carctus	17 kt	200	450	0.36	300,000	32	Severe damage
		er ounted on a structural								
		steel platform.								
	33	Station 1216 reinforced	Cactus	17.Jat	200	450	1.38	300,000	32	No damage
		concrete town load for a								

68

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pipeline.

TABLE 4.1 CONTINUED

Teen eester Deerlat	and	. 8	ă	The		1		Iree-Field	Floor Slab	Benefits
Number Station Dissertiguon and	Buation Userription base a sec					Overpresente	Duration	Camus Reduction	Acceleration	Kemaru
				1	-	ž	ä	2/12	5	
34 Station 1612 . A reinforced Cactus 17 ht	Station 1812 . A reinforced Cactus 17 ht	Cactua 17 ht	17 ki		M	1,600	X	650,000	061	Severe damage to re- taining walk licht
concrete, sarth-monuded Tritar station.	concrete, saruh-mounded Triten station								;	damage to structure.
35 Stational 1823.01. to .04. Carctas 17 ht	Stational 1823.01 to .04. Cactual 17 ht	Carctus 17 ht	17 kc		ł	3	0.34	100,000	32	Complete destruction
Four stani-pija towars en-	Four staal-plie towers on-									
e diette 1910 - Jarme maadiwe. Carine 17 ki	canned by pays out covering. Section 1910 - Jarme massive. Caribes 17 kt	Cartes 17 bt	17 ki		4,136	4.5	0.75	9	0.01	No damega
and the second and a second a	and the second sample for the second se	Parternal 00 In	19		128	ŭ	6.37	2,200	0.3	No damage
remuted after date and the first set of	remotion division, and the Hally field it	Holly 5.8 It	5.8 ht		2,120	7.6	0. ÷1	2,800	0.U	No demage
Marradia 51 kt	Marmolia 57 ht	Marrolia 57 ht	57 ht		1.126	91		5,700	9.4	No damage
Rear 14.5 H	Rome 14.5 ht	Rose 14.5 H	14.5 kt		4.126	4.2	0.74	Ř	6.02	Xo damage
		11.14	11.1 14		2.120	12	3	5,500	0.1	No demonstrate
factoria 5.2 ft	ti C.S. Element	Security 5.2 Lt	5.2 kt		2.120	1.1	1	2,500	9 .0	Ko damana
Pie 21.6 tons	21.6 tons	Ple 21.6 tons	21.6 toms		1,100	1.1	١	360	•	No damega
Plennis 256 b	Plennin 266 ht	Discrete 266 bt	266 14		12.000	3.3	2.10	•	•	No damange
ar thread a 21 Ann and Rutharrant 60 ht	tutter tork A 21 AND and Butternet 60 kt	Butternut 60 ht	198		5.510	9	1.13	350	0.0	Light dumage
		uolle 5.6 ht	S.R Int		4.200	2.4	0.66	190	•	No additional damage
Little of Arthouse Manage in the second of t		Memolia 67 M	1 5		4.810	*-	1.8	995	8.0	Additional light durage
		14.5 ht	14.5 ht		5.510	2.5	96 .0	4	0.02	No additional inner
		11.11	11.11		4.200	1	0.70	និ	0.01	No additional demage
			1111		1 200	2.2	0.64	100	ø	No additional damage
Prisonia 255 kt	Placenta 265 kt	Placenta 255 ht	256 kt		14,400	2.6	2.15	•	•	Yo additional damage
		1 5	11 11		1 740	1.4	1.06	1.4	0	Severa damage
Yvonce Catap. Cactual If Rt	Yronce Carely. Cactual 17 43	CACTURE IT IS							2	Constant destruction
		AL-MANAL BA MA	19		25.5		1.13	R	3.5	

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TABLE 4.2 RECORDED RADIATION WITHIN STATION COMPLEX (ITFM 18)

See Figure 4.3 for detailed location of film balges. All budges are located 3 feet above floor level with the plane of the badge on the surface of the wall except as noted.

Plan of Film-Badge Locations

				E E	C.	The last				
			Rad	liation, r,	at Film	-Badge	Locati	ons		
5001	A	A ₁ *	В	C	D	E	F	G	Н	Īţ
Koa	90.0	_	46.0	4.90	1.02	0.52	0.17	0.12	0.11	
Yellowwood	44.0	-	220.0	5.00	0.30	0.10	0	0	0	—
Walnut	800.0	-	950.0	130.0	7.85	i.80	0.77	-	—	
Elder	700.0	700.0	620.0	44.0	10.2	1.80				830.0

* Plane of badge normal to both wall and ceiling.

† Plane of badge on back side of I-beam stiffener of blast door.



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Figure 4.2 Post-Koa, typical impact crater, 4,800 feet from ground zero.

71



Figure 4.3 PL.n of station complex on Site Irene.



Figure 4.4 Preshot, (Item 18) station complex, close-up of entrance and crack in wing wall, Site Irene.


Figure 4.5 Post-Yellowwood, (Item 18) station complex, close-up of entrance and cracked wing wall. Pressure levels: Koa, 42 psi; Yellowwood, 11.5 psi; and Tobacco, 1.9 psi.



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Figure 4.6 Post-Walnut, (Item 18) station complex, close-up of wing wall failure. Pressure level: Walnut, 28 psi.

73





its painted surface is shown in Figure 4.8. The retaining wall cracked around the outline of the side walls and ceiling of the structure as shown in Figure 4.9. The diagonal cracks indicate the bending failure of the wall. A side view is shown in Figure 4.10. The damage from Shot Walnut is shown in Figure 4.11. No significant damage was observed from the remaining shots.

Thermal radiation burned the paint off the structure, as can be observed by comparing Figures



Figure 4.8 Preshot, (Item 19) Station 1525, Site Irene.

4.8 and 4.9; the total thermal radiation was approximately 350 cal/cm^2 .

4.1.3 Item 20, Station 1311. A reinforced-concrete detector station was constructed during Operation Hardtack (1958). The general location of this station is shown in Figure 4.3 and the detailed plan and elevations are shown in Figure 4.12.



Figure 4.9 Post-Koa, (Item 19) Station 1525, filte-on view. Pressure level: Koa, 42 psi; 350 cal/cm².

The highest overpressure received at this station was an estimated 42 psi from Shot Koa. The station was structurally damaged mainly from the effects of Shots Koa and Walnut. A preshot view of the retaining wall for this station is shown in Figure 4 13, a post-Koa view is shown in Figure 4.14, and a post-Walnut view is shown in Figure 4.15.

The thermal radiation (and sand blast) had some surface effects on the retaining wall; the thermal radiation was approximately 350 cal/cm^2 .

75

The entrance to this station was nearly filled with sand as the result of Shot Koa, as shown by comparing Figures 4.16 and 4.17.

The plain-concrete floor of this station was badly cracked and the five 24-inch pipes entering this station were forced inward about $2\frac{1}{4}$ inches (Figure 4.18). The crack pattern (shown in Figure 4.19) indicates that the existing foundation underneath part of the floor gave additional support to that portion.



Figure 4.10 Post-Kon, (item 19) Station 1525, side-on view. Pressure level: Kon, 42 psi.

4.1.4 Item 21, Stations 1211 and 1410. A reinforced-concrete structure situated at the Irene terminus of a large pipeline from Gene was erected during Operation Hardtack (1958). The highest pressure received by this station was an estimated 43 psi from Shot Koa. The structure was not damaged structurally by any of the shots. However, the earth cover on the



Figure 4.11 Post-Walaut, (Item 19) Station 1525, retaining wall failure. Pressure level: Walaut, 27 psi.

side of the structure facing surface zero for Shot Walnut was blown and washed away, exposing the concrete wall surface (Figures 4.20 and 4.21).

A preshot view of the 5,200-foot-long pipeline leading from this station to ground zero is shown in Figure +.22. A postshot view is shown in Figure 4.23. Only about 800 feet of pipe farthest from ground zero remained in the area and connected in one piece after Shot Koa. This

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Figure 4.12 Plan and elevations for (Item 20) Station 1311, Site Irene.





Figure 4.13 Preshot, (Item 20) Station 1311, face-on view of retaining wall, Site Irene.



Figure 4.14 Post-Koa, (ltem 20) Station 1311, face-on view of retaining wall. Pressure level: Koa, 42 psi; 350 cal/cm².

78



Figure 4.15 Post-Walnut, (Item 20) Station 1311, face-on view of retaining wall. Pressure level: Walnut, 28 psi.



Figure 4.16 Preshot, (Item 20) Station 1311, entrance, Site Irene.

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Tigure 4,18 Post-Koa, (Item 20) Station 1311, 24-inch steel pipes pushed inward $2\frac{1}{4}$ inches. Pressure level: Koa, 42 psi.

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Figure 4.19 Post-Koa, (Item 20) Station 1311, crack pattern in floor. Prossure level: Koa, 42 psi.



Figure 4.20 Preshot, (Item 21) Stations 1211 and 1410, view of side wall facing surface zero, Site Irene.



Figure 4.21 Post-Walnut, (Item 21) Stations 1211 and 1410, view of exposed side wall. Pressure level: Walnut, 26 psi.



Figure 4.22 Preshot, pipeline to ground zero, Site Irene.



Figure 4.23 Post-Koa, pipeline to ground zero. Pressure level at near end: Koa, 45 psi.

portion was thrown from the concrete supports and was bent into a semicircular pattern with an appr mimate radius of 200 feet. The line of concrete supports is shown in the left portion of Figure 4.23. Most of the missing portions of the pipe were thrown into the area to the right in Figure 4.23.

4.1.5 Item 22, Station 3.4, Castle. A reinforced-concrete, signal terminal pit with a gravel floor was constructed and undamaged during Operation Castle (1954); neither was it damaged during Operation Redwing (1956).

The highest estimated pressure received by this station was an estimated 34 psi from Shot Koa. The station was not damaged structurally from any of the shots. However, the hatch cover was not bolted down and the force from Shot Koa moved it horizontally $\frac{3}{4}$ inch away from ground zero.

The plan for this station, including the locations of film badges, is shown in Figure 4.24. The

TABLE 4.3 RECORDED RADIATION WITHIN STATION 3.4 (ITEM 22)

See Figure 4.24 for detailed location of film badges. All badges are positioned with the plane of the badge on the wall surface.

Film-Badge Locations



Koa 6.44 6.79 8.59 Yellowwood 6.29 1.77 0.68 0.67 0.65 Walnut 375.0 21.2 18.0 20.0 104.0 Elder 460.0 35.0 28.0 21.0

results of the film-badge readings are shown in Table 4.3. The water-wave action from Shot Walnut eroded the earth cover away from this structure, as shown in Figures 4.25 and 4.26. The dark area on the concrete walls represents the contact area of the preshot earth cover.

4.1.6 Item 23, Generators. Four 75-kva, diesel-driven generators (each 120 inches long, 37 inches wide, 78 inches high, and each weighing 6,700 pounds), located behind the station complex, were left in operation during Shot Koa.

The generators were located in the estimated 38-psi air-overpressure range for Shot Koa and were severely damaged. A preshot view of the generators is shown in Figure 4.27 along with standard, Navy, steel pontoon sections used as fuel tanks.

The earth mound approximately 15 feet above the ground surface for the station complex shielded the generators from the air blast to varying degrees. The generators were located approximately 40 feet from the intersection of the mound with the ground surface. The generator near the edge of the mound (least protected from air blast) was thrown 60 feet while the gen-

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84 SECRET



Figure 4.25 Preshot, (Rem 22) Station 3.4, side view, Site Irene.



Figure 4.26 Post-Walnut, (Item 22) Station 3.4, side view showing scouring action of water wave; dark area represents original earth cover contact aren. Pressure level: Walnut, 32 psi.



Figure 4.27 Preshot, (Rem 23) generators, Site Irene.



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erator nerver the center of the mound (most prefected) was moved 2 feet. The other two generators were thrown distances of 20 and 40 feet. A postshot view of the four generators is shown in Figure 4.28 and a close-up of one of the generators is shown in Figure 4.29. No additional damage to or movement of the generators occurred as the result of Shots Yellowwood (11.5 psi) or Tobacco (1.8 psi). The Na. ? pontoon sections were not damaged from any of the shots; however, the air blasts from Shots Koa and Yellowwood moved the sections approximately 100 feet. Both the generators and pontoon sections underwent additional movement during Shot Walnut (28 psi). Movement from the remaining shots was not observed.

4.1.7 Item 24, Helicopter Pad. A helicopter pad approximately 100 by 100 feet, constructed of standard, interlocking, steel landing mat, was located near the station complex.

This station was subjected to an estimated air blast of 38 psi from Shot Koa, and was severely damaged. Individual pieces of landing mat were bent, broken, and scattered over a wide area. Both the negative and positive phase of the air blast scattered the mat. Pieces were found 400 feet from the original location away from ground zero; other pieces were moved a similar distance toward ground zero. A postshot view of the landing mat is shown in Figure 4.30. Decause of the complete destruction resulting, from Koa no further observations were made for the remaining shots.

4.2 SITE JANET

The effects of Shots Yellowwood $(2 \le i^{+})$, Tobacco (11.7 kt), Walnut (1.45 Mt), Elder (940 kt), Dogwood (397 kt), Olive (202 kt), and Pine (2.1 Mt) were observed at Site Janet. Shot Koa had no real effect at this site. The shot geometry and pressure contours are shown in Figure 4.31. The thermal radiation from Yellowwood caused grass fires in scattered areas. Cracks on the ground surface apparently caused by ground shock from Shots Koa and Yellowwood were observed throughout the site.

4.2.1 Item 25, Station 1312. A large, 4-room, reinforced-concrete recording station was constructed during Operation Harutack (1958). The general plan for this structure, including the locations of the self-recording air-overpressure gages and accelerometers, is shown in Figure 4.32.

This station was located in an estimated 13-, 3.7-, 33-, 58-, 31-, 21-, and 22-pai air overpressure range from Shots Yellowwood, Tobacco. Walnut, Elder, Dogwood, Olive, and Pine, respectively, and was not damaged by any of the shots.

The concrete face of the structure facing surface zero was plitted from the effects of Walnut and Elder. The total thermal radiation on the face of the structure was approximately 275 cal/ cm² from Walnut and 450 cal/cm² from Elder. Since this station was very close to the shore line, the plitting of the front face must have been almost entirely the result of surface spalling of the concrete due to the thermal radiation. Steel surfaces exposed to this same radiation level on the face of the structure showed no structural effects.

The force of the water waves from Shot Walnut eroded the soil adjacent to the foundation of the structure to depths of 5 and 6 fee. (Figure 4.53). Shot Elder had no additional effect.

The correlation of results of shock-tube tests on diffraction-type targets with similar results of full-scale tests are complicated due to the effects of precursor and dust loading in the field, which are not present in the shock tube. Because of the absence of precursor and dust effects the opportunity was afforded at Station 1312 to obtain data on the effect of a fast-rise-time pressure pulse on a diffraction type structure, which could be more easily compared with similar results of shock-tube tests. Therefore, with the assistance of personnel of the Ballistics Research Laboratories, special efforts were made to obtain blast-diffraction data. For a detailed presentation of the diffraction study, see Appendix B.

The results - air-overpressure measurements are shown in Table 4.4. Due to malfunctions of the accelerometer gages no acceleration data was obtained.

86



Figure 4.28 Post-Koa, (Item 23) generators. Pressure level: Koa, 38 psi.



Figure 4.29 Post-Koa, (Item 23) close-up of damaged generator. Pressure level: Koa, 38 psi.



4.2.2 Item 26, Station 3.1.1, Greenhouse. A multistory, multicompartment structure was constructed during Operation Greenhouse (1951). During Greenhouse the structure was damaged due to a peak reflected air-blast overpressure of about 30 psi from Shot Easy (Reference 9). The air blast from Shot Item caused light damage. In general, the damage to the structure caused by the Mike shot of Operation Ivy (1952, Reference 1) was of the same order of magnitude as that caused by Shot Easy (Greenhouse). No additional damage was sustained by the structure during

TABLE 4.4 FREE-FIELD AIR-OVERPRESSURE MEASUREMENTS, SITE JANET

See	Figure	4.31	lor l	ocation o	f Stations	174.28	and 1	174.31.
-		the second se						_

Shot	Site	Ground Range (d)	d/W ^{1/3} ft/kt ^{1/3}	Positive Duration	Maximum Overpressure	Ground Range (d)	d/W ^{1/3} ft/kt ^{1/3}	Positive Duration	Maximum Overpressure
		ħ		58Q	psi	ħ		34C	pei
		Station	174.28	(near Static	on 1312)	Station	174.31	(near Statio	a 3.1.1)
Yellowwood	Janet	5,995	859	_	16.5	8,254	1,183	1.956	7.3
Tobacco		3,906	1,758	0.719	3.8	6,094	2,814	0.901	1.8
Walnut		5,995	529	1.708	43.0	8,254	729	2.057	15.0
Elder		3,996	407		71.0				

Operation Castle (1954, Reference 10) or Operation Redwing (1956, Reference 11). The overall perspective for this structure is shown in Figure 4.34.

This station was located in an estimated 7.0-, 1.7-, 16.0-, 20-, 12-, 8.4-, and 13-psi airoverpressure range for Shots Yellowwood, Tobacco, Walnut, Elder, Dogwood, Olive, and Pine, respectively. The effects from Tobacco receipted negligible and no further mention of that shot will



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Figure 4.30 Post-Koa, (liem 24) helicopter pad. Pressure level: Koa, 38 psi.

be made. An overall, pre-Hardtack view of this station is shown in Figure 4.35. A preshot view of typical damage to a first floor column (Col. 13C) in Building 5 is shown in Figure 4.36. Building 5, a role forced-concrete structure with window openings, received more damage from previous operations than any other of the buildings. The other noticeable damage from previous

88



Figure 4.31 Shot g ometry with pressure contours for Site Janet.

89 SECRET








Figure 4.33 Post-Walnut, (Item 25) Station 1312, erosion adjacent to foundation. Pressure level: Walnut, 33 psi; Elder, 58 psi; 450 cal/cm².

operations was found in the roof of Building 4, a reinforced-concrete shear-wall structure, see Figures 4.37 and 4.38.

An overall view of post-Yellowwood (pressure level of 7.0 psi) is shown in Figure 4.39. By comparing Figures 4.35 and 4.39 it can be observed that the oil drums and supporting wood frames (outside center of building) were lightly damaged, indicating that the structure itself was



Figure 4.34 Overall perspective for (Item 26) Station 3.1.1, Elte Janet.

not damaged by the shot. A visual inspection and column-offset measurements (see Table 4.5) also proved that the structure received no appreciable damage from Yellowwood.

The structure responded appreciably to the effects of Shot Walnut (pressure level of 16 psi). Figures 4.40 and 4.41 show the overall damage, which can be compared with Figure 4.39 for pre-Walnut sumage. The corrugated siding on the metal buildings was damaged severally. Major damage was observed in Building 5; damage to the front face and first-floor columns is shown in

91



Figure 4.35 Presbot, (Item 26) Station 3.1.1, Site Janet.



Figure 4.36 Preshot, (Item 26) Station 3.1.1, Column 13C, concrete frame building, Site Janet.

92



Figure 4.37 Preshot, (Item 26) Station 3.1.1, crack in ceiling adjacent to Column Line 10 of the shear wall building looking away from surface zero, Site Janet.



Figure 4.58 Preshot, (Item 26) Station 3.1.1, crack in ceiling adjacent to north wall of the shear-wall building looking away from surface zero, Site Janet.



Figure 4.39 Post-Yellowwood, (Rem 24) Station 5.1.1. Pressure level: Yellowwood, 7 psi.



TABLE 4.5 COMPARATIVE DISPLACEMENT OF COLUMNS All reasurements in foot.

							Relative D	isplacemen					
::				Fire	st Floor				Second	Floor		Third F	oor
Building	Column	Puet-					Post-Dogwood,	Post-		Post-Dugwood,	Post-		Post-Dorwood.
Numbe r		3	Post -	Post-	Poet	Poet-	-Olive, and	Ivy	-1804	-Olive, and	<u>I</u>	-1804	-Olive, and
		(1952)	Kua	Yellowwood	Walnut	Elder	-Pine	(1952)	Elder	-Pine	(1952)		-Pine
	2	0.120	1.00.0	104	0.115	0.156	0.135	0.240	0.333	0.271	0.236	0.323	0.281
•	1 5	0.092	0.09	0.069	0.104	C.135	0.125	0.232	0.313	0.266	0.237	0.313	0.27]
	3	6.091	0.115	0.104	0.115	0.156	0.135	0.247	0.292	0.260	0.233	0.281	0.266
	8	0.001	1	ſ	ł	1	0.125	0.244	ł	ł	0.230	ł	I
	5	100.0	0.206	0.099	0.115	0.146	0.115	0.241	0.313	0.276	0.252	1	I
	8	0.107	0.104	0.099	0.104	0.135	0.125	0.238	0.313	0.266	0.252	ł	I
	Ş	0.060	0.043	0.063	0.094	0.115	0.104	0.241	0.313	0.313	0.250	ł	ł
	9	0.101	f	I	1	ł	0.125	0.226	Į		0.246	ł	1
•	11	0.118	0.1.5	0.115	0.146	0.292	I	0.181	0.36	0.354	0.206	0.365	0.406
•	78	0.132	0-1-6	0.135	0.156	0.292	ł	0.190	0.375	0.354	0.218	0.375	0.448
	10	0.111	0.1.15	0.104	0.146	J.271	I	0.210	0.354	0.333	0.224	0.406	0.427
	8	C.143	!	ĺ	0.167	0.313	0.302	0.195	0.385	0.365	0.215	ł	1
	8B	1.129	0.135	0.094	0.156	0.292	0.292	0.180	0.365	0.354	0.205	ł	1
	2	011-)	0.125	0.104	0.135	0.271	0.271	0.174	0.344	0.333	0.216	0.365	0.417
ŝ	VEI	0.248	0.219	0.230	1.063	Collapse	L- 						
	138	0.232	0.230	0.219	1.063	Collapae	1	1	•		<u> </u>		
	180	6.200	0.219	0.206	1.198	Collapse	1						
	51	0.200	0.208	0.219	0.990	Collapse	1	10				**	
	14B	0.209	9.230	0.214	1.042	Collapae		•					
	140	0.217	0.219	0.206	1.104	Collapse	<u>م</u>	- Serora		*			- 2 -
w	154	1022	0.021	0.021	0.083	0.146	0.146	∔- ₽					 }
	168	C.023	0.021	0.021	0.073	0.115	0.146						
	150	C.037	ł	1	ł	9.146	0.146				4		+
	164	C.048	0.042	0.042	0.073	0.125	0.125						
	168	0.032	9.031	0.031	0.063	0.083	I		•	0	F	of et at	_
	160	0.030	í	1	ł	0.083	0.089		Plan o	Columns Station	3.1.1 (ten	a 26)	

• Total permanent displacement of top of column (away from surface zero) relative to bottom of column.

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Figures 4.42 through 4.45. A pre- and post-Walnut view of Column 13C can be compared in Figures 4.36 and 4.45. The columns in the upper two floors of this building did not receive comparable damage as their first-floor counterparts (Figure 4.46). Evidently the first-floor columns took most of the moment and shearing forces while the second and third floors moved away from surface as a unit (Figure 4.42). The tops of the first-floor columns (Columns 13A, B, C and 14A, B, C) were displaced horizontally approximately 10 inches away from surface zero with respect to their bases (Table 4.5).



Figure 4.40 Post-Walnut, (Item 26) Station 3.1.1. Pressure level: Walnut, 16 psi.

The other three frame-type buildings (2, 3, and 5) underwent very little additional lateral movement (Table 4.5). It should be noted that the lateral movement as shown in Table 4.5 is the permanent displacement and not the peak transient deflection. Damage to columns in the third floor of Building 3 is sho. In Figures 4.47 and 4.48. A typical column of Building 2 is shown in



Figure 4.41 Post-Walnut, (Item 26) Station 3.1.1, aerial view. Pressure level: Walnut, 16 psi.

Figure 4.49; this picture also shows the suspended plumb bob that was used in measuring column offsets. The roof in Building 6 lifted upward 3 to 4 inches, tapering to its normal position at a point 7 or 8 feet from the front wall (Figure 4.50). The cracked roof section in Building 4 opened constint ably, being displaced a maximum of 10 inches at the center of the section adjacent to Column Line 10 and the north end of the building (Figures 4.51 and 4.52). The bottom bars (Nc. 4) of the slab failed in tension as was noted by the neck-down of the bars at the point of breakage.

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Figure 4.42 Post-Walnut, (Item 26) Station 3.1.1, close-up of Building 5, a reinforced-concrete frame structure. Pressure level: Walnut, 16 psi.



Figure 4.43 Post-Walnut, (Item 26) Station 3.1.1, front column of Building 5. Pressure level: Walnut, 16 psi.



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Figure 4.44 Post-Walnut, (Item 26) Station 3.1.1, second row of columns of Building 5. Pressure level: Walnut, 16 psi.



Figure 4.45 Post-Walnut, (Item 26) Station 3.1.1, third row of columns of Building 5. Pressure level: Walnut, 16 psi.

97



Figure 4.46 Post-Walnut, (item 26) Station 3.1.1, Column 13C, second floor of Building 5. Pressure level: Walnut, 15 psi.



Figure 4.47 Post-Walnut, (Item 26) Station 3.1.1, Column 8A, 19 2.1 floor of Building 3. Pressure level: Walnut, 16 psi.



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Figure 4.48 Post-Walnut, (Item 26) Station 3.1.1, Column 7B, third floor of Building 3. Pressure level: Walnut, 16 psi.



Figure 4.49 Post-Walnut, (Item 26) Station 3.1.1, Column 5C, first floor of Building 2. Pressure level: Walnut, 16 psi.

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Figure 4.50 Post-W 1994. (Item 26) Station 3.1.1, roof slab damage, Building 6. Pressure level: Walnut, 16 psi.

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Figure 4.51 Post-Walnut, (Item 26) Station 3.1.1, crack in ceiling adjacent to Column Line 10 of the shear-wall building looking away from surface zero. Pressure level: Walnut, 16 psi.

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The top bars (No. 5) held the cracked roof section in place.

Shi t Elder (pressure level of 20 psi) caused additional damage as can be compared by viewing Figures 4.53 and 4.54 with Figure 4.40. The shear resistance of the first-floor columns of Bullding 5, the concrete frame, drag structure, was overcome and the upper floors intact settled down with the second floor girders resting on the collapsed first floor columns (Figure 4.55). The column offset measurements for Buildings 2, 3, and 6 are shown in Table 4.5. A front view of Buildings 1, 2, and 3 is shown in Figure 4.56. Building 3, the reinforced-concrete (diffraction) structure underwent additional permanent lateral movement, but unlike its counterpart, Building 5 (drag-type structure), the columns on each floor displaced laterally approximately the same amount and showed signs of damage (Figures 4.57, 4.58, and 4.59). The rear wall of Building 3 cracked horizontally, evidently from bending (Figure 4.60). Buildings 2 and 6 deflected approximately $\frac{1}{2}$ inch away from surface zero. However, most of the roof section of Building 6 was blown upward by the blast and thrown to the ground surface to the rear of the structure (Figure 4.61). Channel shear keys welded to the roof girder are also visible in the picture as well as the damage to the roof at the south end of Building 4. The major damage to Building 4 occurred at the north end where the roof was punched inward and is supported by the cantilever effect of the reinforcing steel (Figures 4.62, 4.63, and 4.64).

The station was next investigated after Shots Dogwood, Olive, and Pine had been fired; the resulting estimated overpressure levels were 12, 8.4, and 13 psi, respectively. An overall postoperation view of the structure is shown in Figure 4.35. Little additional damage was observed for Buildings 2, 3, or 6. As shown in Table 4.5, the postoperation column displacements for Building 6 were approximately the same as those for post-Elder; the postoperation displacements for Buildings 2 and 3 were less than those for post-Elder, indicating that rebound for the buildings occurred at a slow rate.

Building 4 showed evidence of additional damage. However, the shear walls appeared sound and the damaged roof panels were in about the same condition as observed after Shot Elder. The third-floor slab underwent considerable bending. The maximum sag in the slab between the north shear wall and Column Line 10 was 6 inches, between Column Lines 10 and 11, 3 inches, and between Column Line 11 and the south shear wall, 12 inches. A view of the underside of the third floor along Column Line 11 and the front wall facing surface zero is shown in Figure 4.66. The rotation experienced by the third floor slab caused it to crack at the intersection of both shear walls. A crack, having a 3-inch differential vertical displacement, developed at the intersection of the third-floor slab and front wall between Column Line 11 and the south shear wall (Figure 4.67). 4.2.3 Item 27, Station 3.1.3, Greenhouse. A composite-type, semi-buried shelter was constructed during Operation Greenhouse (1951). No plastic deformations or damage were observed during that operation (Reference 9); however, earth blown by the blast from the Mike shot partially blocked the entrance. The structure consisted of four major parts: a cast-in-place, reinforcedconcrete shelter; three precast, reinforced-concrete pipe sections; a corrugated-pipe section; and a cast-in-place, reinforced-concrete entrance (Reference 9). The structure suffered no major structural damage during Operation lvy (1952, Reference 1); however, the blast doors were removed prior to the test and the woodframe air lock was destroyed by air blast (approximately 18 psi), and the pointed surface of the vent pipe was charred on the side facing ground zero. No additional damage was inflicted to the structure during Operations Castle (1954, Reference 10) and Redwing (1956, Reference 11).

The maximum estimated overpressure received by this station was 29 psi from Shot Eider. The station received no additional damage from any of the shots; however, the water-wave effects from Shot Walnut filled the entranceway with 6 inches of mud and left water standing to a height indicated by the water marks shown in Figure 4.68.

4.2.4 Iter: 28, Stations 20A, B, C, D, E and F, Greenhouse. Reinforced-concrete gage piers were constructed and undamaged, except for Station 20A, during Operation Greenhouse (1951).

101



Figure 4.52 Post-Walnut, (Item 26) Station 3.1.1, crack in ceiling adjacent to north wall of shear-wall building looking away from surface zero. Pressure level: Walnut, 16 psi.



Figure 4.53 Post-Elder, (Item 26) Station 3.1.1, front view. Pressure level: Elder, 20 psi.



Figure 4.54 Post-Elder, (Item 26) Station 3.1.1, rear view. Pressure level: Elder, 20 psi.



Figure 4.55 Post-Elder, (Item 26) Station 3.1.1, close-up of Building 5, first floor collapsed. Pressure level: Elder, 20 psi.

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Figure 4.56 Post Elder, (Item 26) Station 3.1.1, close-up of Buildings 1, 2, and 3. Pressure level: Elder 20 psi.



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Figure 4.57 Post-Elder, (Item 26) Station 3.1.1, Columns 7 and 8B, first floor of Building 3. Pressure level: Elder, 20 psi.

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Figure 4.58 Post-Elder, (Item 26) Station 3.1.1, Columns 7 and 8B, second floor of Building 3. Pressure level: Elder, 20 psi.

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Figure 4.59 Post-Elder, (Item 26) Station 3.1.1, Columns 7 and 8B, third floor of Building 3. Pressure level: Elder, 20 psi.

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Figure 4.60 Post-Elder, (Item 26) Station 3.1.1, Column & D and crack in rear wall, first floor of Building 3. Pressure Level: Elder, 20 psi.



Figure 4.61 Post-Elder, (Item 26) Station 3.1.1, destroyed roof section of Building 6 and damaged area to roof at south end of Building 4. Pressure level: Elder, 20 psi.



Figure 4.6% Post-Elder, (Item 26) Station 3.1.1, outside view of punched-in roof section at north end of Building 4. Pressure level: Elder, 20 pst.

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Figure 4.63 Post Elder, (Item 26) Station 3.1.1, inside view of punched-in roof section, north end of B.ilding 4. Pressure level: Elder, 20 psi.



Figure 4.64 Post-Elder, (Item 26) Station 3.1.1, close-up of punched-in roof section, north end of Building 4. Pressure level: Elder, 20 ppi.



Figure 4.65 Post-Dogwood Olive, and -Pine, (Item 26) Station 3.1.1, aerial view. Pressure levels: Dogwood, 12 psi; Olive, 8.4 psi; and Pine, 13 psi.



Figure 4.66 Post-Dogwood, -Olive, and -Pine, (Item 26) Station 3.1.1, underside of third floor along Column Line 11, and the front wall facing surface zero. Pressure levels: Dogwood, 12 psi; Olive, 8.4 psi; and Pine, 13 psi.


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Figure 4.67 Post-Dogwood, -Olive, and -Pine, (Item 26) Station 3.1.1, crack in third floor at intersection of front wall between Column Line 11 and south shear wall. Pressure levels: Dogwood, 12 psi; Olive, 8.4 psi; and Pine, 13 psi.



Figure 4.68 Post-Walnut, (Item 27) Siziton 3.1.3, entrance filled with mud. Pressure level: Walnut, 21 psi.

109

Station 20A was destroyed either during Operation Greenhouse or Operation Ivy.

The structural details and elevation views of this item are shown in Figure 4.69.

Stations 20B, C, D, and E were destroyed by the air-blast effects from Shot Walnut. Eation 20F was not damaged by any of the shots. See Appendix C for a detailed analysis of the response of these piers to blast pressure.

Table C.1 lists the pressures sustained by the various piers and the subsequent damage. A typical preshot view of a pier (Statior. 20B) is shown in Figure 4.70 and a post-Walnut (pressure level, 25 psi) view of the same pier depicting typical damage, separation of the stem from the base, is shown in Figure 4.71.

4.2.5 Item 29, Station 77.02. A reinforced-concrete recording station was constructed during Operation Hardtack (1958).

This station was not damaged from any of the shots and received a maximum, estimated pres-



Figure 4.69 Structural details and elevation views of (Item 28) Stations 20A, B, C, D, E, and F, Site Janet.

sure of 17 psi from Shot Elder. The antenna and ventilating devices on top of this station (Figure 4.72) were removed prior to Shot Elder.

4.2.3 Item 30, Landing Pier. An earth-filled pier with reinforced-concrete side walls and concrete cubicles (5 by 5 by 5 feet with 6-inch walls and filled with sand) for additional stability received no damage from the first two shots, Yellowwood and Tobacco.

However, Shots Walnut and Elder caused considerable damage (compare Figures 4.73, 4.74, and 4.75). Two of the concrete cubicles were thrown 45 and 75 feet, respectively, the steel tramework at the end of the pier was bent over, and the steel grill-type flooring was blown away from the effects of Walnut (Figure 4.74). The welded horizontal beams were fractured at the welds on the side adjacent to the columns; the columns tilted on a 3-to-1 (vertical to horizontal) slope away from surface zero. During Shot Elder the horizontal structural members of the steel framework were blown on shore and only the tilted legs remained in place (Figure 4.75). The two concrete cubes that were isplaced from Walnut were moved only slightly; no additional cubes were displaced. No additional damage was observed from the other shots.

4.2.7 Camp. This camp was almost entirely dismantled prior to any of the shots; however, the wood frame : r some buildings and tents were left in place.



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Figure 4.70 Preshot (Item 28) Station 20B, view of gage pier facing surface zero, Site Janet.



Figure 4.71 Post-Walnut, (Item 28) Station 20B, view of toppled gage pier. Pressure level: Walnut, 25 psi.

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Figure 4.72 Postshot, (Item 29) Station 77.02, recording station. Pressure level: Elder, 17 psi.



Figure 4.73 Preshot, (Item 30) landing pier, Site Janet.

112



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Figure 4.74 Post-Walnut, (Item 30) landing pier. Pressure level: Walnut, 23 psi.



Figure 4.75 Post-Elder, (Item 30) landing pier. Pressure level: Elder, 30 psi.

113

The wood frames were destroyed by the effects from Shot Koa (pressure level of 5.2 psi). Shot Yellowwood (pressure level of 6.2 psi) scattered oil drums that had been previously scattered (Figure 4.76).

4.3 SITE YVONNE

The effects of Shots Cactus (17 kt), Butternut (80 kt), Holly (5.8 kt), Magnolia (57 kt), Rose (14.5 kt), Linden (11.1 ki), Sequola (5.3 kt), Pisonia (2.5 kt) and Fig (21.5 tons) were observed at Site Yvonne. The shot geometry, with pressure contours and test stations, is shown in Figure 4.77.

4.3.1 Item 31, Station 1130. A reinforced-concrete bunker was constructed during Operation Hardtack (1958). This structure was designed to resist a 470-psi air overpressure and a 3,270-



Figure 4.76 Postshot, Janet Camp. Pressure levels: Yellowwood, 6.2 psi; Tobacco, 1.5 psi.

psi reflected air overpressure. The plan and elevation for this structure are shown in Figure 4.78.

The structure was located in the 450-psi air-overpressure range for Shot Cactus and damaged only from that shot. The damage was confined to the side tunnel. A preshot view of the entrance (side away from ground zero) is shown in Figure 4.79 and a post-Cactus view is shown in Figure 4.80. Thermal radiation estimated to be 20 cel/cm^2 from Shot Butternut, which was fired after Shot Cactus, ourned the black paint off the wall surface as can be seen by comparing Figures 4.79 and 4.80. A preshot view of the entrance to the side tunnel is shown in Figure 4.81. A post-Cactus view, Figure 4.82, shows the damaged entranceway. Apparently the blast wave that entered the tunnel-like entrance (side-on to the shock front) was reflected at the tunnel's end. The resulting increase in pressure caused the tunnel walls and roof to separate and crack as though an explosion had occurred inside the tunnel. An interior crack near the junction with main structure showing the "buging" failure can be seen in Figure 4.83. The tunnel was not fastened with dowels to the main station but merely keyed.

Thermal radiation at this close range was estimated to be 650 cal/cm^2 . Very little of the tunnel was directly exposed to this radiation as can be seen in Figure 4.81; however, the areas that were exposed showed remarkably little effect due to this exposure, Figure 4.82.

114





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Figure 4.78 Plan and elevation for (Item 31) Station 1130, reinforced-concrete bunker, Site Yvonne.



Figure 4.79 Preshot, (Item 31) Station 1130, entrance, Site Yvonne.



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Figure 4.80 Postshot, (Item 31) Station 1130, entrance. Pressure level: Cactus, 450 psi; Eutternut, 20 cal/cm².

117



Figure 4.81 Preshot, (Item 31) Station 1130, side-lunnel entrance, Site Yuone



rigure 4.82 Post-Cactus, (Item 31) Station 1130, side-tunne: entrance. Pressure level: Cactus, 450 psi; 650 cal/cm².

118

4.3.2 Item 32, Station 1220.01. A steel cubicle mounted on a structural-steel platform was erected during Operation Hardtack. This station was located in the 450-psi air-overpressure range for Shot Cactus and was destroyed; only the legs of the structure survived. Preshot and postshot views are shown in Figures 4.84 and ...86, respectively.

4.3.3 Item 33, Station 1216. A reinforced-concrete terminal for a pipeline was constructed during Operation Hardtack (1958).

This station was located in the 450-psi air-overpressure range for Shot Cactus and apparently undamaged. A preshot picture is shown in Figure 4.85 and a post-Cactus view in Figure 4.86.

4.3.4 Item 34, Station 1612. A reinforced-concrete recording station with a timber entrance tunnel and reinforced-concrete retaining wall was constructed during Operation Hardtack (1958). The plans for the station with details for the retaining wall only are shown in Figure 4.87.

This station was located in the 1,600-psi air-overpressure range for Shot Cactus. As a result of the surcharge from this overpressure the timber entrance tunnel was filled in with sand and the adjoining retaining wall cracked and tilted outward 2 to 3 feet. A preshot view of the retaining wall is shown in Figure 4.88 and a post-Cactus view showing both the retaining wall and the entrance to the station is shown in Figure 4.89.

The damaged, said-filled timber tunnel was removed by the use of a bulldover and the interior of the detector station was investigated for structural damage. It was observed that the rear wall (wall away from ground zero) was damaged at the junctures with both the ceiling and floor (Figure 4.90). Apparently air blast entered the collimator pipes and tended to blow out the rear wall. The rear wall was 1 foot thick, the floor and ceiling both were 2 feet thick, and the steel reinforcement for all three elements consisted of No. 7 bars at 12 inches on center, both ways, and in each face.

4.3.5 Item 35, Stations 1523.01 io 1523.04. Four steel-pipe towers encased by a plywood covering were constructed for Operation Hardtack (1958). A corrugated-metal pipe (48 inches in diameter) mounded with sand led from each station to ground zero. A preshot picture of this station is shown as Figure 4.91.

The stations were located in the 450-psi air-overpressure zone for Shot Cactus and were destroyed by that shot. All that remained was the foundations for the towers and remnants of the corrugated pipe.

The air-blast wave smashed the far wall of each tower foundation, as shown in Figure 4.92. A typical failure pattern for the 48-inch, round, corrugated-metal pips leading to ground zero is shown in Figure 4.93.

4.3.6 Item 36, Station 1310. A massive, reinforced-concrete structure was constructed and undamaged during Operation Redwing (1956). A new reinforced-concrete room was added on the roof and the entire structure mounded over with earth for Operation Hardtack (1958).

This station received a maximum, estimated overpressure of 16 psi from Shot Magnolia and experienced no structural damage from any of the shots. A preshot view of this station is shown in Figure 4.94 and post-Rose view showing loss of earth cover is shown in Figure 4.95.

4.3.7 Item 37, Water Tank. A 21,000-gallon tank constructed of $\frac{1}{6}$ -inch steel plates with $\frac{1}{2}$ -inch round bolts spaced at 2 inches on conter, and having a radius of 30 feet 10 inches and a height of 8 feet, was damaged during Hardtack (1958).

The tank was located in the 1.5-, 6.5-, 2.4-, 7.0-, 2.5-, 3.4-, 2.3-, and 3.4-psi air-overpressure zones for Shots Cactus, Butternut, Holly, Magnolia, Ro3e, Linden, Sequoia, and Pisonia. The tank was not affected by Shot Cactus but was damaged by Shot Butternut as shown in Figure 4.96. The tank was half full of water at that time. Shot Holly had no additional effects. The tank was damage u additionally by Shot Magnolia as seen by the local buckling failure around the top perimeter and the dishing of the roof as shown in Figure 4.97. No additional damage from the remain-

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Figure 4.83 Post-Cactus, (Item 31) Station 1130, crack at intersection of tunnel and main structure. Pressure level: Cactus, 450 psi.





Figure 4.84 Freshot, (Item 32) Station 1220.01, cubicle, Site Yvonne.





Figure 4.86 Post-Cactus, (Items 32 and 33) Stations 1220.01 and 1216. Pressure level: Cac'us, 450 psi.



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Figure 4.88 Preshot, (Item 34) Station 1612, retaining wall, Site Yvonne.



Figure 4.89 Post-Cactus, (Item 34) Station 1612, retaining wall and outrance to station. Pressure level: Cactus, 1,600 psi.





Figure 4.90 Post-Cactus, (Item 34) Station 1612, interior view. Pressure level: Cactus, 1,600 psi.



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Figure 4.92 Post-Cactus, (Item 35) Stations 1523.01 to 1523.04, foundation pit for towers. Pressure level: Cactus, 450 psi.



Figure 4.93 Post-Cactus, (Item 35) Stations 1523.01 to 1523.04, 48-inch metal corrugated pipe leading to ground zero. Pressure level: Cactus, 450 psi.

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Figure 4.95 Post-Rose, (Item 36) Station 1310, concrete, earth-covered state ... Pressure levels: Cactus, 4.5 psi; Rutternut, 12 psi; Holiy, 7.6 psi; Magnolia, 16 psi; and Rose, 4.2 psi.

126



Figure 4.96 Post-Butternut, (Item 37) 21,000-gallon water tank. Pressure level: Butternut, 6.5 psi.



Figure 4.97 Post-Magnolia, (Item 37) 21,000-gallon water tank and Yvonne Camp area. Pressure level: Magnolia, 7.0 psi.

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ing shots was observed. Even though the tank was badly dented near the upper rim none of the bolts or bolt holes showed signs of incipient failure, and it appeared that the tank with some minor repairs could easily be placed in use again. The above-ground connections of 4-inch and 2-inch water pipes and the exposed 4-inch, rising-stem, gate valves (125-psi rated) were unchamaged.

4.3.8 Yvonne Camp. The camp located at the south end of Site Yvonne (Figure 4.77) was damaged severely. Damage resulting from the various shots to several types of construction and miscellaneous items is described as follows:

Timber Buildings and Tents. Light temporary timber buildings were severely damaged from the 1.5- to 2.0-psi air overpressure from Shot Cactus. The first two rows of



Figure 4.98 Post-Cactus, camp damage, tents. Pressure level: Cactus, 2.0 psi.

tents (closest to ground zero) were not only collapsed but moved away from ground zero a distance of 6 to 8 feet (Figure 4.98). The remaining tents did not experience this movement but were partially collapsed. The light-plywood-covered buildings were severely damaged, the smaller buildings being damaged the least. The traines of many structures were collapsed to varying degrees and the plywood siding of many was blown off (Figure 4.99). The latrine which was the closest camp building to ground zero was not only damaged but moved 6 inches away thom ground zero. The blast that entered this building apparently exerted a greater pressure than the external pressure, as indicated by the outward ougling of the roof and side walls as shown in Figure 4.100. None of the buildings or tents were charred from the thermal pulse from Shot Cactus. The estimated pressure level of 5.8 to 8.2 psi from Shot Butternut completely destroyed all the tents and timber buildings.

Telephone Poles. Wood telephone poles located in an estimated 2.5-psi pressure range for Shot Cactus with undamaged. The same poles located in the 12-psi air-overpressure for Shot Butternut were bent and one was broken at the base as shown in Figure 4.101; the bent pole

128



Figure 4.99 Post-Cactus, camp damage, light timber construction. Pressure level: Cactus, 1.5 psi.



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Figure 4.100 Post-Cactus, camp damage, latrine. Pressure level: Cactus, 2.0 psi.

129



Physice 4.102 Post-Butternut, radar reflector. Pressure level; Butternut, 5.8 psi.

130



Figure 4.104 Post-Magnolia, helium bottles. Pressure level: Magnolia, 6 psi.

in the right foreground is a 3-inch, round, steel pipe. The same poles were located in an estimated 16-psi range for Shot Magnolia and were snapped off at the base.

Radar Reflector. A multiunit, radar reflector, undamaged from the effects of Shot Cactus, was ripped from its concrete foundation and thrown 50 feet from the effects of Shot Butternut. A view of this station, which was located in the estimated 5.8-psi range from Shot Butternut, is shown in Figure 4.102.

Helium Bottles. Helium bottles stored in the camp area were undamaged but snifted



Figure 4.105 Postshot, fire hydrant. Pressure levels: Cactus, 2.0 psi; Butternut, 8.2 psi; Holly, 3.1 psi; Magnolia, 9.0 psi; Rose, 3.1 psi; Linden, 4.7 psi; Sequola, 3.0 psi; and Pisonia, 2.8 psi.

slightly from some of the shots. This movement can be compared by viewing Figure 4.103 (post-Butternut, 5.8 psi) and Figure 4.104 (post-Magnolia, 6 psi). The remaining shots had no additional effects.

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Fire Hydrant. A typical view of a fire hydrant located in the 2.0-, 8.2-, 3.1-, 9-, 3.1-, 4.7-, 3.0-, and 2.8-psi air-overpressure range for Shots Cactus, Butternut, Holly, Magnolia, Rose, Linden, Sequoia, and Pisonia, respectively, is shown in Figure 4.105. The hydrant was not damaged by any of the shots.

132

Chapter 5 DISCUSSION

The discussion of results is divided into three general categories: prediction curves, radiation and water waves, and damage-distance relationships.

5.1 PREDICTION CURVES

5.1.1 Air Overpressure. Observed pressure-distance data, reduced to a 1-kt surface burst, have been plotted in Figure 5.1, where the solid curve is identical to the 1-kt plot shown in Figure 2.3, which was used for predicting the ground-surface air overpressure for each of the various stations that were investigated and summarized in this report. The points in the high-pressure zone, as plotted in Figure 5.1, represent data (References 12 and 13) from Shots Cactus (17 kt) and Koa (1.33 Mt), thus covering a low yield and a high-yield shot.

In the very-low-pressure range, the plotted points represent data (Reference 12) from Shots Cactus, Koa, Butternut (80 kt), Magnolia (57 kt), and Yellowwood (340 kt). The data, as plotted, have not been corrected for wind, temperature, or any of the other meteorological conditions that can have marked effects on the properties of a blast wave in the ranges of very-low air over-pressures.

The plotted points agree closely with the prediction curve, thus establishing a satisfactory level of confidence for the predicted air-overpressure values for the other shots investigated during the operation.

5.1.2 Floor-Slab Acceleration. Limited acceleration data are available, and only a few points (References 12 and 13) were plotted on the acceleration-prediction curve (Figure 2.5), as shown in Figure 5.2. The points represent data from Shots Koa and Cactus. The data are not sufficient to determine the overall reliability of results obtained from using the curve; however, is appears that a reasonable value can be determined.

5.2 RADIATION AND WATER WAVES

5.2.1 Nuclear Radiation. Methods for predicting radiation within structures were not available at the time of this operation except for the slant-thickness method which, as shown by this report, is not reliable. The path-of-least-resistance method for predicting radiation withi structures was therefore developed and is described in Appendix A. The measured and predicted values using this method were in reasonably close agreement. See Section A.6 for a detailed discussion.

5.2.2 Thermal Radiation Damage. Primary thermal radiation has soldom been a governing factor in damage to structures. However, it is quite important to know thermal levels when designing protective structures for very-high-overpressure regions.

The predominant effect of thermal irradiation is the heating of exposed surfaces of structures. The effect of moderate irradiation on steel is simply to heat the surface; however, thin sections can lose strength. The effect of moderate irradiation on concrete results only in surface spalling.

Observation of structures during this operation showed no case where thermal radiation was a governing factor in structural damage. Observations included steel exposed to $1,400 \text{ cal/cm}^2$ (Item 10) and concrete exposed to 650 cal/cm^2 (Item 31).

133



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Figure 5.1 Peak air overpressure for a 1-kt surface burst, with observed points.



5.2.3 Water Waves. Blast-generated water waves were instrumental in removing considerable quantities of loose material from earth mounds and earth berms. Observations of wave damage in this and past operations indicate that close-in structures surviving the effect of air blast will undoubtedly survive the force of water waves. See Section D.5, Appendix D, for ε detailed discussion.

5.3 DAMAGE-DISTANCE RELATIONSHIPS

Damage to certain common facilities and installations, such as camp sites, generators, and storage tanks, has been observed and reported during several previous operations. For these items, the past damage data, as well as that obtained during Operation Hardtack, have been studied for the purpose of determining damage-distance relationships. Where possible, the damage has been compared with the curves of TM 23-200 (Reference 8).

Damage classification, numely, severe, moderate, and light (Reference 8), has been used throughout this report in describing the degree of damage to the various stations. In the following sections a detailed description of damage classifications pertaining to specific items is given.

5.3.1 Camp and Wood-Frame Structures. The light wood-frame buildings for camp sites were constructed to provide temporary facilities for pressing, storage, maintenance, and administration. Typical construction for these buildings consisted of 2-by-4-inch stude 2 feet on center, trussed rafters 2 feet on center, $\frac{1}{2}$ -inch exterior plywood siding, and corrugated aluminum roofing.

The damage-distance relationship shown in Figure 5.3 represents the results of observations of damage made during Operations Ivy, Castle, Redwing, (Section 1.2.1 and References 1 and 2), and Hardtack. The following descriptions define the damage levels for the curves shown:

Severe Damage. Frame shattered so that the structure is for the most part collapsed. Moderate Damage. Wall framing cracked. Roof badly damaged. Interior partitions blown down.

Light Damage. Windows and doors blown in. Interior partitions cracked.

Distances shown for severe damage are those for which the probability of the damage occurring is 50 percent, the 2.0-psi level. The spread of the data in the severe-damage range supports the methods of obtaining 10-percent and 90-percent probability given in Reference 8. For 90percent probability, use is made of the distance for a weapon of half the desired picture in percent probability, use is made of the distance for a weapon of twice the desired yield.

The moderate-damage level (1.0 psi) was determined by using the distance for a weapon of four times the desired yield, as in Reference 8. The light-damage curve (0.75 psi) is intended to represent the upper limit of nuisance damage and the threshold of light damage. The severe-damage curve (50-percent probability) for wood-frame buildings, one- or two-story house type, as given in Reference 8, is also shown in Figure 5.3.

Damage to several types of heavy-wood-framed structures has been observed, but insufficient data make it impossible to determine damage-distance relationships for such variable structures. However, it has been demonstrated that small, essentially windowless, wood-frame structures can be designed to withstand overpressures up to 4.5 psi (Reference 1), if a moderate degree of damage is acceptable.

5.3.2 Storage Tanks. Damage curves (Reference 8) show that large oil storage tanks (30 feet in height, 50 feet in diameter) are primarily diffraction structures and, therefore, overpressure sensitive. Damage levels for large oil tanks are described as follows:

Severe Damage. Large distortion of sides, seams split, so that most of the contents are lost (approximately 11-psi level).

Moderate Damage. Roof collapsed, sides above liquid buckled, some distortion below liquid level (approximately 5-psi level).

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Light Damage. Roof badly damaged (approximately 1-psi level).

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A 21,000-gallon water tank (Item 37) directly exposed to 6.5 and 7.0 psi of air overpressures received light damage. The roof was dished in, and there was a small amount of buckling of the sides above the level of liquid in the tank. In addition, it was noted that there was no damage to the exterior connecting piping.

Similar tanks exposed during previous operations (Section 1.2.1) confirm the observation that these smaller tanks are considerably less vulnerable to damage at a given pressure level then large oil-storage tanks. There is insufficient data to plot a damage-distance relationship for tanks of the type investigated in this report. However, examination of the data indicates that light damage is to be expected between air overpressures of 3 and 10 psi.



Figure 5.4 Data for Structure 3.1.1 plotted on curves entitled "Severe Damage to Various Structures Primarily Overpressure-Sensitive by Surface Burst of Various Yields" from Reference 8.

5.3.3 Station 3.1.1 (Item 26, Three-story Blast-Resistant Buildings). The response of this structure allowed a limited comparison of observed with predicted damage. However, predicted damage is based on the effects from Blage whots while the structures in question were subjected to many shots. The severe-damage curve labeled "Blast Resistant, Reinforced-Concrete Buildings" shown on Page 7-45 of Reference 8 was used for comparing predicted with observed response. This comparison can be seen in Figure 5.4. Here the observed responses for the various shots are plotted on the prediction curve. The curve labeled "Blast Resistant Reinforced Concrete Bldgs" has an indicated 34 psi at its lower end. The upper end, although not labeled, decreases to 32 psi for the greater yields and ranges.

The curve predicted something less than severe damage for Shots Walnut and Elder alone. Severe damage is defined as the collapse of the first floor columns of the building. Shot Walnut caused the columns of the first floor of Building No. 5 (the concrete structure with windows) to

137

displace laterally about one foot, thereby greatly weakening the structure. It can be assumed that a slight additional load would have caused collapse of the columns. Shot Elder, which had about the same input pressure as Walnut, provided the force necessary to cause collapse of the first floor columns. 57 × 11

Since none of the blast-resistant steel buildings, the concrete building without windows, and the shear-wall building underwent severe damage, the damage curve as used also appears reasonable for predicting the response of these structural types.

Although the roof of the shear-wall building collapsed, the frame and walls were only slightly distressed and the building was not considered to be severely damaged. The roof failure shows the need for careful consideration of roof designs. For example, it was observed that the line of failure for roofs occurred at locations where main stress steel had been terminated; had these bars been continued, these failures may not have occurred.

5.3.4 Station 1312 (Item 25, One-story, Reinforced-Concrete Building). This structure provided the opportunity to record blast-diffraction measurements from four different shots. It was observed that the predicted and recorded pressures on the front and rear faces of the station were in close agreement. The observed and the predicted pressure curves along the roof were in rather poor agreement, especially after the arrival of the vortex. See Section B.2, Appendix B, for a detailed discussion.

5.3.5 Gage Piers (Item 28). Since several of the piers failed from air-blast effects and one did not, an opportunity was afforded to compare predicted response with observed response for diffraction targets oriented at various angles of incidence with surface zero. Even though the analysis was made assuming both the strength properties of the materials and the air-overpressure values for the stations investigated, the predicted and the observed response were in close agreement. See Section C.4, Appendix C, for a detailed discussion.

5.3.6 Miscellaneous Damage. The many support-type structures located at the various sites were exposed to a wide range of overpressure. The heavily reinforced-concrete structures located at the end of Site Tare were subjected to pressures over 1,000 psi from low-yield kt devices without being damaged. An unmounded, reinforced structure (Item 2) located on Site Able was subjected to an estimated 1,200 psi from a 9.3-Mt device and was completely destroyed.

Generators (Item 23), located behind the station complex (earth-mounded station) and exposed to an overpressure of 35 psi, suffered severe damage. However, of particular interest was the striking evidence of the protection afforded objects sheltered from the air blast by an obstruction. The fully sheltered generator moved only 2 feet, whereas the least sheltered generator was thrown 60 feet.

Chapter 6 CONCLUSIONS and RECOMMENDATIONS

6.1 CONCLUSIONS

The objective of recording damage from air blast, radiation, and blast-generated water waves was attained. Detailed conclusions are presented in Appendixes A, B, C, and D. The general conclusions are that:

1. The peak air-overpressure curve (Figure 5.1) is reliable for scaled air overpressures from 0.1 to 350 psi.

2. The peak-ground-acceleration curve (Figure 5.2) gave reasonable predictions of floorslab accelerations. However, the overall reliability of the curve is uncertain, inasmuch as limited data were obtained.

3. Radiation levels inside sheltere discussed in this report were adequately predicted by using a path-of-least-resistance method (see Appendix A).

4. Radiation levels inside shelters were not realistically predicted using the least-slantdistance concept.

5. Thermal radiation was not a governing factor in structural damage for exposures up to 1,400 cal/cm² for steel.

6. Total thermal radiation of up to 650 cal/cm^2 caused only minor surface spalling of directly exposed concrete.

7. Structural effects due to water waves may be neglected for close-in structures designed to withstand air blast.

8. At greater distances, where air blast is of no great consequence, water waves must be considered in structural design and planning.

9. Light wood-frame structures (camp buildings) suffered severe damage from air overpressures ranging from 1.4 to 3.0 psi.

10. Belted-steel, ground-surface storage tanks (27,000 to 30,000 gallons in capacity), tuit of liquid, suffered only light damage from overpressures less than 10 psi.

11. The camage-prediction curve entitled "Blast Resistant, Reinforced-Concrete Buildings," Reference 8, appears adequate for predicting damage to three-story, blast-res'stant structures of the Station 3.1.1 type, i.e., reinforced-concrete building, with and without windows; structural steel, with and without windows; and a reinforced-concrete, shear-wall building.

12. Reinforcing steel in roofs of blast-resistant structures should be designed to provide more uniformity of strength. At least one half (but preferably all), the area of positive reinforcement required within a continuous or restrained section of roof should extend beyond the face of the support for a distance of 30 has diameters. At least one half the reinforcement provided for negative moment at the support should be extended beyond the point of inflection a distance sufficient to develop the allowable stress in such bars or a distance equal to the depth of the member, whichever distance is greater. By this procedure, abrupt changes in the strength of a member would be minimized. Local failures, thus, would not cause the failure of a whole roof section before other portions (of that section) were overstressed.

13. Heavily reinforced concrete structures (earth-mounded and having 5- to 6-foot-thick walls and roof with clear spans up to 5 feet) survived air overpressures of 1,000 psi without damage.

14. Objects located close behind earth mounds within a distance approximately equal to the

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139

height of the mound received considerable protection from dynamic pressures at overpressures of 35 psi and lower.

15. Exposed standard 2-inch and 4-inch water pipes, including standard rising-stem valves, survived pressures up to 8 psi without sign of damage.

16. For structures oriented so that a line drawn through ground zero is normal to the front face of the structure (zero angle of incidence), it was found that the method used in predicting loading on the front and back walls of diffraction-type structures provided results sufficiently realistic for design or analysis purposes.

17. The predicted shape of the overpressure curve for the roof of diffraction-type targets was not in close agreement with measured results.

18. The method used for predicting pressures on the front and rear faces of diffraction targets at various angles of incidence with ground zero is satisfactory for design but not for analysis purposes.

6.2 RECOMMENDATIONS

1. It is recommended that the path-of-least-resistance method (Appendix A) be adopted for use in predicting radiation within structures.

2. The present method available for predicting pressures on the front and rear faces of diffraction targets oriented at a zero angle of incidence is adequate and is recommended for design and analysis purposes. The present method of predicting roof pressure should be used until a better method is determined.

3. Additional high explosive and/c_{s} succh-tube experiments should be performed to: (1) determine a more realistic overpressure distribution along roofs of diffraction-type targets; and (2) determine the pressure distribution on the front and back faces of these targets when oriented at various angles of incidence with ground zero.

4. Continuous beams, slabs, or walls of blast-resistant structures should be designed for greater uniformity of strength throughout their span. Any abrupt changes in the strength of a member invite local failure which can cause the whole member to fail before other portions of the member are seriously distressed.

140

Appendix A NUCLEAR RADIATION

By Edwin S. Townsley, Captain, Corps of Engineers, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi

A.1 INTRODUCTION

Film-badge dosimeters were installed in four structures to obtain additional information on shielding against nuclear radiation. The effectiveness of shielding is determined primarily by the following factors taken from Reference 8: (1) distribution of the energy of radiation, (2) intunsity of the incident radiation, (3) angle of incidence of the radiation, (4) mass of the shielding material, and (5) geometry of the shielding.

The first three of these are functions of die radiation itself while the last two are functions of the protective shelter. Therefore, to better understand the problem of shielding, a brief review of what is known about radiation and how the structure affects radiation will be given.

A.2 THEORY OF RADIATION

Since the purpose of this discussion is to point out the uncertainties involved in making computations of shielding against radiation, the discussion will center primarily on initial gamma radiation. The uncertainties arising in considering neutron and residual radiation are no less formidable. The following definition of flux as pertains to nuclear radiation is taken from Reference 14:

"The flux of any type of radiation is the total number of particles per unit area and per unit time arriving at a particular point from all directions and at all energies. The unscattered flux is that portion of the total flux which arrives directly at the point in question from the source, without having suffered any previous collisions. The unscattered flux is more directional if the source of radiation is a point."

It is possible to write an equation for the unscattered flux at a target in terms of the intensity of the (point) source, distance between source and target and the mean free path in the uniform homogeneous medium in which both the target and source are assumed to be located. This equation becomes less accurate as approximations are added to account for the contribution of scattered flux, size and distribution of energy in the source, and the lack of uniformity and homogeneity in the medium (including both the hydrodynamic effect and the air-earth interface). Therefore, it is obvious that there are considerable uncertainties not only as to the intensity of radiation, but also as to the distribution of the energy and the angle of incidence of the radiation at the exterior surface of the structure. の時間には、「「「「「「」」」

A.3 STRUCTURAL SHIELDING

As was noted in Section A.1, both the mass and geometry of the structure must be considered. In determining the attenuation of rediation with thickness for various materials, the normal procedure is to direct a known radiation perpendicularly against a specimen of the material in question and measure the amount of radiation on the other side of the specimen. Therefore the geometry of the material is assumed to be an infinite plane of given thickness, and the radiation is monodirectional, assumed to be monoenergetic, and normal to the curface of the specimen.

Thus the normal procedure for computing the attenus ion to be obtained in a structure is to assume that a monoenergetic and monodirectional radiation strikes the surface of the structure at an angle determined by the line of sight between the source and the structure. The slant thickness of the structural material measured along this line of sight is used in determining attenuation. Work by the National Bureau of Standards (Reference 15) indicates that the shielding computed in this way may be much greater than actually exists for concrete walls of more than five inches thickness and angles of incidence greater than thirty-five degrees. Therefore, the problem of predicting shielding involves the dual problems of determining what radiation exists at the outside of the structure and of computing how much of that radiation passes through the walls of the structure to its interior. or, to quote Reference 14:

"No generalized treatment of the military gamma shielding problem, either theoretically or experimentally based, can be presented at this time. The geometrical configuration of a structure bears importantly on its shielding effectiveness; the geometry of the most practical structures and of the topography in which they are located cannot be simply described in a mathematical sense. It is extremely difficult therefore to compute the shielding effectiveness of a given

141

structure with any reasonable accuracy. The computational problem is compounded by the general lack of information of the distribution of radiation at the receiver in intensity, energy, and angle. Generalizations based on experimental measurements are equally difficult because the uata are limited and distributed over a variety of structural types, and often lack internal consistency.

"Under these circumstances it is felt that, at present, the best way to determine the shielding effectiveness of a given configuration of materials is to estimate it from experimentally measured values for similar structures under similar conditions."

It was because of this statement that radiation measurements were taken in a variety of structures. But this method of determining the shielding is not adequate for the engineer who faces the problem of designing a structure to protect its contents from all weapon effects. Accordingly, for purposes of predicting the shielding offered by a structure, a somewhat different approach was taken.

A.4 PREDICTION METHODS

A.4.1 Slant Thickness. The conventional method of computing shielding is to determine the thickness of the material of the structure along the line of sight to the source. These thicknesses can be transformed into attentuation factors by reference to numerous available charts. In this study the charts in TM 22-200 (Reference 8) were used.

A.4.2 Path of Least Resistance. Generally, it has been observed that radiation inside structures is greater than could be explained on the basis of slantthickness computation. It has long been recognized that the radiation inside a structure may be much higher than anticipated due to the admittance of radiation through the entranceway. To make some estimate of this effect, and to attempt to account for the weakness of the slant-thickness method found by the National Bureau of Standards, the following assumptions and approximations were made:

1. In regions of high flux, where shielding is a problem, radiation is assumed to be essentially directional along the line of sight in its properties. (An indication of the validity of this assumption will be found in Section A.6.)

2. Where this directional radiation must turn approximately 90 degrees to enter the shelter, the flux is reduced to $\frac{1}{15}$ of its line-of-sight intensity. (This figure was arrived at by observing that radiation intensities in foxholes, where essentially a right-angle $u_{0,0}$ of radiation is required, vary from $\frac{1}{10}$ to $\frac{1}{200}$ of the line-of-sight intensity.) If two right angles or 180 degrees must be turned, the intensity is $\frac{1}{100}$ to the line-of-sight intensity (approximately $\frac{1}{100}$).

3. Since the foxhole is a box structure with one side open as a "window" or radiation, radiation through

more than one side or "window" is assumed to be additive.

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4. Where two different shieldings are offered, such as when a steel door occupies a portion of a wall, the attenuations of radiation through the two are computed separately, and their contributions to the interior dose are assumed to be in proportion to their areas. This, in turn, assumes that the solid angle subtended by these areas at the point of interest is proportional to their areas. Steel doors located to one side of a wall do not satisfy this assumption, but the effect of the door is overestimated and the prediction is on the safe side.

These predictions are assumed to be valid up to a distance from the "window" equal to $1\frac{1}{2}$ times the largest dimension of the "window."

A 5 RESULTS

Internal radiation predictions were made for four structures (Stations 560.01, 78.01, Station Complex, and 3.4) using values of external doses determined from Reference 8 and shown in Tables 3.1 and 4.1. The attenuation factors for materials, i.e., concrete, steel, soil, etc., were also determined by using Reference δ . However, these attenuation factors are applicable for yields below 100 kt and therefore the factors used in this report will be somewhat conservative since the yields of most of the weapons in quesfar exceed 100 kt. Both the slant-thickness and pathof-least-resistance | rediction methods were used. In the following computations the attenuation factors are first determined and the resulting attenuated radiation values which are the product of the attenuation factor and the predicted external dose are presented in Tables A.1 through A.4.

A.5.1 Station 560.01 (Item 2). This was a rectangular box structure with interior dimensions of 25 by 10 by 9 left with 4-foot-thick walls and roof (Figure 3.5). The wall facing surface zero for all shots of interest was shielded by an earth berm which was three feet higher than the structure (Figure 3.6). The berm was six teet thick at the top with a vertical surface adjacent to the structure and a two-on-one slope facing surface zero. This berm was partially eroded by wave action during Shot Fir.

Since the distance from surface zero was the same for Sho's Fir, Sycamore, and Aspen, the shielding computations are the same for all three shots. The erosion of the berm was not surveyed and has not been taken into account, thus 'he ratio of observed to predicted interior doses may be slightly higher for the last two shots. The computations are as follows: Slant-Thickness Method:

Geometry: 20 feet of earth and 4 feet of concrete. Attenuation Factor (AF) for:

$$20 \text{ ft of soil} = 10^{-3}$$

4 ft of concrete - 1.1×10^{-3} Total AF: (a > b) = 1.1×10^{-8} , essentially zero.

142

TABLE A.1 PREDICTED AND RECORDED PADIATION VALUES FOR STATION 560.01

Shot	Predicted Exterior Dose	Dose Behind Door						Average Inverior Dose					
		Pre Mei	dicted hod I *	Predic Method	ted III†	Recorded	Pred	dicted hod I*	Predicts Method I	nd I†	Recorded		
		AF	Dose	AF	Dose		AF	Dose	AF	Dose			
	r		r		r	r		r		r	r		
Fir	7,000	0	0	7 × 10 ⁻³	49	24.5	0	0	8.68×10^{-1}	6.1	3.0		
Sycamore	210	0	0	7 × 10 ⁻³	1.56	0.6	0	0	8.68×10^{-4}	0.18	0.1		
Aspen	1,000	0	0	7 × 10 ⁻³	7.0	21.0	0	0	8.68 × 10 ⁻⁴	8.68	2.5		

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See Section A.5.1 for determination of attenuation factors (AF).

*Slant-thickness method.

† Path-of-least-resistance method.

TABLE A.2 PREDICTED AND RECORDED RADIATION VALUES FOR STATION 78.01

See Section A.5.2 for determination of sttenuation factors (AF).

Shot	Predicted Exterior Dose	Dose Behind Door						Average Interior Dose					
		Predicted Method I *		Predicted Method Ií †		Recorded	Predicted Method I*		Predicted Method If †		Recorded		
		AF	Dosc	AF	Dose		AF	Dose	AF	Dose			
	r		r		r	r		r		r	r		
Гіг	10,000					-	a	0	9.8×10^{-4}	9.8	J.O		
Sycamore	320			·			0	0	9.8 × 10 ⁻⁴	0.31	0		
Aspen	1,500	0	0	3.5×10^{-3}	5.25	23.0	0	U	9.8 × 10 ⁴	1.47	1.3		
Maple						—					1.2‡		

* Slant-thickness method.

† Path-of-least-resistance method.

‡ Radiation due to fallout.

TABLE A.3 PREDICTED AND RECORDED RAD', "HON VALUES FOR STATION COMPLEX

See Section A.5.3 for determination of attenuation f ______(r) (c) (c) (c) (F).

Shot Koa Yellowwood	Predicted - Exterior Dose -	Dose in Entranceway						Dose Beyond 90-Degree Turn					
		Predicted Method I *		Predicted Method II†		Recorded	Predicted Method I*		Predicted Method II †		Recorded		
		AF	Dose	AF	Dose		AF	Dose	AF	Dose			
	r		r		r	r		г		- i	•		
Koa	13,000	0	0	4.1 × 10 ⁻³	53.0	70.0	0	0	2.73×10^{-4}	3.5	4.9		
Yellowwood	600	0.82	480	0.82	480.0	130.0	0	0	5.46×10^{-3}	32.0	5.0		
Walnut	4,100	0.82	3,370	0.82	3,370.0	875.0	G	0	5.46×10^{-2}	225.0	130.0		
Elder	4,100	0.82	3,370	0.82	3,370.0	700.0	0	0	5.46 × 10 ⁻²	225.0	44.0		

• Slant-thickness method.

† Path-of-least-resistance method.

TABLE A.4 PREDICTED AND RECORDED RADIATION VALUES FOR STATION 3.4

See Section A.5.4 for determination of attaiuntion factors (AF)-

Shot	Predicted Exterior Dose	Dose Under Hatch Cover						Avorage Interior Dose					
		Predicted Method 1*		Predicted Method II †		Recorded	Predicted Method I*		Predicted Mechod II †		Recorded		
		AF	Dose	AF	Dose		AF	Doru.	$\overline{\Lambda\Gamma}$	Doru			
	r		г		r	r		r		r	r		
Коя	7,000			_	-		0	0	1.06×10^{-2}	74.0	7.3		
Yellowwood	1,000	0	0	5.46×10^{-2}	54.6	6.3	0	0	1.06×10^{-1}	10.6	0.9		
Walnut	6,70)	0	0	5.46 × 10 ⁻¹	366.0	375.0	0	0	1.06×10^{-2}	71.0	41.0		
Elder	6,700	0	0	5.46×10^{-2}	366.0	460.0	G	0	1.06 × 10 ⁻²	71.0	38.0		

* Slant-thickness method.

† Path-of-least-resistance method.

143



Path-of-Least-Resistance Method:

- AF for one side wall and roof:
- 4 ft of concrete = $1.1 \times 10^{-3} \times 2$
- 1 90-degree turn = $\frac{1}{15} \times 2$
- AF for rear wall:
- 4 ft of concrete = 1.1×10^{-3}
- 1 180-degree turn = $\frac{1}{200}$

Subtotal AF $(1 \times 2 + 3 \times 4) = 2.98 \times 10^{-4}$

AF for side wall with door: (This wall is not only at slightly more than 90 degrees to the line of sight but is also in a radiation shadow caused by the berm. Thus the radiation must turn an angle somewhere between 90 and 180 degrees. A 135degree factor of $\frac{1}{100}$ is used here although the full 180-degree factor of $\frac{1}{200}$ was used in the ITR.)

Four feet of concrete = 1.1×10^{-3}

Wall-area factor $\frac{(25 \times 9) - (6 \times 3)}{25 \times 9} = 0.92$

Door-area factor
$$\frac{(6 \times 3)}{(25 \times 9)} = 0.08$$

135-degree turn = ${}^{1}_{100}$ Subtotal AF(1 × 2 × 5 + 3 × 4 × 5) = 5.7 × 10⁻⁴ Total AF for structure = 8.68 × 10⁻⁴

Total AF just behind the door $(3 \times 5) = 7 \times 10^{-3}$ See Table A.1 for a comparison of the predicted with the measured radiation doses.

A.5.2 Station 78.01. This was a buried concrete structure. The earth cover over the roof, along the side, a.d the surface-zero side of the structure had been eroded since construction and were of unknown but appreciable thickness (Figure 3.18 and 3.19). However, since the walls and roof of the struct..re were so thick, it is believed that no significant radiation entered the structure except through the wall and door located at the back side of the structure. The rear wall was $5\frac{1}{2}$ feet thick, $9\frac{1}{2}$ feet high, and 13 feet wide with $a\frac{3}{4}$ -inch steel door 8 feet $2\frac{1}{2}$ inches wide.

Since the distances to surface zero were the same for all shots except Maple, the shielding calculations are the same for all conditions except Maple. For Maple, the radiation was due to fallout and no calculations have been made. The computations are as follows:

Slant-Thickness Method:

Since the slant thickness was so great, the attenuation factor determined by this method predicted that no significant radiation reached the interior of the structure, hence an AF of zero.

F: h-of Less Resistance Method: AF for wall and door: $5\frac{1}{2}$ feet of concrete = 10^{-4} Wall area factor = 0.721 $\frac{3}{4}$ -inch steel door = 0.7Door area factor $\frac{4.2 \times 8.2}{9.5 \times 13} = 0.279$

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9.5 7 13
180-degree turn = 5 × 10<sup>-3</sup>
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Total AF ($a \times b \times e + c \times d \times e$) = 9.8×10^{-4} Total AF behind door ($c \times e$) = 3.5×10^{-3} See Table A.2 for a comparison of the predicted with the measured radiation doses.

A.5.3 Station Complex. This was a buried, reinforced-concrete structure consisting of many components (Figure 4.3). The thickness of cover and layout of the structure were such that the only significant radiation was found in the entrance tunnel which had a $\frac{1}{4}$ -inch steel door the full height and width of the tunnel. The tunnel made a 90-degree turi, within a distance equal to one and one-half times the height of the door.

For Shot Koa, ground zero was located on the far side of the structure, and the door was completely in the shadow of the structure, thus requiring two 90degree turns of radiation. For all other shots of interest, the door faced surface zero and thus the computations for slant-thickness and path-of-least-resistance methods were identical. The computations are as follows:

Siant-Thickness Method:

The slant thickness for the Shot Koa geometry resulted in an attenuation factor that predicted no significant radiation within the station.

For the other shots, the AF for the entrance was the same as that determined by the path-ofleast-resistance method while the AF for the area beyond the 90-degree turn was negligible.

Path-of-Least-Resistance Method: AF for Koa only, Entranceway: $\frac{1}{2}$ -inch steel door = 0.82 180-degree turn = 5×10^{-3} Total AF ($a \times b$) = 4.1×10^{-3} Area beyond 90-degree turn: 90-degree turn = $\frac{1}{15}$ Total AF ($a \times b \times c$) = 2.73×10^{-4} AF for all other shots, Entranceway: Total AF (a > 0.92Area beyond 90-degree turn: Total AF ($a \times c$) = 5.46×10^{-2} See Table A.3 for a comparison of the predicted with the measured radiation doses.

A.5.4 Station 3.4. This was a reinforced-concrete, box-type structure mounded with earth, the roof being final with the top of the mound. The roof was 30 in class thick and 7 by 7 feet in plan with a sized batch cover $\frac{1}{2}$ inch by 3 feet by 3 feet located in one corner (Figure 4.24).

Since the "radiation window" for this structure was the roof, the location of ground zero or surface zero had no effect on the AF determined by either method. The computations are as follows: Slant-Thickness Method:

Slant-Thickness Method

Since the slant thickness was so great, the attenuation factor determined by this method predicted that no significant radiation reached the
interior of the structure, hence an AF of zero.

Path-of-Least-Resistance Method: AF for roof: 30 inches of concrete = 10^{-2} Roof-trea factor $\frac{(7 \times 7) - (3 \times 3)}{7 \times 7} = 0.816$ $\frac{1}{2}$ inch steel hatch = 0.82 Hatch-area factor = 0.184 90-degree turn = $\frac{1}{15}$ Total AF (a × b × e + c × d × e) = 1.06×10^{-2} AF under hatch: Total AF (c × e) = 5.46×10^{-2}

See Table A.4 for a comparison of the predicted with measured radiation doses.

A.6 DISCUSSION AND CONCLUSIONS

Comparison of the predictions shows that the pathof-least-resistance predictions gave a more realistic appraisal of interior dosages. The location and recorded values of the film badges used for the structures is shown in Tables 3.2, 3.3, 4.2, and 4.3. The following observations were made from a study of the referenced tables:

(1) In Structure 560.01, Film-badge F, which is on the wall opposite the door, showed mgner doses for all shots than any other interior badge.

(2) In Structure 78.01, Film-badge J, also located on the wall opposite the door, showed the highest dose for Shot Aspen.

(3) In Station 78.01, for Shot Maple, where the source of radiation was fallout, the film-badge recordings for all badges were very uniform.

(4) In the Station Complex, the predicted doses using the path-of-least-resistance method are all too high. However, two points should be noted: first, the attenuation around the 90-degree turn inside the structure is of the right order of magnitude; and second, all devices were shielded with 180-degree concrete shields or 10-foot water shields. The effect of these shields on dose rates is not known to the author.

(5) In Station 3.4, Film-badge B, which is the closest interior film badge to the door, showed the highest dose, and Film-badge A in the hatchway showed even higher doses.

(6) The predictions for Station 3.4 from Shots Yellowwood, Walnut, and Elder were more nearly in agreement with observed doses than predictions for the same shots for the Station Complex.

Observations (1), (.:), and (5) above tend to confirm the assumption that radiation follows the line of sight through a radiation window.

Observation (4) and the generally fair predictions for all structures tend to confirm the assumption of attenuation for 90-degree turns.

Observation (6) may be explained by noting that the radiation window for Station 3.4 is horizontal sc that fallout and residual addiations may contribute more significantly to the observations than they do in the Station Complex.

Observation (3) indicates that the 90-degree attenuation is not valid for residual-radiation predictions.

It should be noted that doses were recorded in the same location by several mutually perpendicular film budges. The effect of film-badge orientation was small. These film badges are sensitive to both gamma and neutron radiations, and to both initial and residual radiations. It is not possible to determine how much each of these contributed to the doses reported. Since the weapons considered and the range at which observations were taken were relatively large, it is assumed that neutron radiation is not a large percentage of the total less than 20 percent. None of the structures were in regions of high fallout except as noted for Station 78.01.

The path-of-least-resistance method contains a number of approximations for which greater refinements are possible. Among these is the assumption that all the radiation is monodirectional along the line of sight, and therefore all radiation must turn the 90-degree angle. The actual distribution of radiation at various ranges from the source has been the subject of such studies as that reported in Reference 16. Another is the assumption that the parts of a window contribute to the total radiation in proportion to their area. It is stated in Reference 17 that the effective contribution of each portion of the window is taken as proportional to the solid angle subtended at the point of interest by the portion of the window being considered. It is believed that refinements such as these do not add sufficiently to the accuracy of the prediction to warrant their inclusion in a prediction procedure that an engineer would use in designing a structure.

A.7 RECOMMENDATIONS

It is recommended that the path-of-least-resistance method be used by engineers to predict initial radiation when designing structures to resist the effects of nuclear weapons and for determining structural and/or construction requirements to provide adequate radiation protection. When designing protective structures for which the point of burst is unknown (which will generally be true except at the Nevada and Entwetok Proving Grounds), it should be ascumed that the radiation window faces the point of burst.

Appendix B DIFFRACTION LOADING of STATION 1312

Station 1312, a massive, reinforced-concrete structure, shown in Figure 4.32, made an excellent target for a blast-diffraction study. Consequently, five selfrecording, air-blast gages were installed by personnel from BRL. The gages were placed flush with the front face, the roof, and the rear face of the station. Pressures were recorded for Shots Yellowwood, Tobacco, Walnut, and Elder. The gage geometry, including the plan and elevation for the station, is shown in $F^{i}g$ ure B.1.

B.1 PREDICTION METHODS

The general methods set forth in Reference 18 (which were derived mainly from shock-tube studies) were used in predicting the pressure on the front face, roof, and back face of the structure. However, pressuredecay curves both for side-on and dynamic pressures as presented in Reference 8 (TM 23-200) were used in predicting pressure-time relationships.

The free-field overpressure and duration measurements from Station 174.28, located adjacent to Station 1312, were used in predicting the diffracted pressures on the structure. In this manner a more reliable input value of pressure was obtained since the predicted values shown in Table 4.1 were slightly lower than the measured free-field values. The free-field pressure measurements are presented in Table 4.4. Where duration values were not available, the predicted values were used. Since the time of the preparation of this appendix, the value for the free-field overpressure for Shot Elder at Station 174.28 has been revised and is now 71 psi (see Table 4.4) rather than the 65 psi as used in the calculations for the diffraction study. Since the difference is slight, the values in Figure B.5 have not been changed to reflect the increase in measured pressure.

B.2 RESULTS AND DISCUSSION

The recorded and predicted pressure plots for the value \sim gape locations for Shots Yellowwood, Tobacco, Walnui, and Elder are shown in Figures B.2, 3, 4, and 5, respectively.

The predicted arrival time of pressure at the various gages was in close agreement with the measured values where a comparison of these values was possible.

It was observed that the predicted and recorded

pressures on the front face of the structure were in close agreement; however, the predicted pressures were slightly greater. 通常が

The peak values for the recorded pressures on the roof were very close to the predicted values except for Record 5-C, Shot Walnut. It was also observed that the vortex-action effect on the measured pressure did not cause as great a decrease in pressure as the predicted plot implies; but the recorded duration shows that the vortex lasted for a longer period of time. It was also observed that the greater the pressure, the greater the strength, and the longer the duration of the vortex.

The predicted and the recorded pressures on the back face of the structure were in close agreement; the predicted pressure values were consistently slightly lower.

The predicted durations for the free-field overpressures were in very close agreement with the measured values.

B.3 CONCLUSIONS

The methods used in predicting the load on the front and back walls of diffraction-type structures oriented at a zero angle of incidence provided results sufficiently realistic for design or analysis purposes. The predicted front-wall pressures were higher and the predicted back-wall pressures were lower than the measured values, resulting in the prediction of a conservative, net-lateral load which is greater than the measured load.

The predicted pressures on the roof were in least agreement with the recorded results. The records indicate that the vortex action lasted for a longer period of time than predicted and that the maximum pressure decay was not as great as predicted. It was also obe-real that the vortex action is extremely sensitive to pressure level. These few records indicate that additional shock-tube study is needed for the purpose of revising prediction methods for determining pressures on the roof of diffraction structures. However, the present prediction method for determining roof overpressure, even though conservative, is satisfactory for design purposes until a better method is devised.

The wide range of pressure values presented in this study should enable designers to proceed with a reasonable degree of confidence when designing blastresistant, diffraction-type structures.

146



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148









NOTE A. THE MEASURED ARRIVAL TIME OF THE SHOCK FRONT WITH RESPECT TO THE FRONT FACE OF THE STRUCTURE IS NOT KNOWN.









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Appendix C RESPONSE of GAGE PIERS to BLAST LOADS

Stations 20-B, C, D, and F on Site Janet offered an opportunity to compare predicted with observed response of reinforced-concrete gage piers, hereinafter aiso called beams, oriented at various angles of incidence with surface zero and located at various pressure levels. Stations 20-B, C, and F were cracked through at the base (see Figure 4.71) by the air blast from Shot Walnut; however, neither Shot Walnut nor Elder damaged Station 20-F. Since the length of the pier was Broater than 5 feet it was analyzed as a diffraction ts-get according to Reference 18. A typical pior and structural details can be seen in Figure 4.69. The estimated pressures received by the four stations at the various angles of incidence from ground zero and shown in Table C.1. The angle of incidence is the angle formed by the intersection of a line from ground zero and the normal to the front face of the structure.

Since information on the strength properties of material is necessary in predicting structural response, the stross-strain relations for steel and concrete used in the gage piers have been assumed and are shown in Figures C.1 and C.2, respectively. The compressive stress for the concrete was specified as 2,000 si when the pier was constructed; however, it is assumed that age has increased the strength to at least 3,000 psi. The reinforcing steel was of intermediate grade and a typical curve has been drawn to represent the stressstrain relation of the 1/2 -inch bars used in the piers. To account for the rapid loading by the blast forces, the curves have been increased by 30 percent as shown by the dotted lines. The first of the following analyses uses design strengths of materials under static conditions while the second considers the ultimate capacity of the system under dynamic conditions. Notations as used are listed at the end of this appendix.

C.1 STRUCTURAL ANALYSIS UCING DESIGN STRENGTHS

The static design analysis, including definitions for symbols, was made according to practices set forth in Rafe and a 19 (ACI Code). A lafoot-wide section was assumed and the load causing reactions to the cantilever sections was assumed uniform and normal to the beam, see Figure C.3. The stress relation for the design condition is shown in Figure C.4. The following calculations predict the not lateral pressure (w) that can be applied to the beam as limited by moment, diagonal tension, bearing, and bond. The values listed were used in the computations.

$A_8 = A_8^4 = 0.44 \text{ in}^2/\text{foot}$

$$b = 12 in.$$

$$1_{C}^{+} = 3,000 \text{ psi}$$

Determination of Neutral Axis (NA); Take moment of area about NA. See Figure C.4 for section geometry.

$$6X^{2} - (3 - X) (4.4) - (9 - X) (4.4) = 0$$

$$X^{2} + 1.47X = 8.8$$

$$X = 2.32 \text{ in.}$$

Determine if moment is limited by compression or tension. From Figure C.4,

$$f_{s} = \frac{n f_{c} (d - X)}{X}$$

when

 $f_c = 1,350 \text{ psi} \text{ (design stress)}$

$$f_{\rm B} = \frac{10 \ (1.350) \ (6.68)}{2.32}$$

 $f_s = 39,000 \text{ psi} > 20,000 \text{ psi}.$

Therefore the moment is limited by tension. Determine f_c when $f_s = 20,000$ psi

$$f_c = \frac{X f_8}{n (d - X)} = \frac{(2.32) (20,000)}{10 (6.68)}$$

$$f_c = 695 psi$$

Use this value when computing moment.

152



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TABLE C.1 PREDICTED PRESSURES AND DURATIONS FOR STATIONS 20-A TO 20-F

Station	Shot	Yield	Ground Range	Angle of incidence	Overpressure	Reflected Pressure	Positive Duration	Remarks
			ft	qeP.	psi	psi	sec	······································
20-A	Walnut	1.45 Mt	0,000	24	26	80		٠
20-B	Walnut	1.45 Mt	6,930	26	25	76		Failed
20-C	Walnut	1.45 Mt	7,125	29	23.5	70		Failed
20-D	Walnut	1.45 Mt	7,440	33	21	61	2.1	Failed
20-E	Walnut	1.45 Mt	8,160	40	18	54		٠
20-F	\Valnut	1.45 Mt	8,665	44	16	51	2.2	No damage
20-F	Elder	940 kt	7,105	53	18	4.3	1.9_	No demage

* Destroyed during previous operation.



Moment: From Figure C.4,

$$M = f'_{g} A'_{g} (3 - X/3) + f'_{g} A'_{g} (9 - X/3)$$

since
$$f'_{g} = \frac{n f_{c} (d - X - 6)}{X}$$

Determine the maximum shear (V_t) on the section as governed by allowable shearing stress (v).

 V_{t} = (v) (b) (jd), where jd in this case is 8.23

 $V_t = (90) (12) (8.23)$

 $V_{t} = 8,890 \text{ lb}$

Determine lateral pressure (w) as governed by the maximum allowable shear of 8,890 ib. From Figure ł

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Figure C.3 Assumed loading geometry for typical pler.

then

then

 $M = 106.87 f_{\rm C}$ when

f_e = 695 psi

then

M = 74,300 in-lb

Determine lateral pressure (w) as governed by maximum allowable moment of 74,300 in-Ib. From Figure C.3,

$$W = \frac{M}{21,600}$$

then

w ≈ 3.4 psi

Diagonal " nsion:

w ≈ 12.3 psi

Bearing: Since a 3-inch keyway was used, assume the effective tenting streates 3 by 10 inches (36 square inclusion) and 750 psi (6b) as the design stream in bearing

Vb = 21,000 lb

Determine lateral pressure (w) as governed by the maximum allowable bearing load of 27,000 at the keyway.

$$w = \frac{V_b}{720}$$

w = 38 psi

154

Determin the maximum shear $(V_{\mathbf{u}})$ on the section as governed by allowable bond stress (u).

$$V_{ij} = \Sigma_{ij} (jd) /u$$

$$V_{\rm L} = (2.4) (8.2) (300)$$

Determine lateral pressure (w) as governed by the maximum allowable shear of 5,900 pounds.

From the preceding calculations it is observed that

moment controls the load for the piers and therefore, the design load (w) for the piers is 3.4 psi.

$$w = \frac{v_u}{720}$$

then

w = 8.2 psi

$$\frac{(1-k'-K)d}{Kd} = \frac{\epsilon'_8}{\epsilon_c}$$
(C.2)

$$\frac{(1-\mathbf{k'}-\mathbf{K})\mathbf{d}}{(1-\mathbf{K})\mathbf{d}} = \frac{\epsilon_{B}^{1}}{\epsilon_{B}}$$
(C.3)

Stress Relation:

$$C = T_1 + T_2 \tag{C.4}$$

$$\frac{1}{2}f_{c}Kbd = p'bdf_{s}' + pbdf_{s}$$
 (C.5)

$$M_y = bd^2p' (1 - k' - K/3)f'_g + bd^2p (1 - K/3)f_g$$

(C.6)

From Figure C.1 the following stress-strain relation for steel was determined when $t_{\rm S}$ is less than $f_{\rm dy};$



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Figure C.4 Stress relationship for concrete section at design strength.

C.2 BEHAVIOR OF CONCRETE SECTION UNDER DYNAMIC LOADS

$$f_8^1 = \epsilon_8^1 E \tag{C.8}$$

The analyses were made according to the general procedures set forth in Reference 20 except that dynamic values were used in place of static-strength values for each material. The behavior of the besm (gage pier) was first determined at the yield strength and secondly at the ultimate strength capacity of the section. From the values of moment at yield and ultimate, an idealized resistance curve for the typical beam was determined.

C.2.1 Flexural Behavior at Yield. The following cometric relation: were determined from the stressstrain relation for the concrete section at yield as shown in Figure C.5.

Strain Relation:

$$\frac{Kd}{d} = \frac{\epsilon_{\rm c}}{\epsilon_{\rm c} + \epsilon_{\rm S}}$$

From Figure C.2 the following stress-strain relation for concrete was determined when f_c is less than 3,000 psi:

$$f_c = \epsilon_c E_c$$
 (C.9)

Determination of Moment at Yield (M_y) . The general moment equation (6) was used to solve M_y by letting f_g equal f_{dy} and by determining values for K and f_g . By solving F quation C.5 with the air of Equations C.1, C.3, C.7, C.8, and C.9, K was determined. Once K was solved, f_g^t was found by solving Equations C.3 and C.8. The results are as follows:

$$K = \sqrt{2p'n(1-K') + 2pn + n^2(p'+p)^2 - n(p'+p)}$$
(C.10)

when

$$p = p' = 0.004$$

 $k' = 0.67$
 $n = 10$

155

(C.1)



$$K = 0.256$$

$$f_{S}^{i} = \epsilon_{S} E \left(1 - \frac{k'}{1 - K} \right)$$
(C.11)

when

then

ε₈ = 0.00203 (see Figure C.1)

 $E = 30 \times 10^6$ psi

 $k^{+} = 0.67$

then

f' = 6,040 psi

Solve t_c to make certain that it is less than 3,000 psi, the upper limit of Equation C.9.

$$\Delta_y = \frac{\Phi_y L^2}{4}$$

Where: L = 60 in
 $\Delta_y = 0.256$ in

(C.16)

C.2.2 Flexural behavior at Ultimate. At the ultimate capucity of the section several conditions of steel stress could exist. The first possibility that was investigated assumed that f_g was greater than f_{dy} and that f_g^t was less than f_{dy} when f_c was at ultimate strength. The ascumption proved erroneous since the

strain value for f_s^i exceeded the strain at yield. It was next assumed that both f_s and f_s^i were greater than f_{dy} . However, for this condition, the strain values showed that both stress values were in the yield



Figure C.5 Stress and strain relationships for concrete section at yield strength.

$$\epsilon_{\rm c} = \frac{\epsilon_{\rm s} K}{1-K} = 0.0007 \qquad (C.12)$$

$$f_c = \epsilon_c E_c = 2,100.0 \text{ psi}$$
 (C.13)

By substituting the appropriate values into Equation C.6, $M_{\rm V}$ was determined.

$$M_v = 223,000 \text{ in-lb}$$
 (C.14)

Determination of Maximum Curvature (ϕ_y) of Beam. The maximum curvature of the beam when the moment is equal to M_y was found by solving the following expressions:

$$\phi_{\mathbf{y}} = \frac{\mathbf{M}_{\mathbf{y}}}{\mathbf{E}_{\mathbf{c}} \mathbf{I}_{\mathbf{y}}}$$
(C.10)

Where: $I_V = b(ka)^3 + pnbd^3(1-K)^2 + p^4nbd^3(1-k^4-K)^2$

$$i_y = 251.4 \text{ in}^4$$

 $\phi_y = 2.85 \times 10^{-4} \text{ in}^{-1}$

Determination of Maximum Deflection (Δ_y) at Yield. The maximum deflection of the beam at yield was found by solving the following expression:

range for steel. It was evident that both f_8 and f'_8 were equal to $f_{\rm dy}$ but it was also evident that the quantity "a" shown in Figure C.6 must be calculated curve fully since this value controlled the compressive area of concrete as well as the length of moment arms. Therefore, an idealized stress-strain curve ($f_0 = 60,000$ psi; and $E_0 = 23,800$ psi) as shown in Figure C.1 (which closely approximates the actual curve) was assumed. The stress-strain relation for the concrete section at ultimate capacity is shown in Figure C.6, and the following geometric relations were determined:

$$\frac{a}{d} = \frac{\epsilon_{\rm H}}{\epsilon_{\rm H} + \epsilon_{\rm B}} \tag{C.17}$$

$$\frac{a}{d(1-k')} = \frac{\epsilon_u}{\epsilon_u + \epsilon_s'}$$
(C.18)

$$\frac{\epsilon_{\rm B}}{\epsilon_{\rm B}} = \frac{\rm d(1-k')-a}{\rm d-a} \tag{C.19}$$

Stress Relation:

$$C = T_1 + T_2$$
 (C.20)

156

$$K_1 K_2 f_0^* ba = f_0^* p^* bd + f_N p bd \qquad (C.21)$$

 $M_u = (d - K_2 a) (A_s f_s) + d(1 - k') - K_2 a A_s' f_3'$ (C.22)

From the idealized portion of the stress-strain curve shown in Figure C.1, the following expressions were determined:

$$\mathbf{f}_{\mathbf{g}} = \mathbf{f}_{\mathbf{0}} + \boldsymbol{\epsilon}_{\mathbf{y}} \mathbf{E}_{\mathbf{0}} \tag{C.23}$$

$$\mathbf{f}_{\mathbf{S}}^{\mathbf{i}} = \mathbf{f}_{\mathbf{0}} + \boldsymbol{\epsilon}_{\mathbf{S}}^{\mathbf{i}} \mathbf{E}_{\mathbf{0}} \tag{C.24}$$

Determination of Moment at Ultimate (M_u) . The ultimate moment for the beam was found

Ee = 23,800 psi

then f₈ = 60,650 psi

Solve ϵ_8 from Equation C.23,

$$\epsilon_8 = 0.0273$$
 (C.26)

Solve a by using Equation C.17,

$$a = 1.15 \text{ in.}$$
 (C.27)

Solve ε_g^{i} by using Equation C.19 which ascertains that the strain was in the yield range.

$$\epsilon'_{\rm S} \approx 0.0063$$
 (C.28)



Figure C.6 Stress and strain relationships for concrete section at ultimate strength.

by solving Equation C.21; however, the quantities f_g , f_g^* , and a were first determined while f_c was assumed equal to its ultimate value. The quantity f_g was first determined by solving Equation C.21 with the aid of Equations C.17, C.18, C.19, C.23, and C.24. Once f_g was found, a was determined by solving Equation C.17, and f_g^* was found by solving Equation C.24. The results are as follows:

$$f_{g} = \sqrt{\frac{K_{1}K_{2}f_{C}^{c}\epsilon_{U}E_{0}}{p\beta}} + \frac{p'k'}{p\beta} \left(f_{0}^{2} - 2f_{0}\epsilon_{U}E_{0} + \epsilon_{U}E_{0}^{2}\right) + \frac{C^{2}}{4} - \frac{C}{2}$$
(C.25)

where

$$C = \frac{(\epsilon_{\mathbf{p}} \mathbf{E}_{\mathbf{0}} - \mathbf{f}_{\mathbf{0}}) \left(1 + \mathbf{p}/\mathbf{p}' - 2\mathbf{p}'\mathbf{k}'/\mathbf{p}\right)}{\beta}$$
$$\beta = \left(1 + \frac{\mathbf{p}'}{\mathbf{p}} - \frac{\mathbf{p}'}{\mathbf{p}}\mathbf{k}'\right)$$
when
$$\mathbf{f}_{\mathbf{0}}^{t} = 3,900 \text{ psi}$$

€., = 0.004

$$p = p' = 0.004$$

' = 0.67

By substituting the appropriate values into Equation C.22, $\ M_{u}$ was determined.

$$M_u = 290,000 \text{ in-lb}$$
 (C.29)

in the

Determination of Maximum Curvature (ϕ_u) of Beam. The maximum curvature of the beam when the moment is equal to M_u was found by solving the following expression:

$$\phi_{\mathbf{u}} = \frac{\epsilon_{\mathbf{g}} + \epsilon_{\mathbf{u}}}{d}$$
(C.30)
$$\phi_{\mathbf{u}} = 3.48 \times 10^{-3} \text{ in}^{-1}$$

Determination of Maximum Deflection (Δ_u) at Ultimate. The maximum deflection way found by taking statical moments of the beam loaded with angle changes which is illustrated in Figure C.7.

when

$$M = M_{u}, w = 13.4 \text{ psi}$$
 (C.31)

Find the section on the beam where the moment is equal to $M_{\rm V}$.

$$X = 52.6$$
 inches (C.32)

Determine deflection at and of beam.

157

$$\Delta_{u} = \phi_{y}(10X + 600) + \phi_{u}(1,200 + 10X - X^{2}/6)$$

$$\Delta_{u} = 1.062 \text{ inches}$$
(C.33)

C.2.3 Moment-Curvature Relation. The momentcurvature relation $(M - \phi)$ is shown in Figure C.8. The idealized curve as shown by the dotted line was drawn to establish the idealistic resistance function of the beam. The resistance (r) of the beam was determined by using the idealized moment and found as follows:

$$M_{\rm p} = \frac{M_{\rm y} + M_{\rm u}}{2} \tag{C.34}$$

 $M_{\rm D} = 261,500 \text{ in-lb}$

$$w = r = \frac{M_D}{21,600}$$
 (Figure C.3) (C.35)

r r = 12.1 psi (Resistance of Beam)

C.2.4 Shear-Compression Mode. The moment required to produce failure in the shear-compression mode was determined as shown in Reference 18 and presented as follows:

$$M_{g} = bd^{2} \left[f_{c}^{\dagger} (k + np^{\dagger}) \left(0.57 - \frac{4.5 f_{c}^{\dagger}}{10^{5}} \right) \right]$$
(C.36)
where

$$k = \sqrt{[n(p + p')]^2 + 2n(p + p' - p'k')} - n(p + p')$$

 $M_{s} = 440,000 \text{ in-lb}$

Since this moment is greater than the moment determined for flexural failure, it may be assun.3d that the critical mode is in flexure and not in shear compression.

C.3 DYNAMIC ANALYSIS

Since no measured pressures for any of the piers were taken, the incident pressures were predicted along with reflected pressures for the particular angles of incidence. The positive durations for pressure were also predicted and are shown along with the other values in Table C.1. From the table it was obvicus that it was necessary to construct only two pressure diagrams, namely for Stations 20-D and 20-F for Shot Walnut. The pressure diagram for 20-D gave the minimum observed preasure that caused failure while the diagram for Station 20-E showed the maximum observed pressure that did not cause failure. After the pressure curves were determined the piers were anaand to compare predicted response with observed response.

C.3.1 Determination of Load on Piers. The procedure presented in Reference 18 was used in predicting the pressure-load curves for Stations 20-D and 20-F. A method for ac unately determining the pressure on the rear face of diffraction targets when the

incident pressure is at an angle of incidence greater

than zero is not described. However, for design purposes the reference recommends that the method described for determining the pressure on the back face for the zero-angle-of-incidence condition also be used for conditions when the angle of incidence is greater than zero. This obviously results in a conservative estimate for the net lateral pressure. The pressure and duration values shown in Table C.1 were used in computing the curves shown in Figures C.2 and C.10. The figures show the pressure on the front and back faces of the pier, the net lateral pressures, and the net idealized lateral pressure which was used in the dynamic analysis. A detailed plot of the reflected pressures for both cases is presented in Figure C.11.

C.3.2 Natural Period of Vibration. The following equation from Reference 21 was used to determine the natural period of the beam for the fundamental mode.

$$T_n = \frac{2\pi}{n^2} \sqrt{\frac{W}{gE_c l}}$$
(C.37)

where

$$(n_1 L)^2 = 3.52$$
 (first mode)
 $n^2 = 9.78 \times 10^{-4}$

when $\approx 387 \text{ in/sec}^2$

$$E_c = 3 \times 10^6 \text{ psi}$$

$$I = 332 \text{ in}^4$$

$$W = 12.5 \text{ lb/in of beam}$$

$$I_c = 60 \text{ in}$$

then

C.3.3 Dynamic Analysis of Pier. Since the durations of the pressure spikes in Figure C.11 were significant when compared to the natural period of vibration of the beam, the piers were analyzed for both the effects from the spike and the regular net lateral pressure. A chart entitled "Maximum Response of Single-Degreeof-Freedom System to Initial Peak Triangular Force Pulse," in Reference 22, was used in determining Pm. the maximum transical pressure that the bonds can withstand.

- Station 20-D:
 - Spike alone:
 - t = 0.016 sec (Figure C.11)
 - P = 61 psi (Figure C.11)
 - $T_n \approx 0.0366 \text{ sec}$
 - $\Delta_{\rm V}$ = 0.256 in (Equation C.16)
 - $\Delta_{\rm u} = 0.062 \; (E \; quation \; C.33)$

158



Figure C.7 Determination of deflection at ultimate capacity.



Figure C.8 Moment-curvature diagram for beam.









Figure C.10 Effective blast pressure on Station 20-F.

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162

r = w = 12.1 рві (Section C.2.3)

Then:
$$\sqrt{T_{r_1}} = \frac{0.016}{0.0366} = 0.437$$

$$\Delta_{\rm u}/\Delta_{\rm y} = \frac{1.062}{0.256} = 4.2$$

From Chart, Reference 22:

 $P_m/r = 2.4$ $P_m = 2.4(12.1) = 29 \text{ psi} < 61 \text{ psi}$

Since the net predicted pressure to cause failure was 29 psi and the actual pressure was 61 psi, the beam should have failed from the spike load alone. Idealized lateral pressure (without the spike load):

Then:
$$t/T_n = 33$$
 $\frac{\Delta_u}{\Delta_v} = -\epsilon_2$

From Chart, Reference 22:

$$P_{rr}/r = 0.9$$

 $P_{\rm m} = 0.9 \times 12.1 = 10.9 \, \text{psi} < 17 \, \text{psi}$

The pressure of 17 psi was sufficient to cause failure of the beam.

Station 20-F:

Spike alone:

t = 0.015 sec (Figure C.11) P = 51.0 psi (Figure C.11)

then

$$t/T_n = 0.410$$
 $\frac{\Delta_u}{\Delta_y} = 4.2$

From Chart, Reference 22;

 $P_{\rm m}/r = 2.5$

$$P_m = 2.5 \times 12.1 = 30.2 \text{ psi} < 51 \text{ psi}$$

Since the actual pressure was 51 psi the beam should have failed according to the above calculations; however, the beam did not fail.

Idealized lateral pressure:

t = 1.2 (Figure C.10) P = 11.0 psi (Figure C.19)

then t/7

$$t/T_n = 33$$
 $\frac{-20}{\Delta_y} = 4.2$
From Chart, Reference 22;

 $P_m/r = 0.9$

$$P_{m} = 0.9 \times 12.1 = 10.9 \text{ psi} < 11.0 \text{ psi}$$

The net predicted pressure of 11.0 psi and the minimum pressure of 10 ? psi to cause failure are very close, and it can be assumed that due to this loading the beam

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was very close to failure.

C.4 DISCUSSION AND CONCLUSIONS

Even though the analysis was made assuming; both the strength properties of the materials and the airoverpressure values for the two stations invostigated, the predicted and the observed response are in fairly close agreement.

However, there exists a lack of data for use in determining reflected front-wall pressures as the angle of incidence deviates from zero. There is even less data concerning pressures on the rear faces of such structures. Shock-tube studies and/or highexplosive tests should be conducted to establish the relation of pressure on the front and back faces of diffraction targets at various angles of incidence.

If the spikes are neglected, the analysis predicts that Station 20-D would fail, which it did. The analysis for Station 20-F predicts that the pier was at the threshold of failure; however, the pier did not fail. The analysis predicts that both piers should fail from the spike loads alone.

It can be observed that the ultimate bending capacity of the beam under dynamic conditions is approximately four times greater than the bending capacity under standard design strength conditions.

For design purposes the method used was satisfactory; however, for unalysis purposes refinement is needed.

C.5 NOTATIONS

- a, depth of stress block in concrete at maximum loadcarrying capacity
- A_s, area of tension reinforcement
- As, area of compression reinforcement
- b, width of rectangular flexure member
- C, total compressive force in concrete
- d, effective depth of beam which is the distance from the compression face of the concrete to the centroid of the tension steel
- Ec, modulus of elasticity of concrete in the elastic region
- E_0 , idealized slope of stress-strain curve for reinforcing steel in yield region
- fc, stress for concrete in compression
- fc, ultimate compressive strength of concrete as determined by standard test cylinders
- fdc, dynamic ultimate compressive strength of concrete
- fs, stress for steel in tension
- f_{y} , yield point of steel in tension
- fdy, dynamic yield of steel
- fa, defined in Figure C.1
- Iy, moment of inertia of beam cross section transformed to concrete
- j, ratio of distance (jd) between resultants of compressive and tensile stresses to effective depth

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and the second

- jd, lever arm of resisting couple
- k¹, a factor when multiplied by d gives the distance between tension and compression reinforcement

163

- k, a factor when multiplied by d gives the distance from the cr.npressive face to the neutral axis of transformed section (straight-line theory)
- K_1 , K_2 , coefficients defining the magnitude and position of the inturnal compressive force in concrete
- k_n, ratio of maximum compressive strength of concrete in beam to compressive strength of standard test cylinders, fd
- M, any beading moment
- Mp, idealized bending moment
- Ms, bending moment for shear-compression mode
- M_u, bending moment at ultimate
- My, bending moment at yield point
- n, E_{B}/E_{c} , modular ratio p, A_{B}/bd

p',Ŧ/bd

- Pm, maximum transit pressure the beam can withstand
- r, equivalent static resistance required in a member
- to resist imposed transient load
- sb, allowable bearing unit stress
- t, duration of triangular force pulse T₁, total tensile force in upper reinforcement
- T_2 , total tensile torce in lower reinforcement

- T_n , natural period of vibration
- u, allowable bond stress per unit of surface area of bar v, allowable shearing unit stress
- Vb, shear governed by allowable bearing unit stress
- (S_b) Vt, shear governed by allowable shearing unit stress
- (v) $\boldsymbol{V}_{1}, \ \text{shear governed by allowable bond stress (u)}$
- w, uniformly distributed load per unit of length of
- beam
- X, depth of neutral axis from edge of compression end
- Δ_u , maximum deflection at end of beam at ultimate
- Δ_y , maximum deflection at end of beam at yield
- ϵ_c , strain in concrete
- edy, strain in steel at dynamic yield point
- ε_{u_1} ultimate strain in concrete
- ϵ_{g} , strain in tensile reinforcement
- ϵ_{s}^{i} , strain in compression reinforcement
- Σ_0 , sum of perimeters of bars
- ϕ_y , curvature of beam at yield point, in region of constani moment
- ϕ_{uv} ourvature of beem at maximum load-entrying capacity, in region of constant moment.



Appendix D WATER-WAVE DAMAGE

D.1 INTRODUCTION

Water waves (produced by surface or subsurface bursts) striking shore installations may cause serious damage to the components of such installations. There are many variables; the interrelationships involved in predicting damage from wave action are complex and not well understood at this time. The following discussion, in accordance with this project's objectives, is intended to point out certain salient features concerning wave damage in this operation. A much more comprehensive study devoted to water-wave terminal effects was made in Operation Hardtack by Project 50.1 (Reference 23) to provide more-adequate design data on wave run-up and overtopping of shore structures.

D.2 BACKGROUND

Shot Baker of Operation Crossroads caused waves which reached a maximum height of 7 feet on shore at a distance of about $3\frac{1}{2}$ miles from the target center. In the process of eroding the beach, the waves displaced large slabs of beach rock several feet; these slabs measured up to 9 by 5 by 1 foot in size, Reference 24.

Wave damage on shore had seldom been reported in detail; however, numerous photographs and observations were made by Holmes and Narver during Operation Castle (1954) and Operation Redwing (1956). See Section 1.2.1 concerning previous wave-damage surveys. The following summaries set forth some of the major wave damage.

D.2.1 Operation Castle. There were numerous instances of wave damage during Operation Castle, both at close-in stations and those at great distances. Shot geometries of Operation Castle are shown in Figures 1.1 and 1.2 for Biktni and Eniwetok, Sespectroly. Table D.i summarizes this damage. It should also be noted that at many close-in stations the entrances, on the les side from the blast, were blocked by sand and deoric left by the inundating wave.

D.2.2 Operation Redwing. In Operation Redwing there were fewer large surface shots on water and therefore much less wave damage than in Operation Castle. Shot georgetries for Operation Redwing are shown in Figures '.3 and 1.4. Only one close-in station was observed, Station 1320, Site Dog, previously used in Operation Castle as Station 1210. In this operation, the protective mound of sand was covered by a layer of asphaltic mixture a few inches thick. Air blast and waves from Shots Flathead, Makota, and Navajo broke up the asphaltic layer but only about 2 feet of cover was removed from the top of the station in the three events.

Shot Navajo was a good wave producer. At Site Nan,15 miles away, there was no indication of any air-blast damage; however, the camp area was inunlated manage; however, the camp area was inunlated manage. Frame structures on the lagoon (DUKW repair shop, rigging loft, H&N Marine Department headquarters) were demolished. POL tanks were undermined and slightly moved; a small dynamite storage house was displaced 75 feet; some of the large latrines were displaced 10 to 15 feet; and there were numerous examples of lesser damage.

D.3 THEORY

Wave damage to shore installations according to Reference 8 may result from the following three effects: (1) impact and hydrostatic force; (2) drag force; and (3) inundation. Impact from a front of advancing water or a breaking wave, in addition to the hydrostatic pressure due to the depth of water, is sufficient to damage most onshore structures with the exception of hardened structures such as those which are built at the proving ground. Drag forces may displace medium sized structures or move relatively large objects into collision with a structure, thus causing damage. The third effect, inundation, is due to the long duration of blast-generated waves; the water may reach a considerable distance inland and large areas are covered with water for the period of time until the water recedes.

Generally speaking, it is not accommodly feasible to build protective sea walls so high that they will never be overtopined by waves. The wave phenomena are complex; however, experience at the proving ground has shown that adequate protection for test structures and facilities can be provided (see D.2.1 and D.2.2). Approximate maximum wave heights can be predicted from Reference 8. However, estimates based on Reference 8 are for constant depth of water, i.e., a bottom slope of zero. A more general treat-

165

TABLE DI OBSERVATIONS OF WAVE DAMAGE, OPERATION CASTLE

Description	Site	Shot	Code Name	Damage	Range, feet
Clone-in Stations:					
Station 131: Reinforced-concrete	George	4	Union	Pisr exposed by evosion of sand.	16,430
guge pier, 12 feet long, 4 icet wide, and 4 feet deep.	•	5	Yanken	Pier displaced approximately 100 feet.	15,660
Station 130.07: Reinforced-concrete	George	4	Union	Pier exposed by erosion of sand.	15,430
gage nier, 4 by 4 by 4 feet.		5	Yankee	Pier displaced approximately 500 feet.	15,500*
Stations 1403.07 to 1403.14:	Dog	5	Yankee	All stations displaced considerable	6,890
Reinforced-concrete detector				distances.	7,100 *
stations approximately 7 feet long,					7,470
5 feet wide, and 3 feet deep.					7.700 •
					8,090
					8,280
					8,980
		_	_		9,600 *
submarine terminal pit (similar	Charlie	2	Romeo	Protective mound washed sway and footings undermined; left structure	6,600 *
Station 3.2: Reinforced-concrate	Dog	4	Union	Brotective mound ended completely.	7 200 #
submaring terminal pit (similar		5	Yankee	Completely destroyed: no traces left.	7 400 +
to Item 22, Chapter 4).	Coores		Union		1,400
submarine terminal pit (similar to ltem 22, Chapter 4).	0.001.80	•	U III OLI	FICECUVE MOUNT BEVERALY BROCED.	19,860
station 1342: Reinforced-concrete,	George	4	Union	Sand eroded from around foundation,	15,920
three-story instrument shelter, above ground unmounded (similar to Item 1, Chapter 3).		5	Yankee	very little undermining.	16,130
itation 101: Reinforced-contrate instrument shelter, mounded.	George	4	Union	Protective mound severely eroded.	15,680
reinforced-concrete diagnustic	Dog	4	Union	Mounding partially eroded leaving corners of the building exposed.	6,900
atation, mounded with approxi- mately 10 feet of cover.	Dog	4	Union	Mounding completely eroded; water damage to equipment inside the station; water stood 24 inches doep inside.	6,900
Distant Sites:					
Station 70: Reinforced-concrete timing station.	Nan	5	Yankee	Water stood 2 inches deep inside the station.	84,050
homing beacon shelter.	Nan	5	Yankee	Major damage to scientific equipment by 4 feet of water inside the station.	83,800 *
Roger, Sugar, Tare.	Complex	2	Nomeo	An 11-1006 wave waaned over the com- plex causing damage to causeways and protective berms; 500 feet of co- axial cable ware exposed; one small structure was undermined and knocksd out of alignment.	80,000 -
		4	Union	Causeways were seriously damaged; there was severe crosion around several structures.	59,000 *
fare Complex: Sitza Obos, Peter, Reger, Sugar, Tare.	Tare Complex	5	Yankee	Causeways washed out; one small un- mounded concrets block nouse (5 by 5 by 7 ft high) was displaced; approxi- mately 400 feet.	59,200*
Construction Camp:	Man	4	Union	Water reached most of the camp area and caused damage to several of the light frame buildings.	83,000 +
		5	Yankee	Camp was wrecked.	83.000 *

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munt of wa.a-height prediction is given in Reference 23 where bottom slope, reefs, and shore lines at close-in ranges are all considered.

D.4 WAVE DAMAGE IN OPERATION HARDTACK

Wave damage in Operation Hardtack was not extensive. This was due to the relatively low yields of the shots and the care taken to prevent extensive damage from waves. The wave damage that occurred as reported in Chauters 3 and 4 will only be summarized here.

Close-in stations were affected as follows:

1. Station Redwing 560.01, Site Able (Item 2): a reinforced-concrete shelter surrounded by a circular, sandbagged berm 9 feet high. The water wave (and air blast) from Shot Fir passing over the island removed about 2 feet of earth from the berm.

2. Station Redwing 1519, Site Able (Item 4): a reinforced concrete photographic station approximately 24 feet long, 9 feet wide, and 7 feet high, weighing an estimated 50 tons was displaced approximately 11 feet by Shot Fir.

3. Station 78.01, Site Charlie (Ite., oj: a meilmounded timing station was undamaged but had its entrance blocked by sand and debris as a result of Shot Fir. This effect tended to be repeated in later events.

4. Station Complex, Site Ircne (Item 18) and Station 1525 (Item 19): there was some deep erosion around these stations but no structural damage resulted.

5. Station 3.4, Site Irene (Item 22): a submarine terminal pit had nearly all of its protective mound eroded.

6. Station 1312, Site Janet (Item 25): a very large, unmounded, concrete structure was not damaged or undermined although some sand was eroded from around the foundation.

7. Landing pier, Site Janet (Gem 30): several of its large 6-foot concrete cubes were washed on shore by waves from Shots Walnut and Elder. The pre-Yellowwood condition of the pier is shown in Figure 4.73; post-Walnut is shown in Figure 4.74; and the final state, post-Elder, is shown in Figure 4.75. This last figure also indicates the extent of inundation on Janet due to shot Elder.

Distant sites received vory little wave action. This was mainly due to firing the larger-yield shots at low tides and in shallow water. The only notable wave diamage was at Sile Elmer due to Shot Oak. The main damage was to the personnel pier and a pipeline discharging into the lagoon. One of the later waves from Shot Oak is shown striking the pier in Figure D.1. Damage could have been mush more extensive if protective berms had not been placed around shoreside installations

The protession offered by a sandbag berm is illustrated in Figures D.2, 3, 4, and 5. The equipment shown in these figures was a vital link in the electrical distribution system for Sites Elmer and Fred.

D.5 DISCUSSION

Two facts observed in past operations of the proving grounds were once again demonstrated during Operation Hardtack:

 Generally, close-in structures which survived air-blast effects received no appreciable damages from water waves; however, erosion war sometimes extensive.

2. Distant sites (several miles) suffered wave action from the larger-yield devicer air ranges where air-blast damage was small or negligible.

Close-in structures which are designed to survive high blast pressures are not susceptible to wave damage since close-in sir blast is much more severe than water-wave impact and drag forces. In designing for air blast, the prevention of flooding of a station during invodetion should be considered. The only close-in effect from waves on large structures seems to be erosion and this only becomes a serious concern after several events, particularly when there is no opportunity between shelts to replace protective cover.

As distance from ground zero increases, the peak overpressure attenuates very rapidly. For pressures in the range of 1 to 1,000 psi, pressure is inversely proportional to the $\frac{5}{4}$ power of range.

$$P \sim \frac{10 W^{5/5}}{R^{5/3}}$$

Where: P = peak side-on pressure, psi

W = yield, kilotons

R = range, kilofest

Water waves, however, scale in a different fashion. For a wave moving in open water, the crest height (height above tide stage) is invorsely proportional to the range. For shallow water conditions, the relationship of the variables can be expressed approximately by:

$$H_c \sim \kappa \frac{W^{1/2} d^{1/2}}{R}$$

Where: H_{c} = crest height, feet

K = a constant generally less than 1

W = yield, kilotons

d = depth at surface zero, feet

R = range, kilofeet

The major characteristic of the blast-generated water waves that reach intermediate range and distant sites is their long period. The height of these waves is not large, in fact, storm waves are often higher. However, the long period of these waves causes water to continue to "pile up" at the shore

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Figure D.1 Wave action st the personnel pier from Shot Oak, Site Elmer.



Figure D.2 Transformer station prior to wave arrival. Shot Oak, Site Elmer.



Figure D.3 Transformer station, first wave striking the lagoon shore. Shot Oak, Site Elmer.



Figure D.4 Transformer station, first wave moving onshore; the start of inundation. Shot Oak, Site Elmer.

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168

line so that water runs inland to great distances. Protactive works can dissipate much of the energy of the water on shore but flooding of large land areas cannot be prevented. works offer reasonably adequate protection against impact and drag effects by dissipating wave energy. The long period of blast-generated waves makes protection from inundation very difficult. Inundation and



Figure D.5 Transformer station after wave action ceased and water subsided. Shot Oak, Site Elmer.

D.6 CONCLUSIONS AND RECOMMENDATIONS

Structural effects due to water wave the $\eta_{\rm c}$ is the neglected for close-in structures designed to withstand air blast.

At greater distances, where air blast is of no great consequence, water waves must be considered in structural planning. The standard shore-protection flooding that cannot be prevented may be provided for in design of facilities by waterproofing vital equipment and by making doors seal tightly. One structural feature that has shown its usefuln'ss is the provision of proper drainage for a station, i.e., eliminating sunkenfloors and sills that trap water, and having floors slope toward the entrance, so that any water that gets into the station can be readily drained out.

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- Neval Construction Bn. Center, Fort Russies, CAlit. Commanding Officer, Ruslear Vespons Training Center, Atlantic, U.S. Raval Neve, Norfolk 11, Va. ATN: Ruslear Warfare Dept. Commanding Officer, Ruslaar Vespons Training Center, Pacif.c, Neval Station, San Diego, Ca.ff. Commanding Officer, U.S. Raval Namage Control Thg. Center, Reval Ease, Philadelphia 12, Pe. ATN: ADC Defense Course Commanding Officer, U.S. Raval Air Davaloument Center 103 4.
- 105
- 106 0.0
- 107
- Defense Course ommanding Officer, U.S. Naval Air Development Center, Johnsville, Pa. ATTN: MAS, Librarian ommanding Officer, U.S. Naval Medical Research Institute, National Baral Medical Centor, Detheeda, Md. ommander, U.S. Naval Ordnance Test Station, China Lake, 108
- Calif. 109
- Calif. Commanding Officer and Director, David W. Taylor Nodel Basin, Washington 7, D.C. ATTW: Library Officer-in-Charge, U.S. Havel Buyply Research and Development Facility, Hvwal Supply Center, Bayonne, 110
- Jeve: Commander, Morfolk Maval Shipyard, Portamouth, Wa. ATTH: 111
- Undervater Explosions Research Division Mmander-in-Chief, U.S. Atlantic Fleet, U.S. Maval Base, Morfolk 11, Va. 112
- Commendant J. C. Marines Corps, Washington 25, D.C. ATCM: Code A03H Director, Marine Corps Landing Force, Lyrelopment Unster NES, Quantizo, Va. 113
- 114
- Chief, Bureau of Ships, D/N, Washington 25, D.C. ATTN: 115 Code 372
- Code 372 Commanding Officer, U.S. Maval CIC School, U.S. Maval Air Station, Glymoo, Brunavick, Ga. Chief of Maval Operations, Department of the Mavy, Washington 29, D.C. ATH: OT-OPB? 116 117
- 118
- Computer of New Yorks, Wespons, Navy Department, Washington 25, D.C. ATTN: R012 Communder-in-Chief, U.S. Pacific Fleet, Fleet Post Office, San Francisco, Calif. 119

AIR FORCE ACTIVITIES

- Deputy Chief of Staff, Operations, EQ. UBAF, Washington :: 5, D.C. ATTM: AFOOP 120
- Eq. USAF, ATTH: Operations Analysis Office, Office, Vice Chief of Stoff, Magnageton 29, D. 0 Director of Civil Engineering, M. URAF, Washington 25, D.0. 121
- 122 ATTE: AFOCE-ES
- 123-133
- Air Force Intelligence Center, H(, USAF, ACS/I (ArCH-5V1) Webington 25, D.C. Director of Beenarch and Developent, DCS/D, HQ, USAF, Massington C5, D.C. ATTH: Outdance and Wespone Div. The Surgeon General, HQ, USA/, Washington 25, D.C. ATTH: Bio-DBf, Fre. Med. Division 1 24
 - 135
 - Commander, Teotical Air Coumand, Langley AFB, Va. ATTH: Doc. Security Branch 136
 - 137
 - 1.38
 - Doe, Security Branch Gemender, Air Defense Command, Ent AFB, Colorado. ATTH: Assistant for Atvaic Energy, ADEDC-A commander, BG, Air Pescerch and Development Command, Andrews AFB, Vashingt-u.25, D.C. ATTH: MEMAA commander, Air Prov. "Literic Missile Div. HQ, AMEC, Air Force Unit Post ..."Literic Missile Div. HQ, AMEC, Air 139

- 140-141 142-146
- 147-148 149
- :50
- Commander, AF Cambridge Research Canter, L. G. Hanscom Field, Bedford, Mess. ATTN: CRGFT-2 Commender, Air Force Special Wespons Center, Kirtland AJE, Albuguesque, N. Mex. ATTN: tech. Info. A Intel. Div. Director, Air University Library, Maxwell AFE, Als. Commander, Lowry Technical Treining Center (TW), Lowry AFB, Denver, Coloredo. Commandant, School of Aviation Medicine, USAF Aerospace Medical Center (ATC), Brocks Air Porce Pase, Tex. ATTN: Col. Cerritt L. Hekbuiz 151 Commander, 1009th Sp. Wpns. Squadron, HQ. USAF, Washington
- 25, D.C. 152-154
- 155-156
- 25, D.C. Commander, Wright Air Development Center, Wright-Patteruon AFB, Dayton, Ohio. ATTN: WCACT (For WCGSI) Director, USAF Project RAID, VIA: UEAF Lisison Office, The BAND Corp. 1700 Main Bt., Santa Monica, Calif. Commander, Bons Air Development Center, ANDC, Griffies AFB, H.T. ATTN: Documents Library, NCSKL-1 Commander, Air Technical Intelligence Center, USAF, Wright-Fatterson ATB, Ohio. ATTN: AVCH-hBLs, Library Wright-Fatterson ATB, Ohio. ATTN: AVCH-hBLs, Library Wright-Fatterson ATB, Chio. HEAF, Wachberg ATB. 157
- 158 159
- Headquarters, 1st Missile Div., URAF, Vandenberg AFB, Calif. ATTH: Operations Analysis office Assistant Chief of Staff, Intelligence, H. URAFS, APO 53., New York, N.T. ATTH: Directorate of Air Tergets 160
- 161
- 162
- Ognander, Aisskan Art Command, AVC 942, Bestle, Weshington, ATTR: AAVT 'Commander-in-Chief, Pacific Air Forces, APO 953, San Francisco, Calif. ATTR: PFCIF/8, Base Recovery

OTHER DEPARTMENT OF DEFENSE ACTIVITIES

- Director of Defense Research and Engineering, Washington 25, 163 D.C. ATTN: Tech. Library
- 164
- 165
- D.C. ATTH: Tech. Library Chairman, Armad Berrices Kaplosites Safety Board, DOD, Building T-7, Gravelly Point, Washington 25, D.C. Director, Washons Systems Evaluation Group, Room 18880, The Pentagon, Washington 25, D.C. Commandant, The Industrial College of The Armed Forces, Ft. McMair, Washington 25, D.C. 166 167
- Pt. Nossir, Washington 29, 20. Commandani, Armad Forces Staff College, Korfolk 11, Ye. ATTN: Library Chief, Defense Atomic Support Agency, Mashington 29, D.C. ATTN: Dougant Library Commander, Field Command, DASA, Sandia Base, Albuquerque, 168-171
 - 172 I. Nez.

- 173 ander, Field Command, Datia, Sandia Base . Albuquampus Com 174-175
 - T. Noz. ATT: FOX ommander, Field Command, DASA, Sandia Base, Albuquerque, J. Noz. ATT: FOXT Smander, JT-7, Arlington Hall Statiou, Arlington 12, Va. Co 176 Con
 - Administrator, Mational Agronautics and Space Adminis-tration, 1500 "R" St., N.V., Washington 25, D.C. ATTH: Mr. H. V. Rhods Commander-in-Chief, Strategic Air Command, Offutt AFD, 177
 - 178
 - 179
 - 181
 - J.S. Documents Officer, Office of the United States Rational Military Representative SMAPE, APO 35, 182
 - New York, N.Y.

ATCHIC ENTROY CONCLUSION ACTIVITIES

- U.S. Atomic Energy Commission, Technical Library, Washington 25, D.C. ATTM: For 1948 183 -185
- 186-187
- 188-192
- ton PD, 0.6. ATTN: FOR DAA Los Alamo's delentific Laboratory, Neport Library, P.O. Box 1665, Los Alamos, H. Max. ATTN: Helen Redman Bandia Corporation, Classified Document Division, Sandia Rame, Albuquerque, H. Nex. ATTN: H.J. Smyth, Jr. University of California Lavrence Badiation Laboratory, P.O. Box 808, Livermore, Calif. ATTN: Clovis G. Craig 193-202
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174

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FORMERLY RESTRICTED DATA



Defense Special Weapons Agency 6801 Telegraph Road Alexandria, Virginia 22310-3398

TRC

27 August 1998

MEMORANDUM TO DEFENSE TECHNICAL INFORMATION CENTER ATTN: OCQ/Mr William Bush

SUBJECT: CLASSIFICATION CHANGES

The Defense Special Weapons Agency Security Office has reviewed and declassified the following documents and distribution statement A now applies:

WT-1631, AD-355505 WT-1619, AD-357951

Also WT-1619-EX should be withdrawn from the system.

Also WT-1637, AD-339275, has been downgraded to Confidential FRD.

Andith Janet

ARDITH JARRETT Chief, Technical Resource Center