Historical Information
H.6 Seismic/Ground Motion Activity

Book 3

The Effects of the Rulison Event on Buildings and Other Surface Structures

HSG18

THE EFFECTS OF THE RULISON EVENT ON BUILDINGS AND OTHER SURFACE STRUCTURES

By

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INTRODUCTION

Project RULISON is a joint experiment sponsored by Austral Oil Company Incorporated, Houston, Texas, the U.S. Atomic Energy Commission and the Department of the Interior, with the Program Management provided by CER Geonuclear Corporation of Las Vegas, Nevada under contract to Austral. Its purpose is to study the economic and technical feasibility of using underground nuclear explosions to stimulate production of natural gas from the low productivity, gas bearing Mesaverde formation in the RULISON Field.

The nuclear explosive for Project RULISON was detonated successfully at 3:00 P.M. plus 0.1 seconds Mountain Daylight Time, September 10, 1969, at a depth of 8425.5 feet below ground level and was completely contained. Preliminary results indicate that the RULISON device behaved about as expected; i.e., with a yield of about 40 kt. The wellhead of the emplacement well, Hayward 25-95A, is at an elevation of 8154 feet above mean sea level (MSL) and is located 1976.31 feet east of west line and 1813.19 feet north of south line of Section 25, Township 7 South, Range 95 west of 6th P.M., Garfield County, Colorado which corresponds to geodetic coordinates of longitude 107°56'53" west and latitude 39°24'21" north.

John A. Blume & Associates Research Division, under contract with the Nevada Operations Office of the U.S. Atomic Energy Commission, has been assigned responsibility for structural inventories in the range of probable damage, structural response and damage predictions, surface earth structure hazard evaluations, and recommendations for safety measures in these particular aspects. The predictions were based on field data, office studies, ground motion predictions from the Environmental Research Corporation (ERC), and pertinent published information.

This paper is essentially an interim report of currently available data. Studies are continuing to further develop the relationship of ground motion, structural properties, and damage.

STRUCTURAL RESPONSE

The geographical distribution of towns, dams, and major population centers with regard to RULISON Ground Zero (GZ) is shown in Figure 1. Major industrial facilities within 35 kilometers include the Oil Shale Research Center at Anvil

Points, the Union Carbide Plant at Rifle, and the Public Service Company Steam Plant at Cameo. The major dams are Rifle Gap Dam, Harvey Gap Dam, and Vega Dam. Smaller dams are located on Battlement Mesa, approximately 3 kilometers south of GZ. Several of the Battlement Mesa dams have been inoperative for a considerable number of years, and of those that do contain water the outlet control works are inoperative. Consequently, the flow that reaches Battlement Creek is normal overflow from the reservoir surface water, sustained by seepage through the ground from the reservoirs' areas in late summer. Of the other three major dams, Harvey Gap above the town of Silt presented an apparent hazard in view of its age, obvious disrepair of outlet works, and because of the high water levels in the reservoir in early spring. However, when the shot detonation time was extended to September, the reservoir was predicted to be nearly empty and no hazard was then presented.

Within the range of 0 to 5 kilometers from GZ there are 3 log cabins and 3 wood-frame cabins generally used during the summer. There is also a televison relay station with guyed television antennas and a small metal shack housing the electronic equipment.

Within the range of 5 to 10 kilometers there are approximately 184 locations with 28 log houses, 145 wood-frame houses and 20 masonry houses. There are also 558 minor outbuildings. Most of the structures within this 5 to 10 kilometer range are associated with farms or summer cabins.

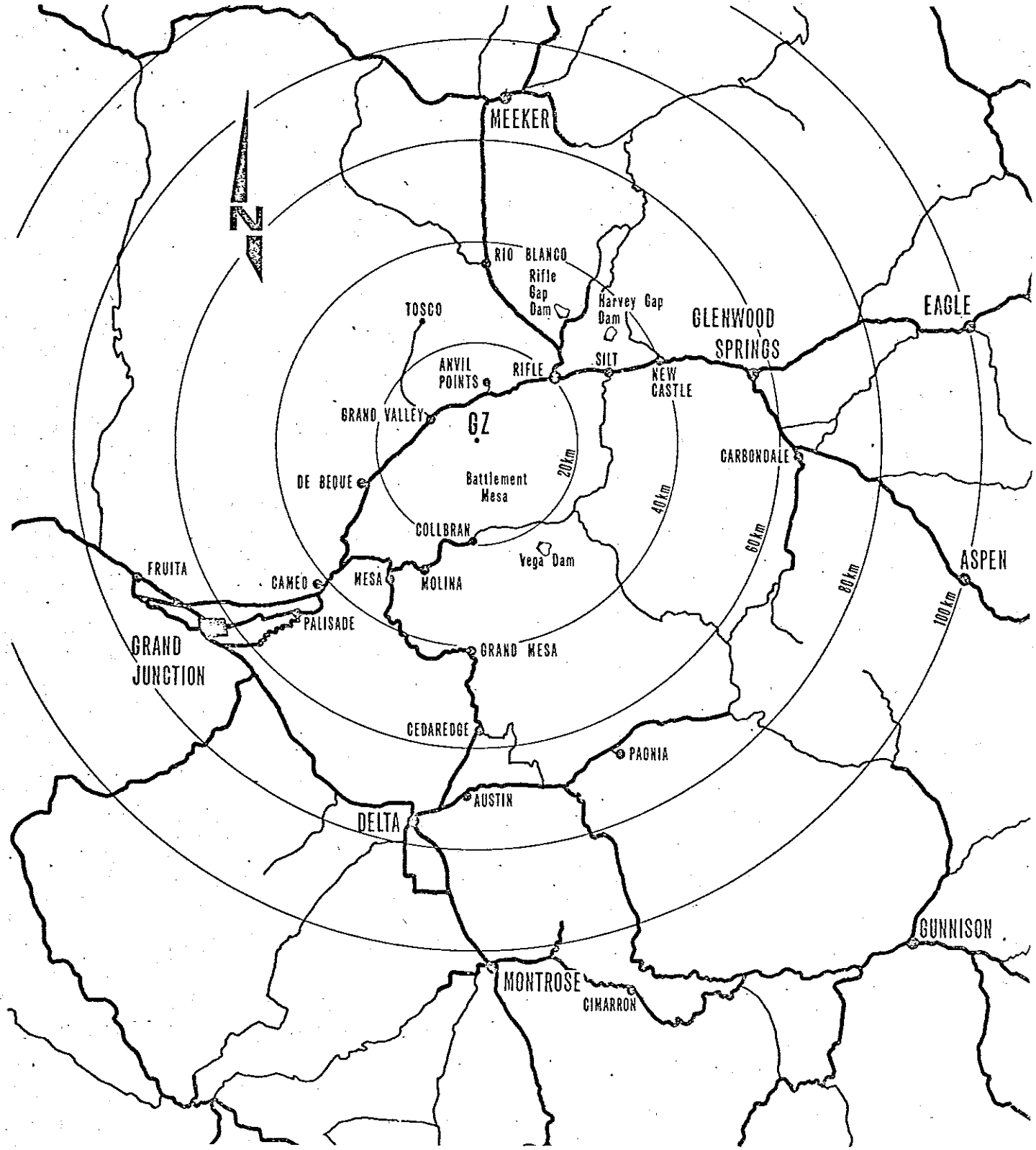
The area from 10 to 15 kilometers includes the town of Grand Valley, population 245, and the Anvil Points Oil Shale Research Station. Also included within this range are the steel truss bridges over the Colorado River at Grand Valley and at Rulison. Table I indicates that there are approximately 146 locations in this range which could be the source of damage complaints. The structures include 143 residences and 269 outbuildings associated with these residences.

From 15 to 20 kilometers there are many small ranches, the town of Collbran, and the large Union Carbide Plant near Rifle. Generally, the structures located here are again as found in Table I with 209 locations, 218 houses, and 614 associated outbuildings.

The range of 20 to 25 kilometers includes the towns of Rifle with a population of 2135, the town of De Beque with a population of 173, and Vega Dam. With the many small ranches and the houses in Rifle and De Beque, there are 893 locations with 935 associated outbuildings. The Oil Shale Company of America, a consortium of several oil companies, has a facility approximately 25 kilometers northwest of GZ in the Parachute Canyon area known as the TOSCO Facility. The structures are conspicuous and there is a large tower approximately 200 feet high which is situated in the Canyon.

Major locations within the range of 25 to 30 kilometers include the small town of Silt just east of Rifle, and Rifle Gap Dam as well as many small ranches. There are 184 locations with 177 houses and 601 associated outbuildings.

The final ring in the area of interest covers the range from 30 to 35 kilometers and includes the town of Mesa, many small ranches, and Harvey Gap Dam. At the 265 locations in this range there are 266 houses with 519 associated outbuildings.



PROJECT RULISON

General Area Map

Figure 1

TABLE I - STRUCTURE DISTRIBUTION

Distance (kilometers)	No. of Locations	House Type			Outbuildings
		Log	Wood	Masonry	
0-5	6	3	3		1
5-10	184	28	145	20	558
10-15	146	20	108	15	269
15-20	209	25	170	23	614
20-25	893	33	576	226	935
25-30	184	26	126	25	601
30-35	265	11	217	38	519
TOTAL	1887	146	1345	347	3497

DAMAGE PREDICTIONS AND SAFETY RECOMMENDATIONS

Ground motion predictions for the maximum credible yield and corresponding predictions of 5% damped Pseudo Relative Response Velocity Spectra (PSRV) were provided by ERC. These data were then used in developing the damage predictions and safety recommendations.

Hazards to personnel were predicted to exist within 7.4 kilometers as a consequence of predicted ground motion in excess of 0.3g and evacuation and other appropriate safety measures were taken. In the area from 7.4 to 14 kilometers lesser hazards to personnel were predicted to exist as a consequence of ground motion between 0.1 to 0.3g. Inhabitants in this area were requested to be outside and clear of their structures to avoid hazards resulting from possible damage to the structure. These criteria for the safety of non-participating personnel have been used extensively for previous AEC events. School buildings were also temporarily evacuated in Rifle, Collbran, and Plateau Valley during the event to eliminate the possible hazard which could be created by over-response of school children to structural motion.

Rockfalls are a normal hazard in many areas surrounding GZ. As a result of extensive investigation, these potential rockfall areas were identified. Ranch occupants, and highway and railroad traffic were kept clear of these areas.

Based on ground motion forecasts and spectra, a distance of 35 kilometers was selected as the range of potentially damaging ground motion. Within this area of 35 kilometers from GZ all structures were located, inventoried, and evaluated for possible damage. Towns were treated as separate units. Outside of the 35 kilometer radius and to a distance of about 100 kilometers, where ground motion was predicted to exceed 0.001g, all areas were visited and particularly vulnerable structures were noted and evaluated for possible damage.

Following the period of reconnaissance, inventory, and evaluation of structures, a pre-shot report was prepared and submitted. This report summarizes

safety recommendations and structure damage predictions. Recommended structural revisions to specific structures were also included in the pre-shot report. These involved brick chimney removal, undercribbing of structures, anchorage and bracing, and the placement of safety guys on tall chimneys to guide their direction of fall in the event of failure. Removal of the chimneys was based on an analysis of response under median ground motion and considered the present condition and the consequences of further damage to the structure in the event of failure.

Damage predictions were arrived at by the use of the Blume-developed Spectral Matrix Method of Damage Prediction, and separately confirmed by an engineering judgment prediction. The damage predictions in the pre-shot report involved a qualitative prediction of damage at various locations, as presented here in Table II. Repair costs were also predicted and presented in the pre-shot report.

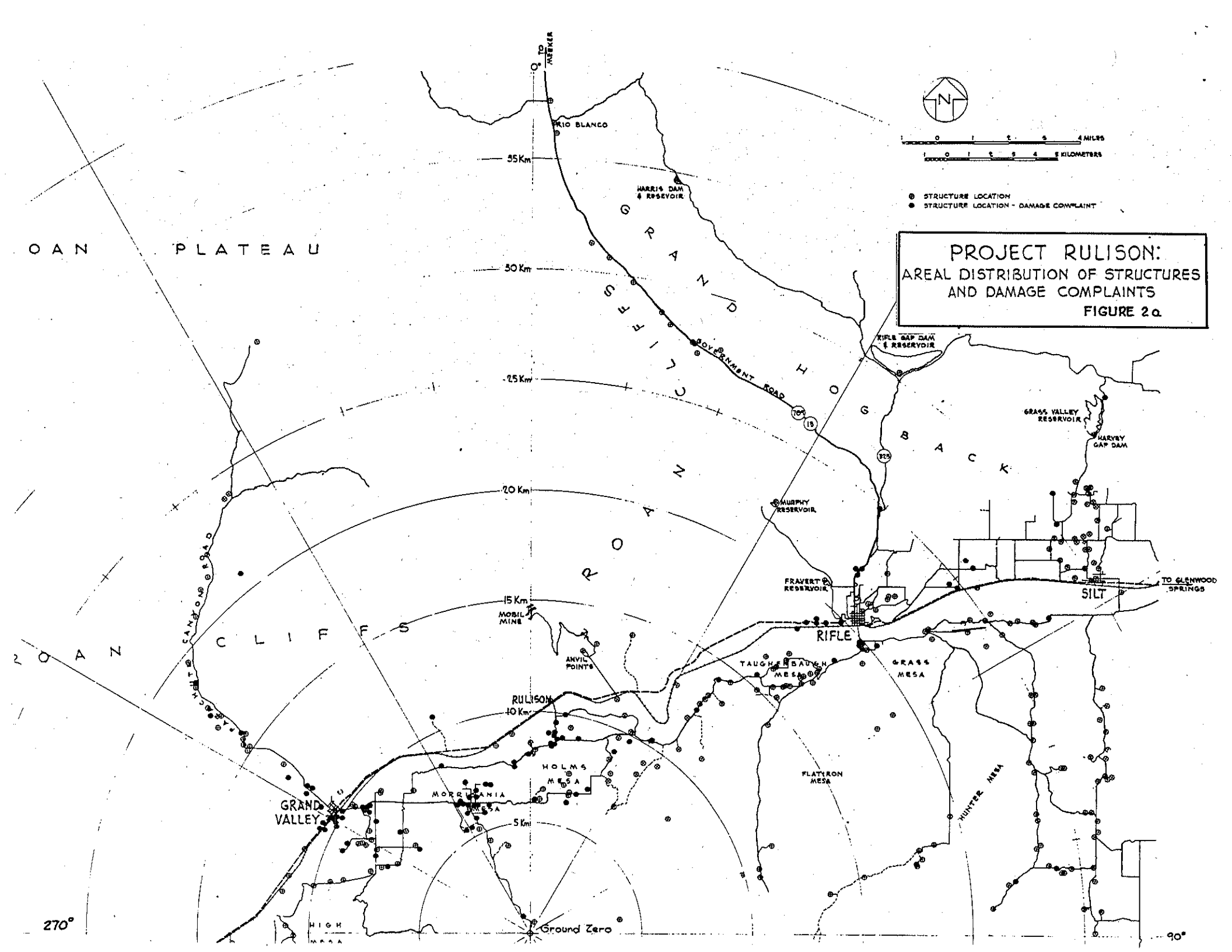
By the end of 1969, more than 90% of the damage claims had been settled at a total cost of approximately $55,000. This figure is less than the predicted repair costs and may be explained in part by the fact that the prediction was based on cost figures for actual professional repairs. Many claimants, however, preferred to accept lesser cash settlements and either make their own repairs or simply accept the damage.

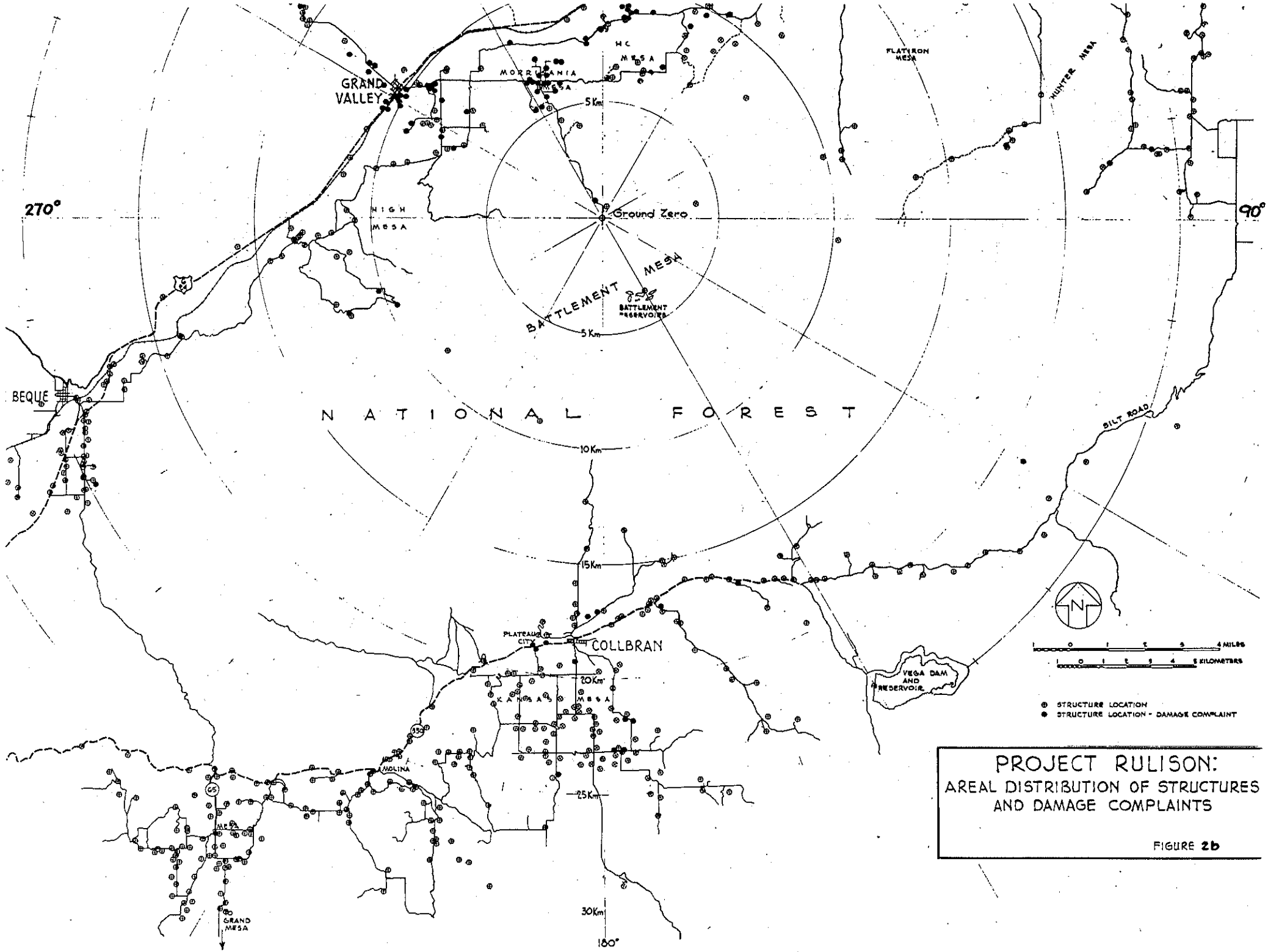
ANALYSIS OF COMPLAINTS

As of the first week of January 1970, 251 damage complaints have been analyzed from the area within 35 kilometers of GZ. A few other complaints, minor in nature, have been received from outlying areas and are not included in this presentation. Table III summarizes the various types of damage claims grouped in 5-kilometer increments from GZ. Many of the complaints are multiple types involving two or more different kinds of damage at the same location.

Table IV presents a breakdown, again by 5-kilometer increments, of the total number of structure locations versus damage complaints. A structure location as used here is a house or cabin location with or without outbuildings. Thus, a ranch is a structure location and a house in Grand Valley is also a structure location. The areal distribution of structure locations and damage complaints outside of the towns is shown in Figure 2. The 69 complaints in Grand Valley and the 74 complaints in Rifle are not shown in this Figure.

Table V presents a comparison of complaints in the three main categories (chimneys, interior plaster, and masonry walls) with the inventoried number of chimneys and the estimated number of interior plastered walls and exterior masonry walls. Also presented is the approximate peak 5% damped spectral response in the horizontal and vertical direction and for the corresponding distance increment. These peaks represent the upper envelope of measured spectra in that distance band.


PROJECT RULISON:
AREAL DISTRIBUTION OF STRUCTURES AND DAMAGE COMPLAINTS
FIGURE 2a
STRUCTURE LOCATION
STRUCTURE LOCATION - DAMAGE COMPLAINT
4 MILES
5 KILOMETERS
0° TO MEEKER
RIO BLANCO
35 Km
30 Km
25 Km
20 Km
15 Km
10 Km
5 Km
HARRIS DAM & RESERVOIR
GRAND HOGBACK
GOVERNMENT ROAD
RIFLE GAP DAM & RESERVOIR
GRASS VALLEY RESERVOIR
HARVEY GAP DAM
MURPHY RESERVOIR
FRAVERT RESERVOIR
TO GLENWOOD SPRINGS
SILT
RIFLE
MOBIL MINE
ANVIL POINTS
TAUGHENBAUGH MESA
GRASS MESA
RULISON
HOLMS MESA
MORRISANIA MESA
GRAND VALLEY
FLATIRON MESA
HUNTER MESA
HIGH MESA
Ground Zero
270°
90°
PLATEAU
CLIFFS
ROAN



PROJECT RULISON:
AREAL DISTRIBUTION OF STRUCTURES AND DAMAGE COMPLAINTS

FIGURE 2b

TABLE II

COMPARISON OF DAMAGE PREDICTIONS AND ACTUAL EFFECTS

(Based on predicted PSRV at design yield of 40 kilotons)

Name	Distance & Direction From GZ (km)	Predicted Effect	Actual Effect
Rulison	8(-) N	Moderate damage	Moderate damage
Grand Valley	10 NW	Moderate damage	Moderate damage
Anvil Points	12 N	Moderate to minor damage	Possible minor road damage
Microwave	14 W	No damage	No damage
Ranches	14(+) SE	Minor damage	Minor damage
Union Carbide	18 NE	Minor damage	Minor damage
Collbran	19 S	Minor damage	Minor damage
Rifle	20 NE	Minor damage	Minor damage
De Beque	25 SW	Minor damage	Minor damage
TOSCO	25 NW	No damage	No damage
Vega Dam	25 SE	No damage	No damage
Rifle Gap Dam	30 NE	No damage	No damage
Silt	30 NE	Minor damage	Minor damage
Mesa	32 SW	Minor damage	Minor damage
Harvey Gap Dam	34 NE	No prediction	No damage
New Castle	40 NE	No damage	No damage
Glenwood Springs	58 E	No damage	No damage
Grand Junction	64 SW	No damage	Several minor complaints
Delta	76 S	No damage	No damage

TABLE III - SUMMARY OF DAMAGE COMPLAINTS

Type of Damage	Distance in Kilometers from GZ							Total
	0-5	5-10	10-15	15-20	20-25	25-30	30-35	
Chimney	-	31	56	4	23	-	-	114
Interior Plaster	-	17	44	12	50	2	1	126
Window	-	5	1	2	5	1	1	15
Fireplace	-	2	-	2	4	-	-	8
Foundations	-	8	4	7	9	1	-	29
Masonry Walls	-	4	14	1	16	2	1	38
Other Exterior Walls	1	1	3	2	1	-	1	9
Roof	-	3	1	-	-	-	-	4
TV Sets	-	2	-	-	-	-	-	2
Household Items	-	4	-	2	2	-	1	9
Cisterns	-	15	1	1	2	-	-	19
Wells	-	1	-	-	-	-	-	1
Earth Slides	-	2	1	2	1	-	-	6
Utility Lines	-	1	-	-	2	-	-	3
Other Damage	1	7	17	2	15	-	-	42

TABLE IV - COMPARISON OF STRUCTURE LOCATIONS AND COMPLAINTS

Distance (Kilometers)	Number of Structure Locations	Damage Complaints
0-5	6	1
5-10	184	54
10-15	146	87
15-20	209	17
20-25	893	84
25-30	184	3
30-35	265	5
TOTAL	1887	251

TABLE V - COMPLAINT COMPARISON VERSUS APPROXIMATE PEAK PSRV RESPONSE

Distance	Ratio of Complaints to Inventory			Approximate Peak 5% Damped Spectral Response					
				Vertical			Horizontal		
(Kilometers)	Chimneys	Interior Plaster	Masonry Walls	Sa (g)	Sv (cm/sec)	Sd (cm)	Sa (g)	Sv (cm/sec)	Sd (cm)
0-5	0/0	0/0	0/0	*	*	*	*	*	*
5-10	31/175	17/41	4/20	3.5	56	1.3	2.3	42	1.3
10-15	56/107	44/54	14/15	1.6	16	0.4	1.0	21	0.60
15-20	4/159	12/71	1/23	0.37	7.0	0.20	0.40	8.2	0.26
20-25	23/449	50/350	16/226	0.62	12	0.27	0.36	13	0.46
25-30	0/121	2/44	2/25	*	*	*	0.13	7.0	0.36
30-35	0/201	1/87	1/38	0.12	3.0	0.10	0.13	3.7	0.10

*Data not available.

The precautions taken in having people evacuated from the area or outside of the house and two building heights away from the house were well advised as was the care taken during the pre-shot activity in removing or re-building chimneys at close-in locations. At these locations none of the remaining chimneys fell, although some loose bricks on the tops of small chimneys did fall as was predicted. Chimneys in most old homes in rural areas are unlined and because of repeated heating and cooling, and freezing and thawing cycles during the years, the mortar joints near the brick cap become loose to the point that none of the bricks are bonded. Many of these chimneys which were damaged were noted in the original inventory as being a hazard because of the loose bricks or badly deteriorated condition.

Ground motions from the event were quite close to predicted motions, and as shown in Table 2, damage occurred in the locations and generally to the extent predicted. It is easier to predict damage to structures on a qualitative basis than to predict the actual cost of damage settlements. This is demonstrated by the difference between settlement costs and predicted damage repair costs. The latter is intended to cover all damage, even that which may not be discovered or claimed. Predicted damage costs will therefore very likely never be actually attained.

Further study of RULISON damage claims will hopefully lead to understanding of relationships between settlement costs to predicted damage repair costs for use on future Plowshare projects.