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Book 3

Structural Response Studies for Project Rulison

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Rick Hague

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Prepared under Contract AT(26-1)-99
for the Nevada Operations Office, USAEC

John A. Blume & Associates Research Division
san francisco

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STRUCTURAL RESPONSE STUDIES FOR PROJECT RULISON

John A. Blume & Associates
Research Division
San Francisco, California

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STRUCTURAL RESPONSE STUDIES FOR PROJECT RULISON

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ABSTRACT

Project RULISON, an experiment using an underground nuclear explosive to fracture and thereby increase production from a gas-bearing sandstone, was detonated in western Colorado on September 10, 1969. Comprehensive structural response investigations were required for the detailed prediction of response and damage to natural and man-made structures in the area, to eliminate hazards to the public and also to provide a quantitative assessment of probable damage repair cost. These studies were carried on by John A. Blume & Associates Research Division, under the terms of a contract for structural response research studies for the Nevada Operations Office, U.S. Atomic Energy Commission.

Structures respond to seismic ground motion as oscillating mechanisms with well-defined dynamic characteristics, and response prediction techniques have been devised accordingly. Methods are available for broad delineation of general damage patterns (the Engineering Intensity Scale), quantitative predictions of damage in various building classes (the Spectral Matrix Method), and individual structure threshold and degree of damage determinations (the Reserve Energy Technique and other evaluation methods).

Detailed surveys and field evaluations were necessary to provide the basic information required for the response and damage predictions. These included inventorying the structural population out to 25 kilometers, observation and evaluation of earth structure stability and hazards (including earth and rock slopes, earth dams, and canals), a brief seismic history study, and engineering evaluations and recommendations as to specific hazards and appropriate corrective measures.

Recommendations were provided for ground motion time-history instrumental recording. Mechanical gages for structure motion recording, crack movement measurement, and water wave observations were installed.

Damage to structures occurred generally as predicted. A delay of the original shot date from May 1969 to September allowed slopes to dry out. As expected, there was an increase in stability, and little earth and rock slope movement occurred. Reservoir water levels were low, and some concern which had been expressed for the behavior of older earth dams was thereby eliminated.

Initial analyses show correlation between response motion and damage occurrence, and further detailed analyses of the motion damage relationship are in progress. As of October 31, 1970, damage payments plus amounts offered in settlement of a few remaining claims totaled about $117,500. This compares well with the damage repair cost of $123,000 predicted for the 40-kiloton design yield.

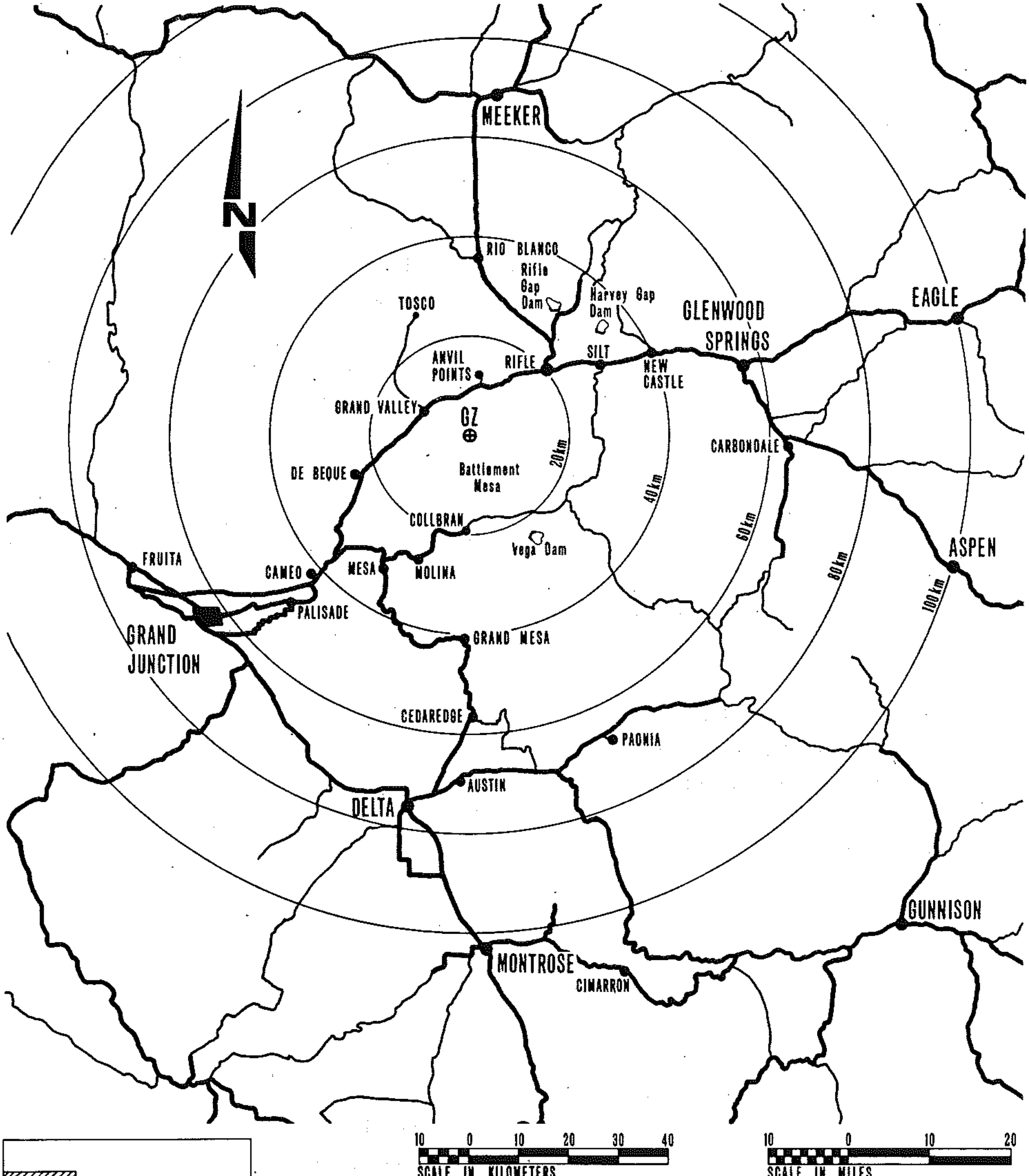
I. INTRODUCTION

RULISON PROJECT DESCRIPTION

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. ± 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 40^{+20}_{-4} 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. Figure 1 is a general map of the area.

The discussions and other content of this report are strongly influenced by the order of certain events. One of these was the program scheduling. The RULISON event was originally planned to be fired in May 1969 but was delayed until September 10, 1969. Another important chronological aspect is that damage complaints were received until September 10, 1970, one year after the event date.



PROJECT RULISON
General Area Map

Figure 1

At the time this report was being prepared, all claims had not been settled, and therefore final information was not available on the total cost or distribution of damage from the RULISON event. However, detailed studies of structural response and damage are in progress. Further reports on these aspects of the RULISON event are planned. The present report provides general data on structural response and on the pre-shot studies, and only limited discussions of the currently incomplete damage data.

SCOPE OF STRUCTURAL RESPONSE INVESTIGATION

John A. Blume & Associates Research Division (JAB), under contract to the Nevada Operations Office (NVOO) of the U.S. Atomic Energy Commission, was assigned the responsibility for structural response predictions for the RULISON event.

These predictions formed the basis for calculating structural damage and related hazards and for developing recommendations to prevent damage-related injuries and to reduce structural damage. "Structure" for the purposes of the discussion primarily refers to buildings but may also include any man-made or natural structures above ground which can be moved and damaged by ground motion. Depending upon the characteristics of both the ground motion and the dynamic properties of the structures involved, the response motion may produce stress levels in the structures high enough to cause damage. Such damage can lead to injuries to occupants or persons in the vicinity of the damaged building if appropriate safety measures and controls are not used. Structural response analysis is thus necessary for the design of such safety measures and controls, as well as to forecast damages and devise measures for reducing structural damage.

Basic structural response participation for industrial projects includes:

- Initial studies to determine the probable scope of work and define the areas of interest.

- Reconnaissance surveys of structures and foundation materials in the region of significant ground motion for planning purposes, and also to identify as early as possible any major hazard which may affect project feasibility.

- Subsequent studies which consider ground motion predictions by others to identify locations of potentially damaging structural response and other hazards and to prepare predictions of the extent and nature of possible damage.

- Recommendations for specific instrument locations to record motion.

- Detailed inventories of all structures in the range of damage, and pre- and post-shot condition surveys of selected typical and critical structures.

- Visual observations and documentation of response at selected locations.

- Subsequent analyses of response records and damage.

- Investigation of damage complaints.

RESPONSE OF STRUCTURES TO SEISMIC MOTION

The following discussions are intended to provide some basic information on the nature of structural response and the techniques used for response and damage predictions. An understanding of these processes is helpful in appreciating the rationale for the extensive and detailed studies described in this report.

Fundamental Considerations

Buildings respond to ground motion. Depending upon the vibrational characteristics of the structures, the response amplitude may be several times the amplitude of the ground. That is why motion is often felt by persons on upper floors of tall buildings while others are completely unaware of the disturbance. The amplitude, duration, and the characteristics of the ground motion can vary over a wide spectrum depending upon many factors, the most important of which include the amount of energy at the source, the distance from the source, and the local soil characteristics. The dynamic response of buildings also depends upon the ratios between the natural periods of vibration of the buildings and the periods of ground motion that contain the maximum amount of energy. In other words, there is a tuning process. Tall buildings have long periods of vibration. In addition, ground motion at considerable distances from the energy source tends to contain a considerable portion of its energy in the long-period range. This selective nature of response, which governs damage as well, is one major reason why peak ground motions cannot be used directly as damage criteria.

It must be kept in mind that ground motion is oscillatory. There is no continuity of motion in one direction. Instead the motion is back and forth, with changing acceleration, velocity, and displacement. In fact, the particle motion is three-dimensional -- up and down, and sideways in both directions.

The motion of real soil and real structures is quite complex. In order to simplify the problem, idealized models are often used to represent elements or structures and to enable response calculations to be made.

Every structure and every element of a structure has one or more natural periods of vibration. Unless damage occurs these periods generally remain nearly the same for many, but not all, types of buildings, no matter what causes the element to move or for how many times. The structural dynamicist is concerned with the periods of vibration, their possible changes and ratios, the damping (internal friction characteristics), and amounts of motion.

Response of A Simple Elastic Structure

If a one-story flexible structure, shown schematically in Figure 2, is subjected to ground motion it will be excited into motion and will respond by vibrating. The response of such a structure is primarily defined by the time variation of the coordinates that represent its degrees of freedom. The mathematical expressions from which the displacements are determined are known as "equations of motion" of the system. One such equation may be written for each degree of freedom. The structure being considered here is a one-degree-of-freedom system because only a horizontal displacement is possible. The system consists of a single mass M located at the top of the structure whose motion is resisted by weightless columns having a total spring constant K, and by a damper which absorbs energy from the system. In this structure it is assumed that the damping force is proportional to the velocity of the mass where the damping coefficient is designated by η.

The dynamic equilibrium of the system is expressed as follows:

$$F_I + F_D + F_S = 0 \qquad (1)$$

where:

$$F_I = \text{Inertia force} = M\ddot{u}_t = M\ddot{u} + M\ddot{u}_g$$

$$F_D = \text{Damping force} = \eta\dot{u} \qquad (2)$$

$$F_S = \text{Elastic force} = Ku$$

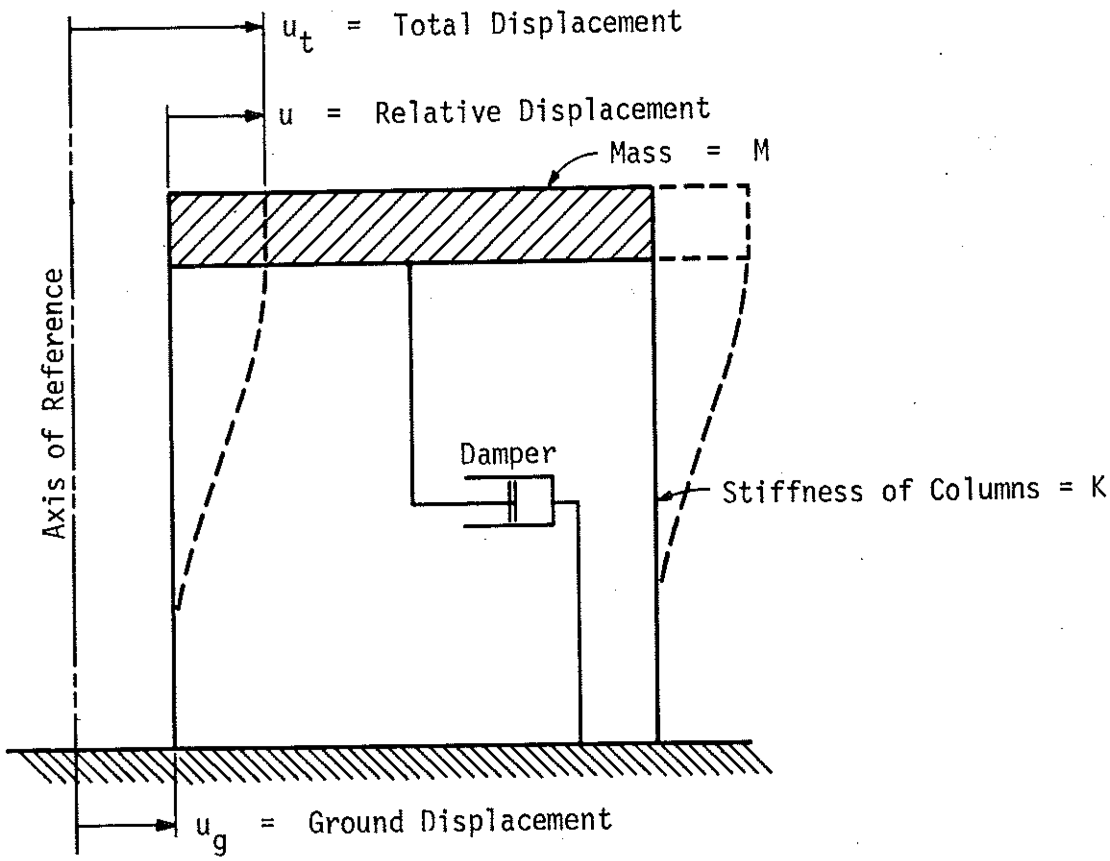


FIGURE 2. SINGLE-DEGREE-OF-FREEDOM FLEXIBLE FRAME

The dots designate differentiation with respect to time.

Substituting the expressions for inertia, damping, and elastic force into Equation 1 there is obtained the following expression of seismic motion.

$$M\ddot{u} + M\ddot{u}_g + \eta\dot{u} + Ku = 0 \qquad (3)$$

The foregoing relation can be solved by several methods. If the ground motion is zero, Equation 3 represents a damped free vibration. That value of η which corresponds to the limiting case for periodic motion is known as the "critical damping coefficient" whose magnitude can be expressed as:

$$\text{critical value of } \eta = 2M\omega \qquad (4)$$

in which ω is the circular frequency of undamped vibration given by:

$$\omega^2 = \frac{K}{M} \qquad (5)$$

The natural frequency f and the period T are determined from:

$$f = \frac{\omega}{2\pi} \quad \text{and} \quad T = \frac{1}{f} = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{M}{K}}$$

It is common to define the proportion of critical damping, β, as the ratio between η and its critical value, in the relation

$$\beta = \frac{\eta}{2M\omega} \qquad (6)$$

The dynamic structural response as a function of a system of particular characteristics may be a tedious task to compute by hand but lends itself readily to modern digital computers. It is apparent from the form of Equation 3 that for a given ground motion u_g as a function of time, the response of an elastic system depends only on the magnitude of damping and on the circular frequency of vibration of the system or, what amounts to the same thing, on the percentage of critical damping and on the natural period of the system. In other words, the magnitudes of the mass and of the spring stiffness of the structure do not independently affect the response to a ground motion. However, because the structure is subjected to a base motion and not to an applied force, the maximum deflection that the structure experiences for a given ground motion is a function of its stiffness as well as of its period of vibration.

Response Spectrum

Many prediction methods use a processed form of ground motion data called a response spectrum. This shows the peak response motion of a series of simple oscillators, such as just described, to the entire ground motion. Response spectra can be more easily predicted than can the ground motion itself, and the response spectra are more easily used in the complex structural response prediction procedures.

The concept of the response spectrum is attributed to Biot(1) who used a torsional pendulum to obtain dynamic response to a trace of actual ground motion. Today most spectra are developed with the aid of large-capacity high-speed computers. Response spectra are made for most horizontal ground motion records obtained in the NVOO Effects Evaluation Program. These are then used for various purposes including computation of response, and in the damage prediction methods described in the following sections.

The spectral response computation may be performed with the Duhamel Integral which, using recorded ground acceleration $\ddot{u}_g(t)$, takes the form

$$S = \left[\frac{1}{\omega\sqrt{1-\beta^2}} \int_0^t \ddot{u}_g(\tau) e^{-\omega\beta(t-\tau)} \cdot \sin \omega\sqrt{1-\beta^2}\,(t-\tau)\,d\tau\right]_{max} \qquad (7)$$

wherein:

S = the relative displacement response spectrum point for the particular set of values of ω and β, cm

ω = the natural undamped angular frequency of the idealized oscillator, rad/sec

β = the fraction of critical damping, dimensionless

$\ddot{u}_g(\tau)$ = the ground acceleration as a function of τ, cm/sec^2

t = time, seconds

τ = time to a pulse, $d\tau$, seconds

Equation 7 can be simplified if β is small, by letting $\sqrt{1-\beta^2}$ = unity. It is to be noticed that the only structural characteristics involved are ω and β. For a given value of β the angular frequency ω is varied over the entire range of interest in order to obtain the required points for the spectral curves. Since $u_g(\tau)$ is generally a long, complex function and $d\tau$ must be taken in very small increments in numerical operations, the total computation is a massive effort. Simpson's numerical integration procedure is often employed. Generally the results are plotted directly on four-way log paper by a plotter. The four-way log plot shows simultaneous values of spectral response motion (displacement, velocity, and acceleration) related according to the following equations. Since two of the three parameters are derived from measured values of the third, the two are termed pseudo values. However, the difference between the pseudo values and the actual values is negligible in almost all instances.

$$S_v = \omega S = \frac{2\pi S}{T} \tag{8}$$

and

$$S_a = \omega^2 S = \frac{4\pi^2 S}{T^2} \tag{9}$$

wherein:

S_v = the spectral value of velocity relative to the ground, cm/sec

S_a = the spectral value of absolute acceleration of the oscillator mass, cm/sec^2

T = the natural period of the oscillator, sec

The response spectrum shows at a glance the maximum response of a simple oscillator of period T and damping β to the entire time-history of the ground motion under consideration. Using the four-way log plot one can enter the chart with the period T, go to the proper damping curve and read S, S_v, and S_a. For example, at a period of 0.2 seconds in Figure 3, the spectral displacement is 0.06 cm, the spectral velocity is 2.0 cm/sec, and the spectral acceleration is 0.06g[(2)].

For short-period (low-rise) structures, the spectral values at these short periods are motion parameters for damage evaluation. Response spectra for spectral velocity are often plotted on an arithmetical basis, as shown in Figures 4, 5, and 6 to provide a better appreciation of the actual amplitudes of S_v, and for a better comparison between locations.

SOURCE: NVO-1163-197[2]

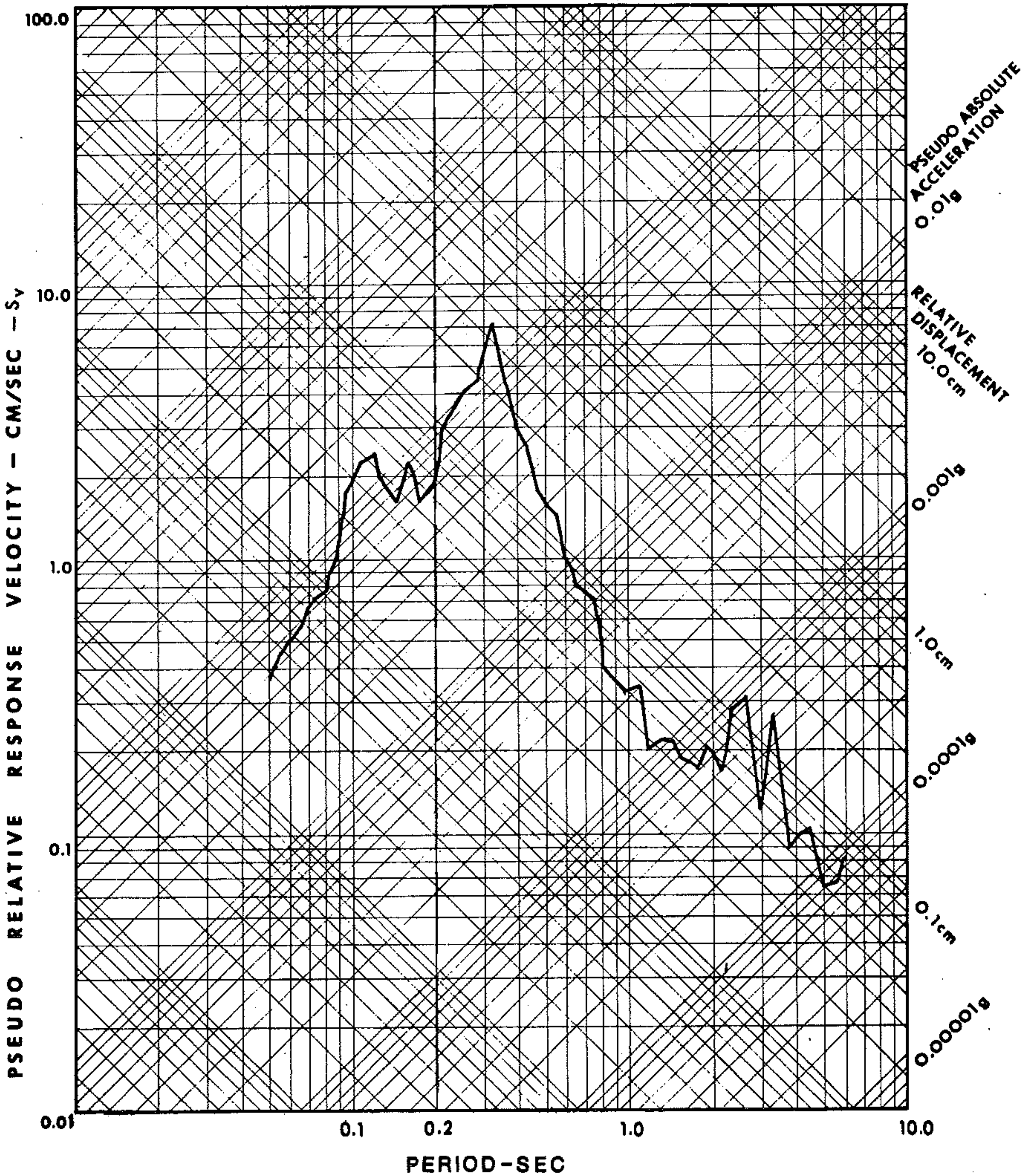


FIGURE 3 - RESPONSE SPECTRUM (RADIAL COMPONENT)
FOR SILT, COLORADO GROUND MOTION,
RULISON EVENT. (5% DAMPING)

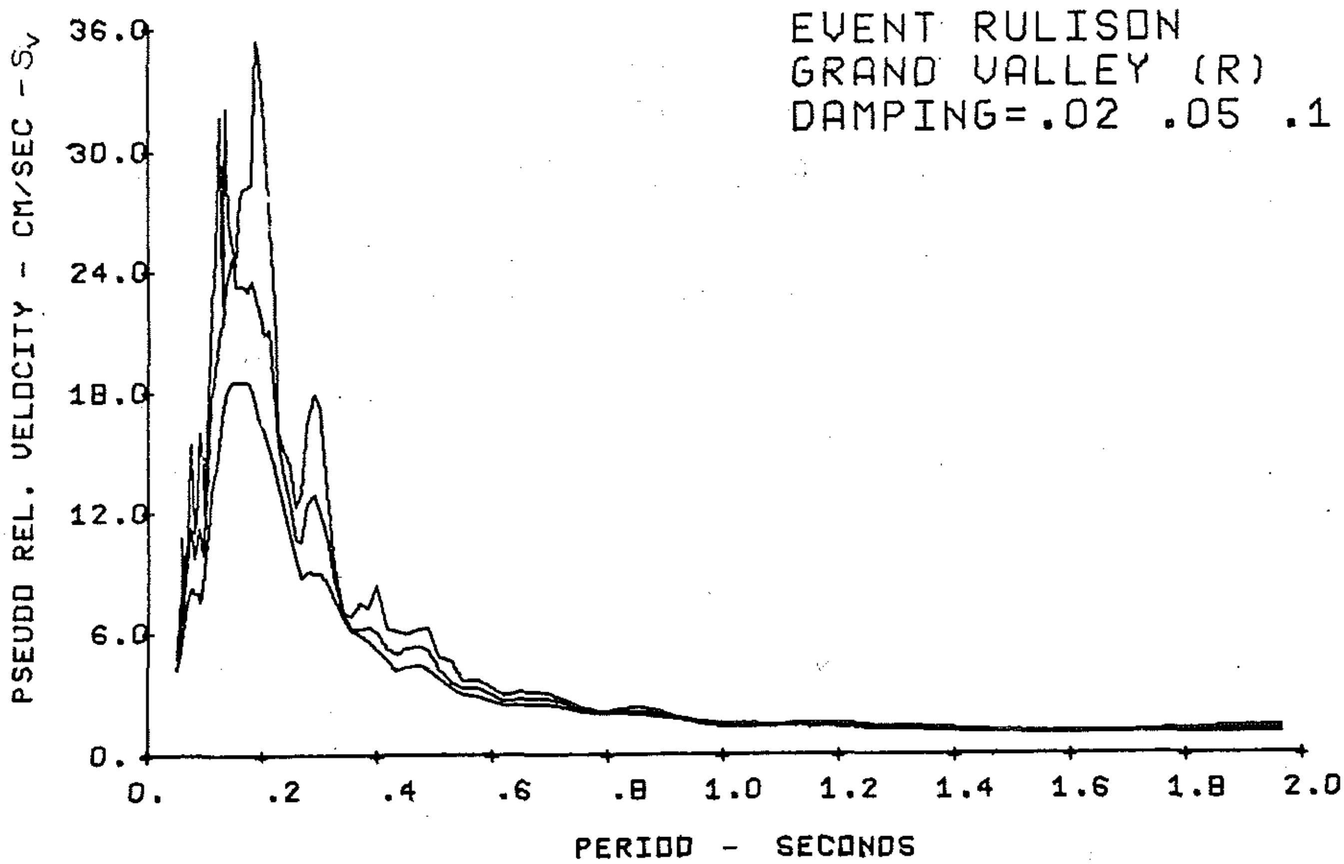


FIGURE 4 - SPECTRAL MOTION DISTRIBUTION, GRAND VALLEY (10.6 KM)

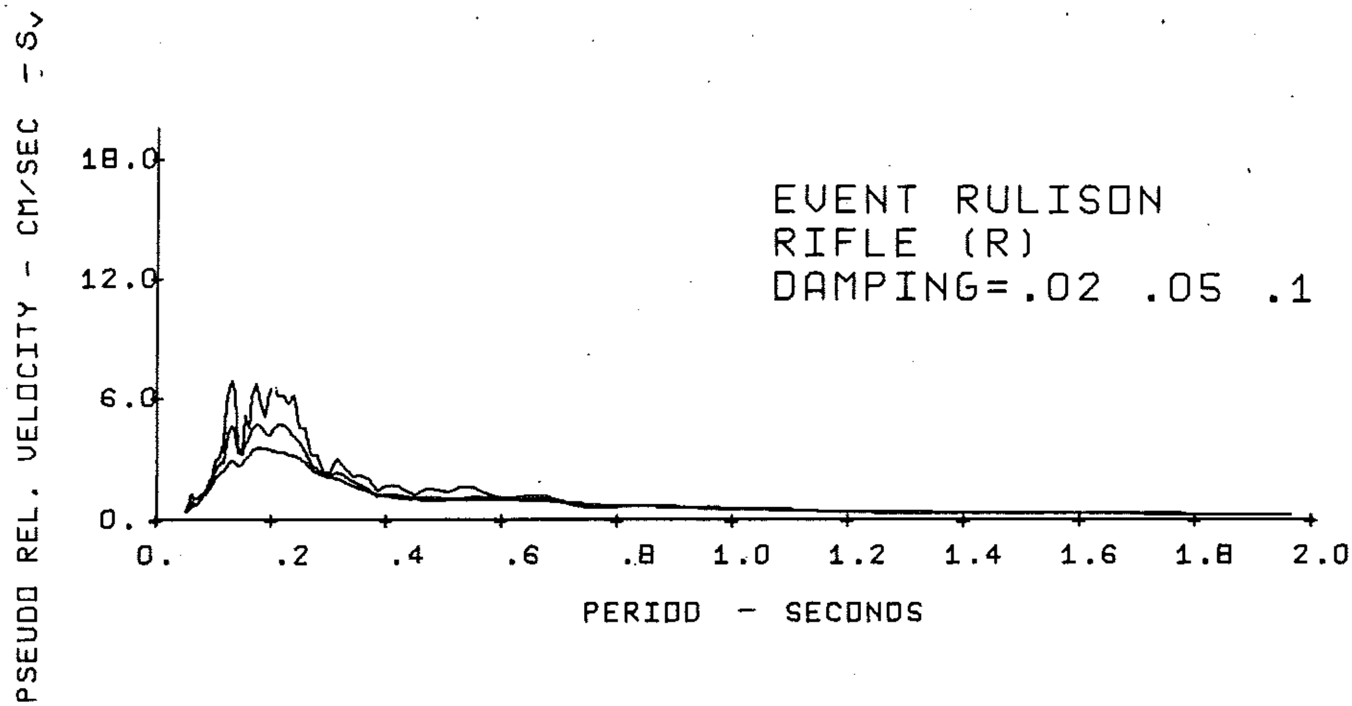


FIGURE 5 - SPECTRAL MOTION DISTRIBUTION, RIFLE-CHURCH (20.2 KM)

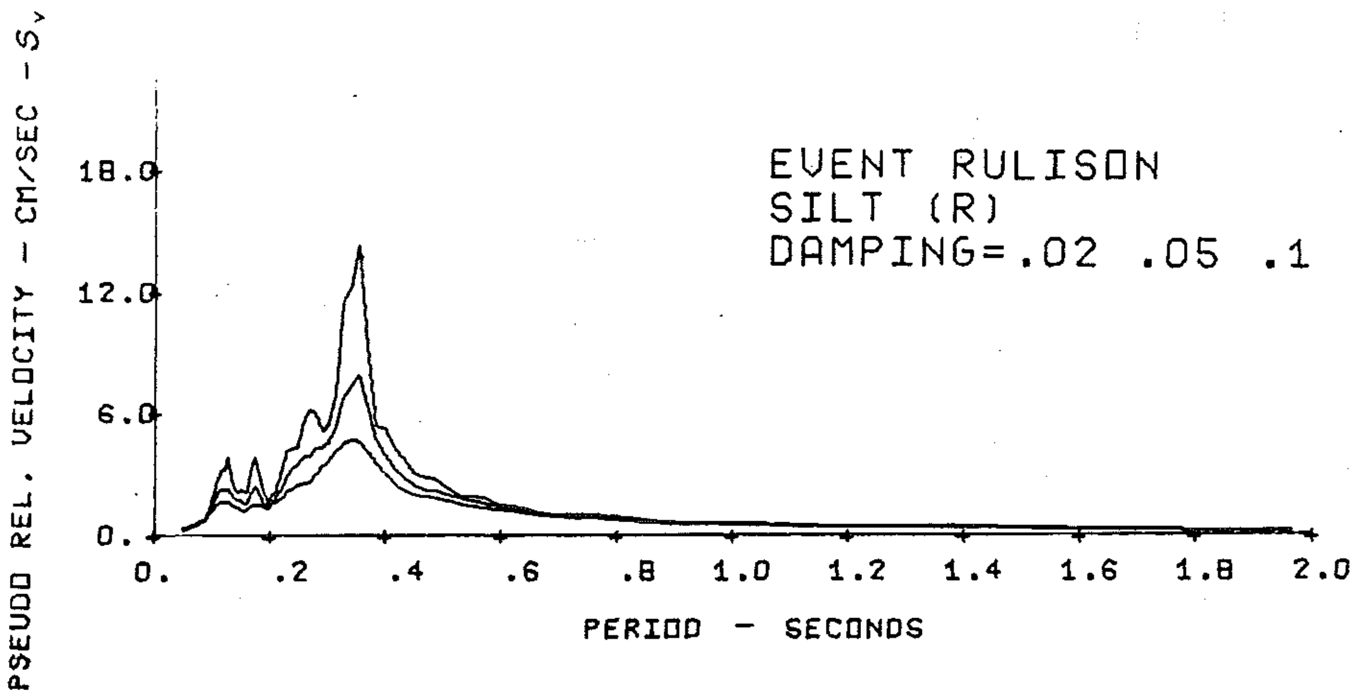


FIGURE 6 - SPECTRAL MOTION DISTRIBUTION, SILT (29.8 KM)

II. STRUCTURAL RESPONSE PREDICTION

GENERAL

Chapter I contained discussions of the theoretical aspects of the response of structures to seismic ground motion. Chapter II discusses current prediction techniques available for forecasting response and damage.

Prediction of structural response to ground motion from underground nuclear detonations has many similarities to earthquake engineering. Recent advances in the field of structural dynamics make it possible to predict in great detail the response of a structure to a known time history of ground motion. Such an analysis, however, requires an intimate knowledge of the structure and its foundation, and detailed knowledge of the physical behavior of its materials. Sophisticated analyses of this nature require a major professional effort and are therefore inappropriate for most structures of interest. Less complete analyses involving various degrees of approximation and complexity by experienced engineers are satisfactory for most aspects of the structural response program, unless special studies are needed for a particularly critical situation.

ENGINEERING JUDGMENT

Based on the ground motion predictions supplied by Environmental Research Corporation (the ground motion study contractor for the Nevada Operations Office) and the results of JAB preliminary reconnaissance and detailed condition surveys, various structures and locations were analyzed to predict the property damage which could be caused by the RULISON event. This prediction, based on engineering judgment, entailed consideration of the condition and construction of individual buildings and evaluation of damage potential due to predicted ground motions for the 40-kiloton design yield and for the 60-kiloton maximum yield.

Structures vary widely in their ability to resist ground motion. Some buildings will actually sustain damage to non-structural elements before the structural members have reached design stress, and other buildings have sufficient reserve strength to allow the structural frame to be stressed beyond the yield point and yet not show any visual evidence of damage. Most buildings, however, show evidence of damage long before the building is in any danger of major failure or collapse. This characteristic leads to the situation whereby some physical damage from an underground nuclear detonation may be considered acceptable as long as safety hazards are eliminated and the concerned property owners are fully compensated for such damage. A few special structures lack this considerable reserve strength and have only a narrow margin between no damage and severe damage. Recognition of such critical structures is an important function of the structural response program, and is accomplished by careful and detailed field evaluations by experienced professional engineers, architects, and engineering geologists.

The variability in the threshold of damage for buildings implies that a dynamic analysis does not solve the question of how much damage, if any, the structure will sustain. Most damage from past underground nuclear detonations has been sustained by nonstructural elements of buildings, and is often the result of the response motion triggering cracking in an element in an already weakened or pre-stressed condition or aggravating an intermittently progressive minor damage mechanism. Typical contribution factors are deterioration from age and weathering, poor foundation conditions which lead to differential settlement of even very light structures, poor construction materials and practices in the original construction, a lack of seismic design for the structure, and overloading of the structure. Field surveys are therefore directed to discovering existing faults in structures; developing of data for dynamic analyses is restricted to the more complex or unusual structures which may actually be overstressed in a structural sense. The latter type of buildings often has low damping and correspondingly high dynamic amplification and/or heavy masses at considerable height which leads to exceptionally heavy lateral forces. Typical "flags" for recognition of such structures are: heavy concrete or masonry roofs; elevated bulk storage; absence of lateral bracing; bare steel-framed cantilevers; heavy signs improperly mounted; and weak foundation materials or foundations on loose, saturated sands.

In combination with these essential field survey procedures to identify specific hazards, there are other empirical and theoretical methods for broader scale predictions. The Engineering Intensity Scale (EIS)[3], which is based on past experience with damage from various seismic motion sources, is an aid in determining the probability of damage to various kinds of buildings. For more detail as to the extent of damage to various locations and building classes, another prediction technique called the Spectral Matrix Method (SMM)[4] has been devised.

Finally, for specific engineering analyses of particular structures, we have developed methods for determination of specific thresholds and the prediction of behavior beyond these limits[5]. These techniques are available for use but were not required for the RULISON event.

THE ENGINEERING INTENSITY SCALE

The engineering intensity scale is for earthquakes and for ground motion resulting from nuclear or chemical explosions. It is based upon 5% damped response spectra developed from the ground motion and a standard 10 x 9 matrix with columns representing period bands and rows representing prescribed response velocity levels, S_V. Acceleration or relative displacement can also be readily assigned with the use of 4-way logarithmic paper. The EI scale can be reported by period column as 9-digit, 3-digit, or 1-digit numbers, or by all three in a standard format. The more digits reported, the greater the amount of information on the period bands. The advantages over existing scales are many, including ratings that are directly informative and useful in damage estimations. The ratings are made objectively, and have period identification lacking in other scales.

Figure 7 shows the nine period bands that have been selected after much study to best represent categories or classifications of real structures. These bands are the same as used in the Spectral Matrix Method of Damage Prediction. Each column or band has 10 intensity levels. The figure shows the S_V boundary values in cm/sec. Superimposed on the matrix is the 5% damped spectrum for the Silt Hard Rock Station, with its EI ratings in the appropriate cells.

If the response spectrum does not cross a period column the letter X is substituted for the intensity number of that band.

Table 1 shows some engineering intensity ratings for the RULISON event for several locations.

It is interesting to note that damage has occurred at some of the rating levels shown in Table 1. Using the three-digit report, estimating the periods of the then existing buildings at each location, and using an underline to represent damage, the data in Table 2 are obtained. The prime mark is used as an indication that buildings of that period class existed at the time of the ground motion. No damage occurred at ratings less than 3. With the 3 rating, in some cases there was very minor or superficial damage (or some claims were reimbursed), and in other cases there was none. Thus a rating of 3 is at or below a damage threshold for the cases con-

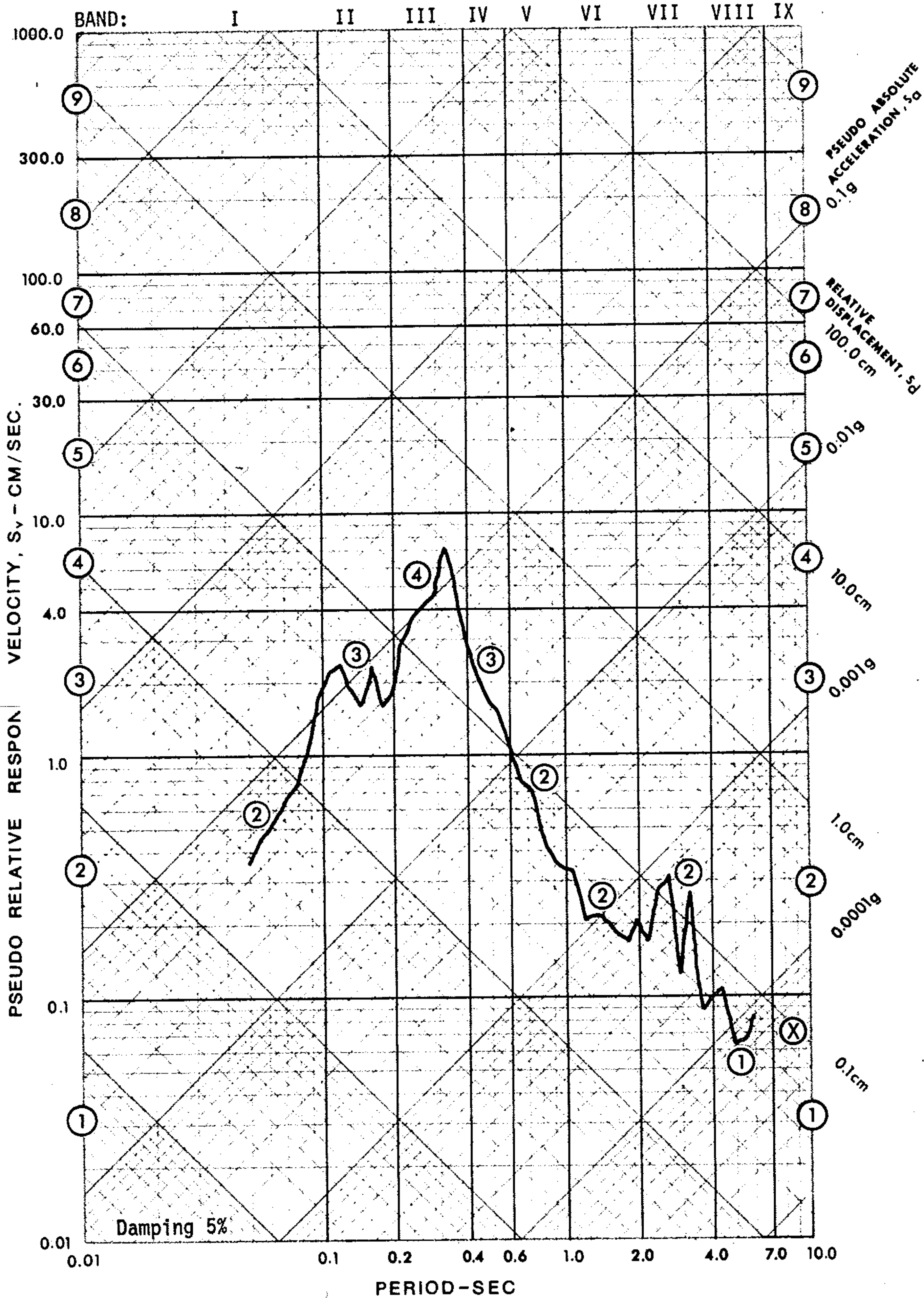


FIGURE 7 - ENGINEERING INTENSITY SCALE MATRIX WITH EXAMPLE SPECTRUM

TABLE 1 - ENGINEERING INTENSITY RATINGS
RULISON EVENT - SEPTEMBER 10, 1969

Motion at	Component	9-digit	3-digit	1-digit	Slant distance, km*
Rulison	Radial	455,433,32X	5,3,2	3+	8.7
Grand Valley	Radial	455,332,22X	5,3,2	3+	10.6
Union Carbide	Radial	344,322,22X	4,2,2	3-	18.0
Rifle, Church	Transverse	343,322,22X	3,2,2	2+	20.2
Rifle, Hill	Radial	234,332,22X	3,3,2	3-	20.2
DeBeque #1	Transverse	233,322,21X	3,2,1	2	22.8
DeBeque #2	Transverse	344,332,22X	4,3,2	3	22.8
Silt	Transverse	234,322,21X	3,2,1	2	29.8
Glenwood Springs	Radial	122,221,11X	2,2,1	2-	56.2

* From NVO-1163-206[6]

TABLE 2 - DAMAGE ASSOCIATED WITH THREE-DIGIT INTENSITY RATING

RULISON EVENT - SEPTEMBER 10, 1969

Location	Intensity Rating*	Remarks
Rulison	<u>5</u>', 3, 2	Minor to moderate damage
Grand Valley	<u>5</u>', 3, 2	Minor to moderate damage
Union Carbide	<u>4</u>', 2, 2	Minor damage
Rifle, Church	<u>3</u>', 2, 2	Minor damage
Rifle, Hill	<u>3</u>', 3, 2	Minor damage
DeBeque #1	<u>3</u>', 2, 1	Minor damage
DeBeque #2	<u>4</u>', 3, 2	Minor damage
Silt	<u>3</u>', 2, 1	Slight damage
Glenwood Springs	2', 2', 1	No damage

* Underlines indicate damage to structures of period classes underlined. Prime marks indicate that buildings of period classes marked existed at the time of the ground motion.

sidered. For ratings of 4 or greater where buildings existed in the corresponding period category there was some damage. Of course, where there were no buildings in a period category, there is no basis for rating the damage threshold.

As seen in Table 2, RULISON event damage occurred in the period ranges and at the intensity levels that would have been expected using the EI Scale.

THE SPECTRAL MATRIX METHOD

An important consideration in the damage investigation for the RULISON event was the application of a formalized procedure known as the Spectral Matrix Method (SMM). SMM has been in development and in use over a period of several years and has recently been refined, extended, and adapted to rapid computer execution[(4)]. The Spectral Matrix Method is an orderly procedure for the prediction of damage, or no damage, in structures subjected to ground motion. It includes consideration of the frequency distribution of ground motion and corresponding structural response based upon the response spectrum technique, the distribution of natural frequencies for the various kinds of structures to be subjected to ground motion, foundation materials, structural conditions, and construction practices and standards. It also considers the probabilistic aspects of the problem in that it recognizes that there can be a significant variation of both the ground motion (demand) and the structural resistance (capacity). The method is suited to either computer or manual processing. With computer aid, however, it can readily be extended to large areas and a wide complexity of structure types. The same period division is used as for the EI Scale (Figure 7).

Joint Probability Relationships

Figure 8 is a schematic diagram of two sets of discrete probability

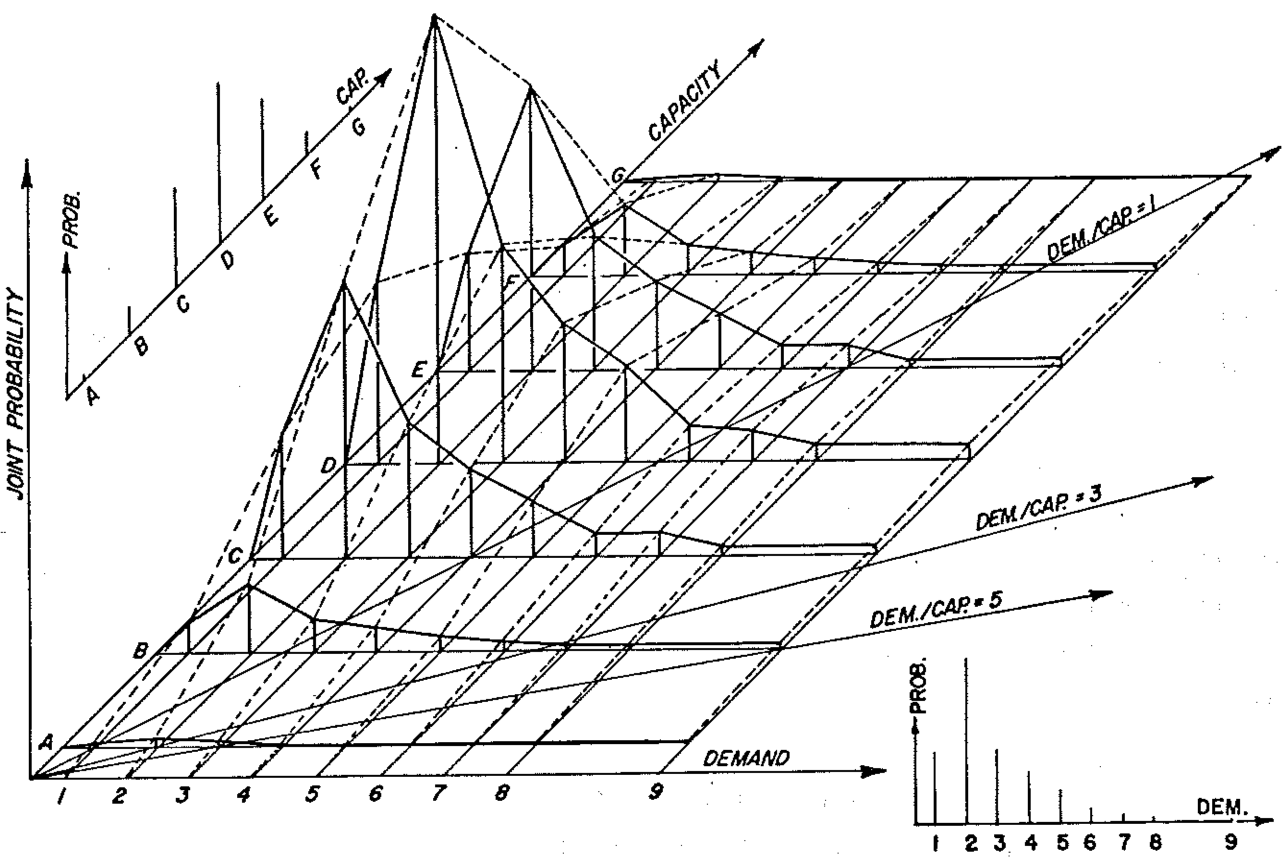


FIGURE 8. SCHEMATIC DIAGRAM OF JOINT PROBABILITY

distributions combined in a joint probability diagram. Capacity, shown at the upper left, is roughly normal in distribution (although discrete values are shown). Demand at the lower right side may be roughly lognormal if a continuous function. The sum of each set is unity. For each CAP value there is a probability of combining with any DEM value, and vice versa. These combinations of probabilities are called joint probabilities.

SMM for RULISON

For the RULISON event, fairly large uncertainties accompanied the predictions of spectral response, because the event was the first in that area. These uncertainties affected the SMM predictions unduly, having the same effect as if ground motion would actually have a wide probabilistic distribution and thus occur at abnormally high and therefore damaging levels at a number of locations. This effect can be seen by comparison of dollar damage predictions in Table 3. The first column shows predicted damage using lognormal distribution with large variations from the median ground motion predictions. Compare these values with the expected values for the median predictions, in which all data points are assumed to fall directly on the median curve. Note also in the third column the comparison with the damage predicted using spectral values for the measured ground motion. This total is larger than the pre-shot median prediction total because as is seen in Table 4 which presents data on predicted motion, probability distribution (β) and actual motion, the actual spectral velocities are generally higher than predicted.

TABLE 3 - COMPARISON OF PREDICTED DAMAGE USING THREE SETS OF GROUND MOTION WITH IDENTICAL CAPACITY VALUES

	PREDICTED AVERAGE DAMAGE -- DOLLARS		
UNIT	PRE-SHOT 40 KT LOGNORMAL S_V	PRE-SHOT 40 KT MEDIAN S_V	POST-SHOT ACTUAL S_V
RULISON 8.7 KM N6°47'E	43,695	5,993	98,933
GRAND VALLEY 10.6 KM N59°43'W	80,258	2,772	61,715
ANVIL POINTS 13.3 KM N10°53'E	40,039	878	943
RIFLE 20.2 KM N45°38'E	233,592	2,271	2,103
DEBEQUE 22.8 KM S71°05'W	5,970	16	503
SILT 29.8 KM N57°56'E	2,784	22	23
TOTALS	420,885	14,536	169,423

Note: Actual payments plus offered claim settlement costs as of October 31, 1970 totaled about $117,500.

TABLE 4 (cont'd)

PERIOD (Sec)	ANVIL POINTS			RIFLE				
	PREDICTED		RECORDED S_v (cm/sec)	PREDICTED		RECORDED S_v (cm/sec)		
	MEDIAN S_v (cm/sec)	β (dimensionless)		MEDIAN S_v (cm/sec)	β (dimensionless)	CHURCH	TOP OF HILL	UNION CARBIDE
0.05	2.5	3.60	1.5	0.55	3.60	0.48	0.52	1.9
0.06			1.8			0.98	0.80	1.8
0.07			3.4			0.95	1.2	2.5
0.08			5.7			1.3	1.3	3.7
0.09	6.0	3.34	6.3	1.2	3.34	1.7	1.5	5.0
0.10			7.3			2.4	1.6	5.0
0.11			9.4			2.6	2.4	5.7
0.12	7.5	3.10	9.4	1.4	3.10	4.0	3.4	5.9
0.13			7.6			3.7	4.0	4.8
0.14			8.3			3.5	4.4	5.4
0.15			9.5			3.4	4.9	5.5
0.16	8.2	2.95	10.4	2.6	2.95	4.0	4.0	5.6
0.17			9.4			4.2	4.0	5.7
0.18			8.0			4.0	4.2	5.5
0.19			9.0			4.0	4.4	4.5
0.20			10.3			4.1	3.8	4.5
0.21								
0.22	13.8	2.95		4.0	2.95			

PERIOD (Sec)	DEBEQUE				SILT		
	PREDICTED		RECORDED S_v (cm/sec)		PREDICTED		RECORDED S_v (cm/sec)
	MEDIAN S_v (cm/sec)	β (dimensionless)	SCHOOL #1	SCHOOL #2	MEDIAN S_v (cm/sec)	β (dimensionless)	
0.05	0.38	3.60	0.53	0.90	0.27	3.60	0.37
0.06			1.0	1.1			0.50
0.07			1.0	1.6			0.64
0.08			1.3	2.1			0.77
0.09	0.74	3.34	1.9	3.0	0.54	3.34	1.2
0.10			3.3	3.1			1.9
0.11			3.9	4.5			2.3
0.12	1.13	3.10	3.7	6.7	0.80	3.10	2.4
0.13			3.4	7.3			2.0
0.14			4.2	7.4			1.7
0.15			4.5	7.8			1.7
0.16	2.02	2.95	4.3	7.8	1.43	2.95	2.2
0.17			3.7	7.9			2.0
0.18			3.1	7.8			1.6
0.19			3.1	7.1			1.7
0.20			3.0	6.7			1.9
0.21							
0.22	3.1	2.95			3.1	2.95	

TABLE 4

PREDICTED AND OBSERVED S_V VALUES*

FOR THE RULISON EVENT

PERIOD (Sec)	RULISON			GRAND VALLEY		
	PREDICTED			PREDICTED		
	MEDIAN S_V (cm/sec)	β (dimensionless)	RECORDED S_V (cm/sec)	MEDIAN S_V (cm/sec)	β (dimensionless)	RECORDED S_V (cm/sec)
0.05	2.0	3.60	4.8	2.5	3.60	4.8
0.06			7.2			6.4
0.07			8.8			10.0
0.08			10.0			10.0
0.09	3.6	3.34	10.4	6.6	3.34	10.1
0.10			16.0			10.1
0.11			19.0			17.0
0.12	6.7	3.10	23.0	5.3	3.10	20.0
0.13			29.0			22.0
0.14			37.0			22.0
0.15			40.0			22.0
0.16	13.0	2.95	41.0	8.6	2.95	21.0
0.17			41.0			21.0
0.18			41.0			21.0
0.19			42.0			21.0
0.20			42.0			20.0
0.21			42.0			20.0
0.22	22.0	2.95		14.0	2.95	

*<u>Note</u>. The predicted spectral response is generally in terms of a median S_V value with the standard geometric deviation, β_i, where i refers to the period.

$$S_{Vi} = \breve{S}_{Vi}\ \beta_i^{\ y}$$

in which

$\breve{S}_{Vi}$ = the median pseudo spectral response relative to the ground; cm/sec.

S_{Vi} = the possible pseudo spectral response relative to the ground; cm/sec

β_i = the geometric standard deviation; dimensionless

y = the standard normal variable having zero mean and unit variance ; dimensionless

THRESHOLD DETERMINATIONS

Another tool used in the Structural Response Program but not required for RULISON is a threshold determination procedure which provides a means of determining the probability of the response of a particular building crossing various thresholds of interest. This method requires detailed knowledge about each building under consideration as well as the probable ground motion demands on the structure. It has been developed in the Structural Response Program as an aid in safety considerations. While the threshold determination procedure has been primarily used for high-rise structures, it also can be applied to other buildings which can be described with the same quantitative methods.

Some thresholds are more important than others. For example, an upper level beam in a tall building overstressed in flexure is much less important than a lower story column overstressed in compression or in shear. A further consideration is redundancy in framing with which a local overstress merely causes the transference of force from an initial point to some other part of the structure, which part may offer greater or more sustained resistance.

THE RESERVE ENERGY TECHNIQUE

If a particular threshold should present an unacceptable probability of being reached, a more detailed analysis may be conducted in the inelastic range in order to verify the results or to estimate the consequences of the threshold crossing in more detail. The Reserve Energy Technique (RET)[5] is ideal for this in that it takes into account energy absorption as well as strength, and provides information as to the mode and consequences of failure and the risk resulting from same. However, RET was not required for RULISON.

A story shear-deformation diagram is developed for the critical story.

This takes into account all of the resisting materials and elements and the inelastic as well as elastic range properties of each. Figure 9 shows some common types of shear-deformation diagrams. It is necessary to know a great deal about a building to plot a reliable diagram.

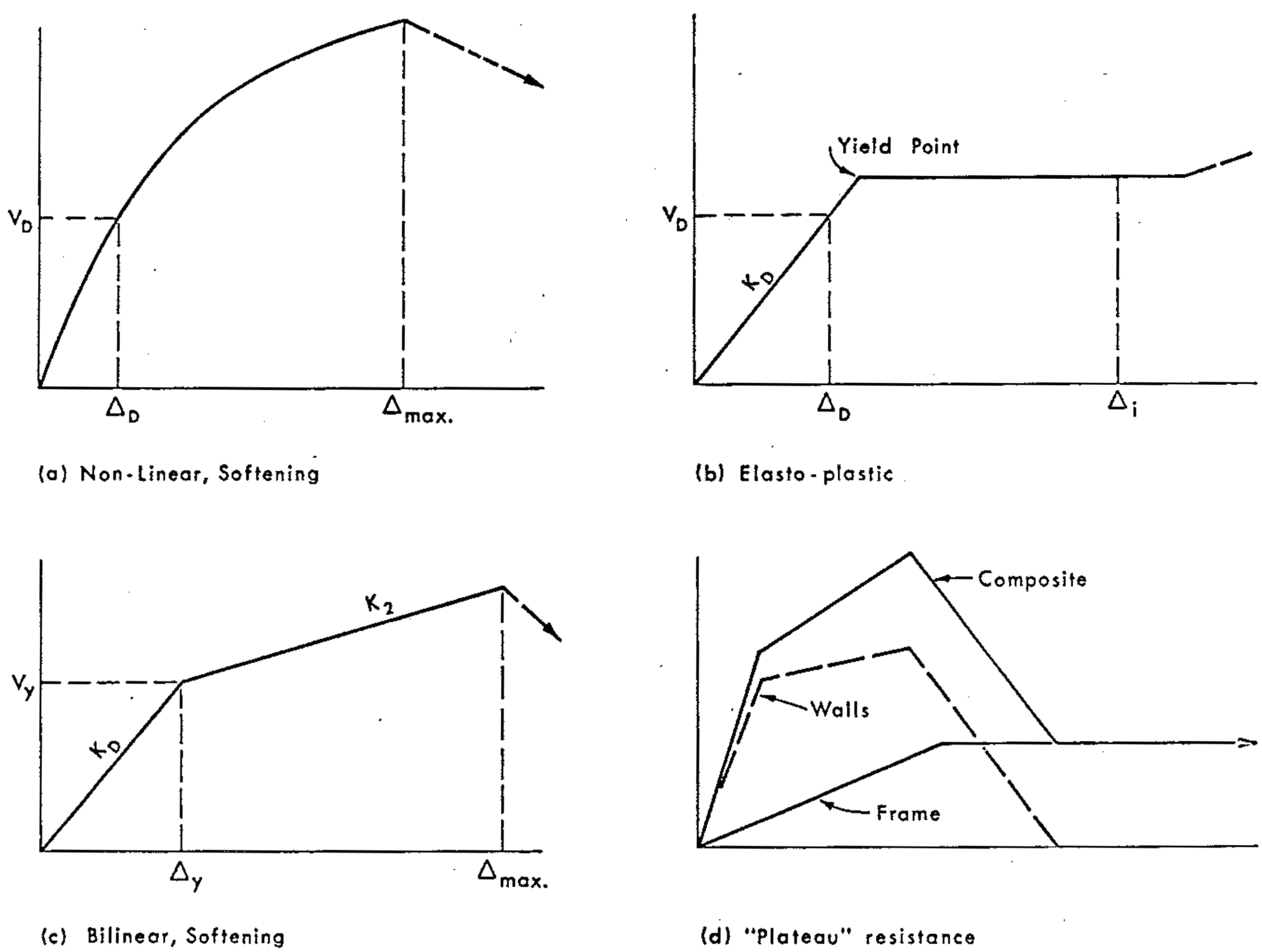


FIGURE 9. COMMON TYPES OF SHEAR-DEFORMATION DIAGRAMS

III. STRUCTURAL DATA ACQUISITION

INITIAL STUDIES

The authorization to begin RULISON structural response studies was given late in January 1969, for a proposed May detonation.

To obtain the broad background of special skills desirable for recognition and evaluation of structural response problems, a team approach of engineers, engineering geologists, and architects was established. The engineers are specialists in earthquake engineering and dynamic response of structures; the engineering geologists specialize in earth structures, foundation materials, and soils dynamics; the architects are familiar with the non-structural elements of typical building construction which produce the majority of damage claims. None of these elements could be omitted from the evaluation unless some alternative solution to evaluating or precluding damage and hazard were provided.

JAB pre-shot efforts began with a planning study of readily available data on the location and nature of the experiment, to arrive at a preliminary plan for the structural response program. Using initial ERC ground motion predictions, the distance from RULISON GZ at which structural response could be considered to reach damaging levels was estimated. The seismic history of the area was reviewed to provide estimates of the magnitude of peak ground motion that occurred in the past as a possible basis for evaluating damage threshold values for structures pre-dating a particular earthquake. Studies of this nature are especially useful for preliminary evaluation of stability of earth structures, also prevalent in the RULISON area.

A reconnaissance survey was conducted to more accurately determine the scope of the work and develop information for a preliminary report. Information was obtained or estimated on structure numbers, types, ages, conditions, evaluations, and foundation material influences. Unusually hazardous conditions were also noted. Sources of information were contacted for plans of important structures, local building costs, seismic history, distribution of close-in utilities, and similar data. Potentially hazardous buildings and special structures such as earth dams, steep slopes in developed areas, and tailings ponds possibly requiring special analysis were identified. Photographic coverage was widely used and the best available maps were utilized. Reasonably thorough coverage was conducted close-in, but somewhat less coverage at greater distances from GZ. Aerial reconnaissance was also utilized. Because it was essential during this phase to recognize potentially serious structural hazards, a high level of pertinent professional experience and mental alertness was demanded of the reconnaissance teams.

In this phase of the survey it was necessary to determine the range to which all structures should be inventoried. This was selected on the basis of initial ground motion predictions and expected minor to moderate damage, to be about 25 kilometers, although slight to minor damage was expected to occur out to about 35 kilometers. It should be noted that isolated individual structures or groups of structures were assigned numbers by location, rather than by structure. For example, a ranch with outbuildings was considered as one location. Towns were also inventoried as single locations.

Cost is a factor in conducting such surveys and the expected cost cannot exceed the gain, with gain measured in terms of possible claim overpayment with absence of adequate data to refute unfounded claims. Safety of persons is an overriding consideration, however, and cost does not enter as a factor in such cases except perhaps as the means of ensuring safety.

Visits were made to all Federal, State, County, and City agencies having needed data, and to many industrial and commercial institutions with data or interests in the area. Contacts were made with the U.S. Bureau of Reclamation, the U.S. Geological Survey, the Office of the State Engineer, County and City offices, Chamber of Commerce, the University of Colorado and the Colorado School of Mines, and many other public and private organizations.

Foundation material investigations were also conducted because the static and dynamic properties of these materials can be of great importance in determining the extent of damage to a structure exposed to seismic motion.

In view of the expected major instability of earth and rock slopes in the RULISON area during the spring thaw and wet weather, a considerable effort was expended in evaluating potential instability of all slopes near habitation or transportation routes. Reservoirs and dams were also investigated at considerable length because of expected high water levels at shot time.

The evaluations made led to our early recommendation (March 1969) that consideration be given to delaying the event to a period late in the summer, when slopes would be drier and more stable, and when reservoir water levels would be low. The event was subsequently delayed (not necessarily for these reasons) and, as expected, slopes were obviously stable since only minor rockfalls and slope failures occurred and there was no damage to reservoirs or dams.

INVESTIGATION AND ANALYSIS PROCEDURES

The data obtained were analyzed to provide the basis for a preliminary hazards evaluation. For this preliminary investigation, the damage cost estimates encompassed a relatively broad range and special problem structures were generally defined rather than specifically evaluated.

A more detailed description of the scope of work and initial recommendations on safety precautions were included in pre-shot reports. The major tasks for pre-shot reporting included structure inventory; condition surveys; analysis of data to predict structural response; identification of hazards and development of appropriate safety recommendations; and damage predictions. Recommendations for structural modification or bracing, and for instrument locations were developed concurrently. Initial pre-shot report drafts were submitted on schedule in mid-March, 1969. Ideally, there would have been a continuous interpretation of all data as it was developed and a concurrent review by the AEC. In view of the tight time schedule, however, the effort was primarily directed toward an orderly presentation in the pre-shot report, and was supplemented by letter reports before and after the report date as results were developed or previous results modified.

The structure inventory was conducted to compile pertinent data on all structures of interest. The location and sufficient information to classify the structures for SMM processing was adequate for most buildings. Photographic coverage was carried out to an extent which would allow supplementary information to be obtained from the photos without special field visits. Assessor data was used for estimating the present value of buildings. The condition surveys were restricted to selected buildings. These buildings were given a thorough initial survey to document their existing condition. Photographic coverage was the primary method of documenting RULISON examples of existing cracks and general condition. Repeat surveys were conducted prior to the detonation to detect progressive deterioration, if possible. Passive gages and wax seals across existing cracks were utilized where applicable to aid in documenting building motions and minor distress not connected with the RULISON project. If selection of buildings for condition surveys was ideal, each post-shot claim for damages would be located in close proximity to a similar building which had been condition-surveyed and which was close to a ground motion recording instrument. The condition-surveyed buildings have proven to be very useful for establishing the validity of damage complaints and have been helpful in defining ground motion criteria. In cases where analysis indicated a high probability of damage for a structure, the structure was examined to determine if modifications or temporary bracing were economical or afforded means to eliminate a potential hazard.

Investigation of special problem structures does not follow a set pattern. Usually a review of a structure's design basis was appropriate and a dynamic analysis performed. The required extent of the analyses was determined as the investigation proceeded. Approximate methods were usually sufficient.

As noted, the condition-surveyed buildings were again checked shortly before the event, and detectable changes were documented. Shortly after the event the condition surveys were repeated. (Figures 10 and 11 show a RULISON area chimney before and after damage). Absence of detectable damage was documented as well as detectable damage.

During the event JAB personnel were stationed at twelve locations where damage was considered probable or where structure response was of particular interest. Any detected damage was immediately documented.

STRUCTURE INVENTORIES

Initial planning established the need for a building inventory to evaluate structural characteristics and determine possible hazards to structures and persons. Engineers planning the inventories reviewed information and photographs from the reconnaissance survey to become familiar with the geography of the area as well as the types of structures, distribution, and potential hazards. The reconnaissance information was useful in developing a proper scope of work as a basis for efficient conduct of the structure inventories.

Early in the pre-event stage, a field office was established near the inventory area, determined from ground motion predictions and spectra to be an area out to 25 kilometers from GZ where damage could occur. Outside the 25-kilometer radius, structures were noted that could be vulnerable to long-period motion or other effects, out to a distance of about 100 kilometers.

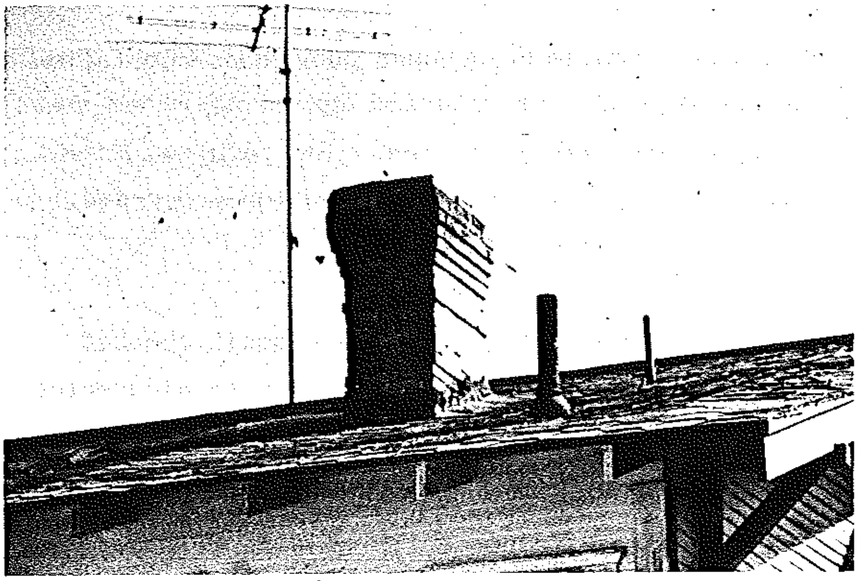


FIGURE 10. PRE-SHOT CHIMNEY CONDITION.

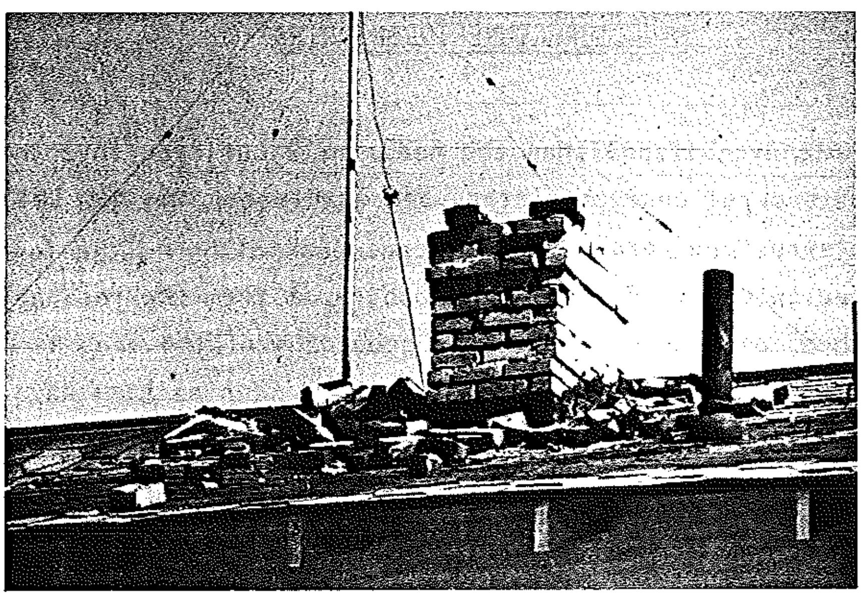


FIGURE 11. POST-SHOT CHIMNEY CONDITION.

Two factors had considerable influence on how the structure inventories for Project RULISON were conducted: unfavorable weather and population density. The bulk of the inventory field work was conducted during the winter months of February and March. Access to some areas was greatly limited by snow, and in some cases even four-wheel-drive vehicles were not effective. High-altitude locations were nearly impossible to reach, even when using snowmobiles. Some locations were obscured by many feet of snow. Frequent blizzard conditions made it difficult to take photographs. Aerial flights with light planes and helicopters were made later in the study period to view all areas and to ensure that inventory coverage was complete.

Project RULISON, unlike other off-site events, has a considerable population density in proximity to ground zero. Other off-site areas may have had one or two dozen locations within a few kilometers of ground zero; RULISON had several hundred. Because of the structure density within the potential damage range, a greater number of detailed inventories was conducted than for prior off-site events. These detailed inventories are comprehensive and can readily be adapted for computer processing. The inventory proper is a huge volume of data on RULISON structures, compiled and made available to RULISON participating agencies for planning purposes. Appendix A is the index for the inventory, which demonstrates the large number of structures actually described in detail as part of the structural response program. This index does not include those separate inventories made for the structures in the towns proper.

Structure inventory teams used topographic maps, county maps, city maps, and aerial photographs as general guides to the study area. From these sources, a large-scale map delineating the structure locations in relation to ground zero was compiled. Routes of travel were also mapped as a check on ground coverage.

No high-rise buildings were encountered (10 stories, 100 feet or more). Only a few intermediate structures were inventoried (3 to 10 stories, 30 to 100 feet). Most of the inventoried structures were low-rise (under 3 stories, or 30 feet). Also inventoried were towns, ranches, refineries, stacks, an ore processing plant, bridges, overpasses, trestles, dams and reservoirs, ground-based and elevated tanks for liquids, silos, water supply and sewage treatment facilities, power generation facilities, canals, microwave and other communication facilities, highway and railroad cuts, pipelines and penstocks, tunnels, tailing ponds, gas wells, schools, hospitals, government structures, churches, substations and powerlines, lakes, and structures presenting hazards or unusual importance, such as the Colorado National Monument. Figures 12, 13, and 14 show storage tanks and a silo typical of the RULISON area.

The inventory approach varied according to the type of structure because data concerning a dam or reservoir, for example, would differ from information collected for a residence or two-story commercial building, although some basic types of information were common to each inventory location. Common information included location number; location name and owners; latitude and longitude; state and county; township, range, and section; baseline and meridian; elevation; date; names of observers; foundation classification; records of photographs; and general descriptions of observations.

Additional information pertinent to preliminary structural evaluations including building dimensions, frame type, exterior and interior wall finishes, floor materials and construction, roof geometry and materials, chimney description, percent of fenestration, construction costs or estimated replacement costs, and building classes. Table 5 defines building classes for structure inventories. A sample inventory sheet for a ranch north of ground zero is shown in Figure 15 to illustrate the nature of the structural inventory. Inventories for dams, reservoirs, and lakes -- whether natural or man-made -- contained basic information as well as bathymetric, dam, and spillway data.

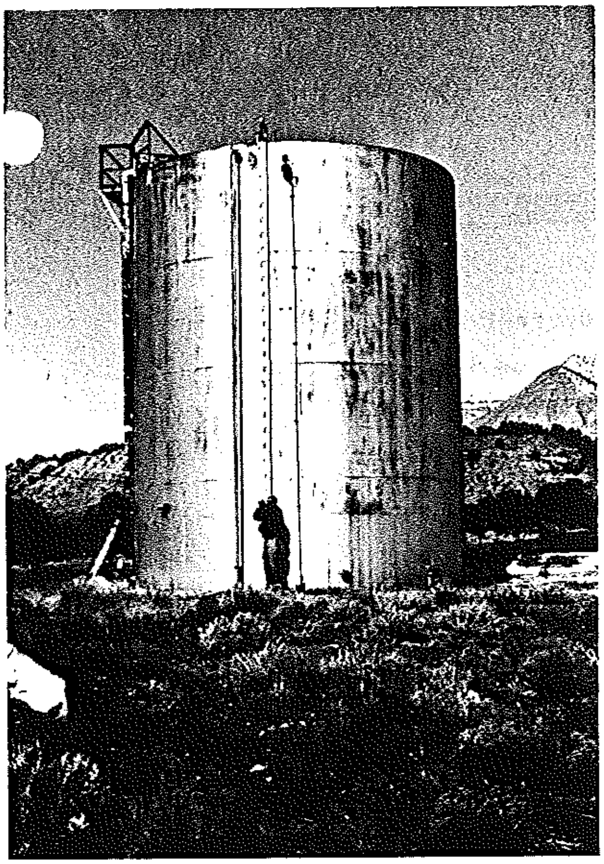


FIGURE 12. A WELDED STEEL PLATE DOMESTIC WATER TANK IN GRAND VALLEY. 24-FT DIA, 30 FT HIGH.

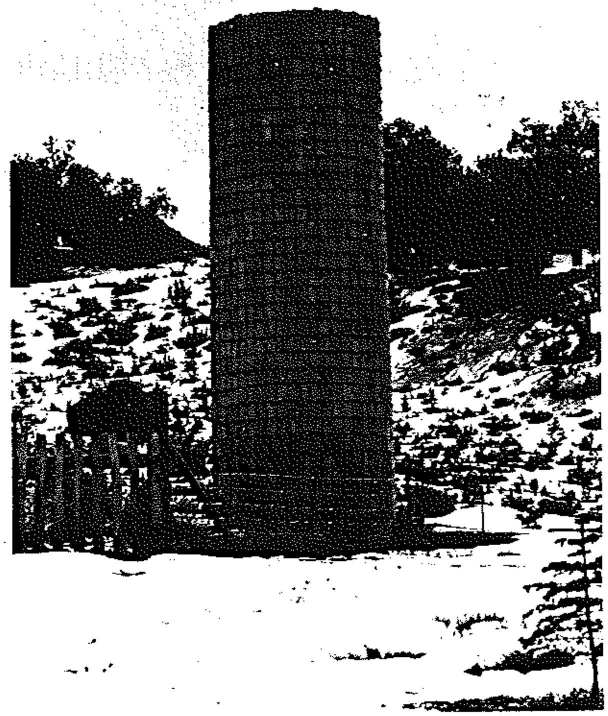


FIGURE 14. A FODDER SILO CONSTRUCTED OF CONCRETE SLABS. THE INTERIOR IS PLASTERED. 12-FT DIA, 40 FT HIGH.

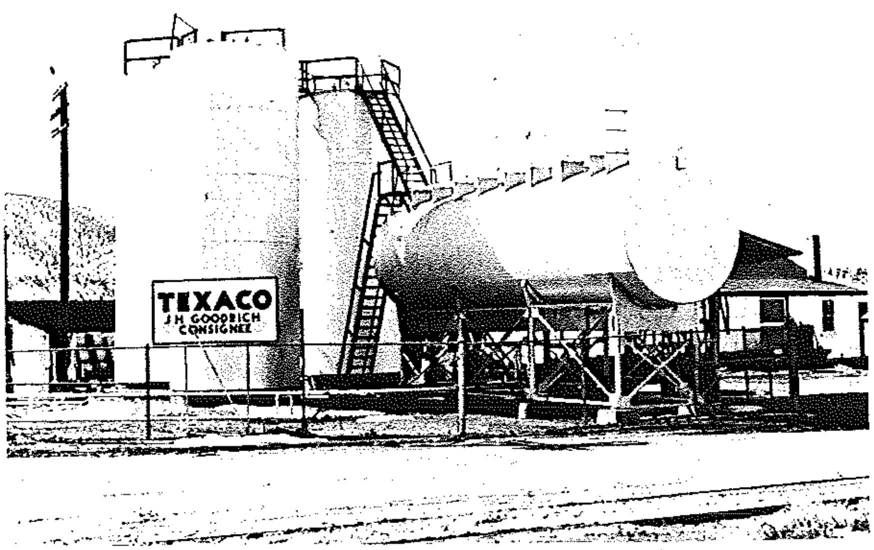


FIGURE 13. WELDED AND RIVETED ROLLED STEEL TANKS. 10-FT DIA, 36 FT LONG.

TABLE 5. BUILDING CLASS CRITERIA

Building classes for Project RULISON, indicated near the bottom of each structure inventory sheet, were assigned on the basis of the following data:

Building Class Number	Construction Type	Building Period Limits
1	Adobe	0.05 - 0.15
2	Adobe	0.15 - 0.20
3	Brick & Stone	0.05 - 0.15
4	Brick & Stone	0.15 - 0.20
5	Wood Frame	0.05 - 0.15
6	Wood Frame	0.15 - 0.20
7	3-5 Story Commercial	0.20 - 0.40
8	6-8 Story Commercial	0.30 - 0.50
9	6-8 Story Commercial	0.50 - 0.80
10	6-8 Story Commercial	0.80 - 1.00

Note: In assigning a building class, the building period limits govern whether or not the stated construction type is applicable. For instance, a wood frame barn with a period of 0.30 to 0.50 seconds would be assigned to class 8.

STRUCTURE INVENTORY

Location No. ______ Latitude 39°28'30" N. Longitude 107°53'30" W.

Location Name ______

Owners ______

State Colorado County Garfield T. 6S R. 94W S. 33

Baseline & Meridian 6th Elevation 5840' Condition Good

Date 2/19/69 Observers C. Kensler and F. Stejer

Year Built 1910's Number of Stories 2 Height 22'±

Length & Width Approximately 35' x 25' (Main house)

Frame Type Wood frame on 2" x 4" studs

Exterior Wall Finish Ship-lap board

Interior Wall Finish Plaster on lath

Ground Floor Wood joists on field rock and concrete (full basement)

Intermediate Floors Wood on wood joists

Roof Pitched with composition shingle

Chimneys (Type) Brick 18"x18" w/4' stickup (not used), 18"x24" full length w/6' sticku

Percent of Wall Openings N. 40 S. 30 E. 50 W. 50

Construction Costs or Estimated Replacement Cost $ 37,000

Bldg. Class	5	6			
Cost	$12,000	$25,000			

Foundation Classification Bouldery alluvium, deep 200'±, dry

Photographs Yes Roll 21-69 Negatives #6 thru #17

Description This ranch has about 16 structures, mainly wood frame and log construction. The dominant structure is the two-story residence. It has 2 chimneys and both are in poor condition. A second important wood frame building is the shop which is about 40'x25'x25' high. Many buildings have concrete foundations and slab floors - the foundations are cracked mainly with vertical cracks. There is a metal grain tank at ground level that holds 2,200 bushels - this container is new. The ranch water is transported by a plastic pipeline from a spring about 1 mile upslope to the south. The pipeline is buried in part. There is a large root cellar constructed of logs and sod.

FIGURE 15

Location No. ______

Inventories performed for long-period structures such as tanks, bridges, trestles, and overpasses included information on the type of construction, capacity, and dimensions. The inventory for the Grand Valley Bridge near Highway 6/24 is shown Figure 16; Figure 17 shows the bridge. Inventories for towns included total numbers of structures estimated for the area and classified by numbers of residential, commercial, and institutional buildings. For these building counts, materials utilized in construction were listed. Descriptions were given for typical structures of the area.

Existing damage for the area was described generally, with patterns of damage noted in some cases. Figures 18, 19, 20, and 21 illustrate damage noted during the inventory phase.

The inventory of hydraulic structures in the area was initiated with systematic examination of maps. Included were both privately and publicly owned dams, reservoirs, lakes, and ponds which provide water storage, control, and regulation of water flow. Projects operated by the U.S. Bureau of Reclamation were described in detail, and storage and diversion dams in the Colorado River Basin were listed in tabular form. Over 230 hydraulic features were inventoried in this manner. If this map research revealed a problem or potential hazard, field inventories were made in greater detail. The hydraulic structure inventory for the Harvey Gap Dam is shown in Figure 22 to illustrate the nature of the information acquired in this aspect of the study program.

The time required to perform a structure inventory depended on the location and kind of inventory desired. A location such a a ranch usually involved 15 to 20 minutes of actual field investigation. When possible, especially when the locations were in close proximity to ground zero, the tenants were told of the kind of data to be collected. When private property was involved permission was always requested before an inventory was begun.

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612 HOWARD STREET SAN FRANCISCO

Bridge, Trestle, Overpass, etc..

Location No. G-129 C Latitude 39° 27' N. Longitude 108° 02' W
Location Name Grand Valley Bridge
Owners Garfield County
State Colorado County Garfield T. 7S R. 95W S. 7
Baseline & Meridian 6th
Date 3/2/69 Observers C. Kensler and F. Stejer

Type of Structure Steel bridge
Type of Construction Two, simple span truss
Capacity Approximately 10 tons
Length Approximately 420'
Width Approximately 18'±
Height Approximately 12' above river; bridge 30'±
Contractor
Year Built Early 1900's

Foundation Classification

Photographs Yes Roll 28-69 Negatives #27 thru #32
Description Bridge across the Colorado River. The south section is 180' long and the north 240'. On the east side there is an 8" flanged steel water pipe carried at road level. Also, at road level a 3" gas pipe on the west side. These pipes are tied to the bridge beams. The buttress-retaining wall on each end is concrete with a concrete pier linking the two sections. The north buttress has a large crack. On the south end there is cut stone showing which probably indicates the original buttress or retain wall. The road bed gives under a car's weight. The bridge is in fair condition.

FIGURE 16

Location No. G-129 C

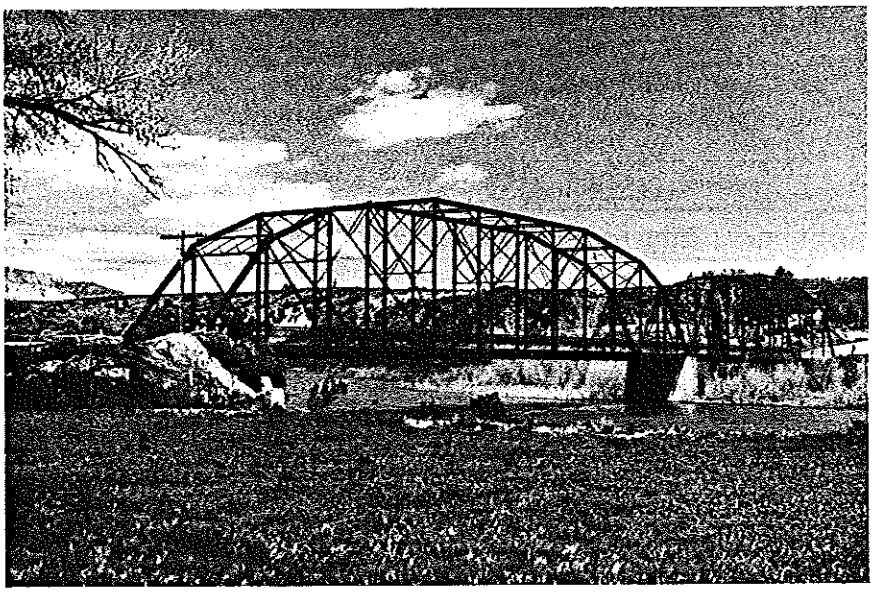


FIGURE 17. GRAND VALLEY BRIDGE, APPROXIMATELY 10 KM NW OF GROUND ZERO. THIS TYPE OF CONSTRUCTION IS TYPICAL FOR BRIDGES IN THE STUDY AREA.

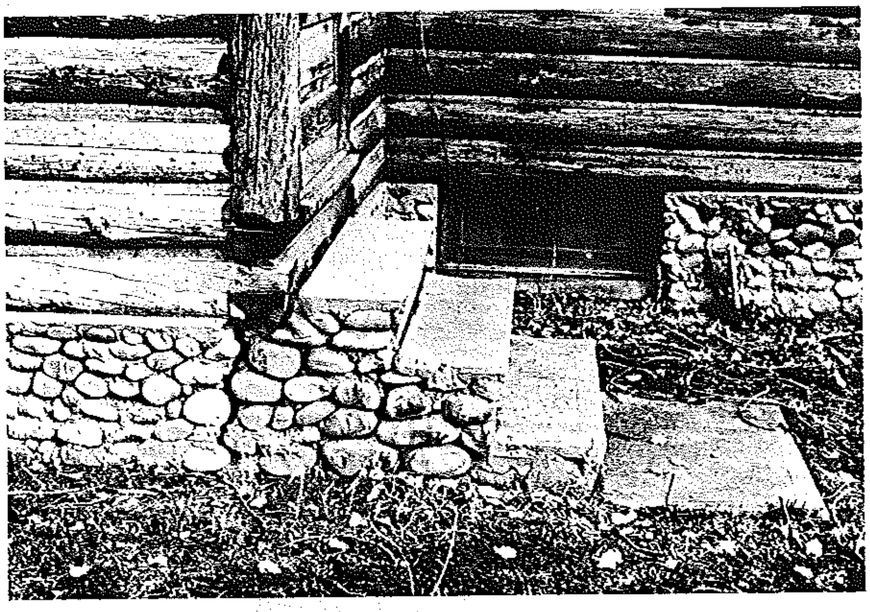


FIGURE 18. CRACKED FOUNDATION AND STEPS SEPARATED FROM HOUSE.

FIGURE 19. TYPICAL CRACKING AND SPALLING OF STUCCO OVER MORTARED STONE WALL.

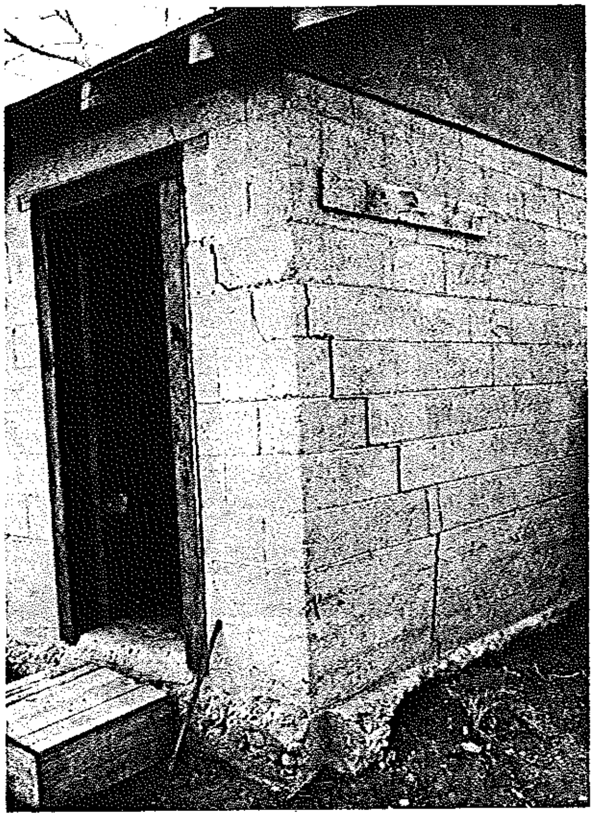


FIGURE 20. STAIRSTEP CRACKING OF MORTARED JOINTS IN CINDER BLOCK WALLS.

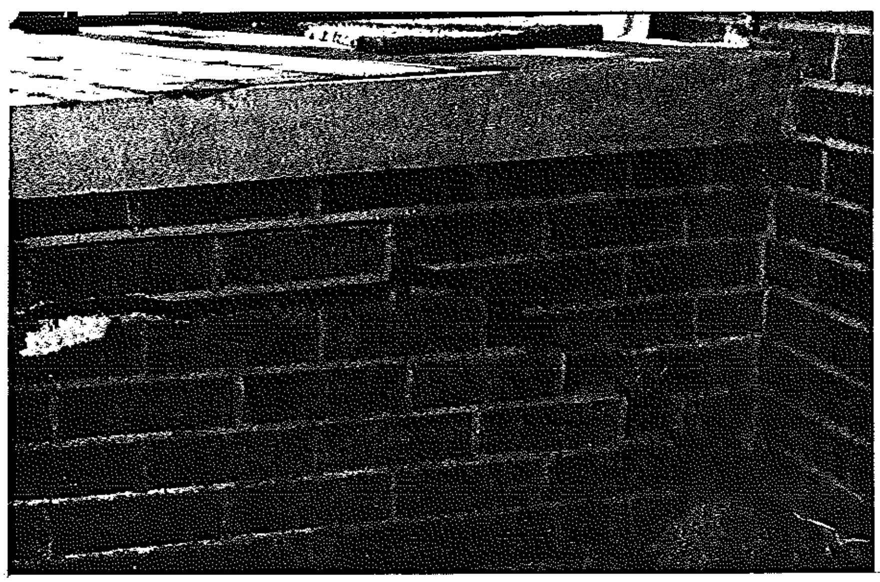


FIGURE 21. STAIRSTEP CRACKING OF MORTARED JOINTS IN BRICK WALL.

INVENTORY OF NATURAL AND MAN-MADE LAKES

Location No. G-010 Latitude 39°36'30" N. Longitude 107°38'30" W.

Location Name Harvey Gap Dam and Grass Valley Reservoir

Owners Farmers Irrigation Company (operators)

State Colorado County Garfield T. 5S R. 92W S. 13 & 24

Baseline & Meridian 6th Quad: Silt Series: 7½' Yr: 1962

Date 2/12/69 Observers C. Kensler & F. Stejer

Bathemetric Data

Water Surface Area Estimated 210 acres

Water Depth 30+ Maximum - Average -

Width - Maximum 2500' Average 1500'

Length (Straight Line) 1.1 miles

Volume 5,000 acre-feet

Water Surface Planform Irregular - crudely rectangular

Use Irrigation and recreation (irrigation for Harvey Mesa)

Dam Data

Type Earthfill

Length at Crest 700' ±

Spillway yes Type see descr. Capacity - Length 20'±

Elevation - Crest 6410' Spillway 6400' Base 6350'±

Width at Crest 20'± Width at Base -

Foundation Classification Mesa Verde - thin bedded sandstone and shale dipping 52° south - estimated 60'

Photographs yes Roll #4-69 Negatives #16, #18, #19 and #20

Description Harvey Gap Dam was originally constructed about 1881 and failed about 1895. In 1909 the dam was rebuilt, and in 1921 it was rehabilitated and raised to a height of 60'. Failure would involve possible loss of life and property in the vicinity of Silt. There is an old landslide downstream on the left abutment, which has been excavated at the base and now appears stable. There is an old landslide upslope and east of the reservoir. The spillway may not stand much of a flow. The spillway type is side channel. See FRC photos:3/6/69 Roll #69-3-2 Neg.#3-19.

FIGURE 22

Information from the tenant that was pertinent to the inventory, such as cistern location, age of the structures, etc., was recorded. One of the inventory team members recorded structure information while the other member took photographs and made a soils foundation-structure investigation. Both team members discussed and noted, for later evaluation, any obvious hazards. These kinds of detailed structure inventories were conducted out to a radius of 25 kilometers from ground zero. Approximately 450 detailed structure inventories were performed.

Beyond the 25-kilometer radius inventories were performed differently than the detailed inventories. These general inventories were made over areas whose boundaries were usually defined by geomorphic features; that is, area limits were defined by dominant valleys, mesas, ridges, or stream terraces and the like. These general area inventories included the number of structures, kind of construction, total value, condition, structure risks, and photography. To perform this kind of general inventory about 15 minutes of field time was used for each location inventoried. Approximately 385 locations were inventoried using the general inventory method.

Five towns were inventoried for Project RULISON. The methods, described elsewhere, were found to be efficient and adequate for the inventory. Each of the towns required varied amounts of inventory time dependent on the density of the structures.

To obtain a building count, the streets were travelled by vehicle and a tabulation made for various structures.

The town of Grand Valley is located about 10 kilometers northwest of ground zero. Of these structures 105 were counted as residential, 34 as commercial, and 7 as institutional. This count of 146 structures included unused buildings. The remainder of the Grand Valley structures were classified as outbuildings. Obtaining and recording this information involved about one man-day of effort.

Rifle, located approximately 20 kilometers northeast of ground zero, was the largest town inventoried in the study area. Residential structures were counted at 631, commercial at 104, and institutional at 24. The total count of these structures was 759, with remaining structures in Rifle primarily classified as outbuildings. To accomplish and record this structure count required about 2 man-days.

The town of Silt is located about 30 kilometers northeast of ground zero. Residential structures number 140, commercial 48, and institutional 6, for a total of 194 structures. Remaining structures were primarily outbuildings. One man-day was required for the count and recording.

DeBeque is located approximately 23 kilometers southwest of ground zero. The count on residential structures was 77, on commercial 14, and on institutional 11, for a total of 102 structures. The remaining structures were generally outbuildings. Like Grand Valley and Silt, the inventory count and recording for DeBeque took about one man-day.

Collbran is about 19 kilometers south of ground zero. Collbran has 91 residences, 27 commercial, and 9 institutional buildings, for a total of 127 inventoried structures, not including outbuildings. The inventory count and recording took approximately one man-day.

Information collected about the structures was reviewed by the inventory teams during field office time. Proper photographs were associated with the text and a review made of each location for hazards. If a location warranted additional study or perhaps remedial work, it was recorded as a recommendation for a condition survey or special investigation. These daily inventories were immediately forwarded to the JAB office for processing, office studies, and report preparation. Figure 23 shows an example of a location where remedial work was suggested.

Maps and aerial photographs were studied for routes of travel and area coverage. The inventory teams exchanged information and discussed inventory coverage and the next day's itineraries. Areas that could not be covered on the ground were designated on a master map so that an aerial inventory could be performed efficiently at a later date.

Information exchange also took place with other organizations and agencies involved in the early phases of field work. Through these conversations and exchanges the inventory teams gained additional information on such topics as locations of cisterns, pipelines and canals, rockfall slide areas, remote structures, impassable roads, communication installations, etc.

Three aerial inventory trips were taken of the study area. These flights, generally of about one hour's duration, were taken of predetermined areas; usually areas impossible to cover on the ground. One of these flights was by helicopter. Although much more expensive to rent than fixed-wing aircraft, the helicopter permitted landing and investigation at remote structures, such as Battlement Reservoirs. Also, the helicopter offered closer ground observations and shorter routes through canyons, with the result that the area was covered easier and faster.

FIGURE 23. PRE-SHOT REMEDIAL WORK WAS RECOMMENDED FOR THIS INADEQUATE BUILDING FOUNDATION CONDITION.

CONDITION SURVEYS

Condition surveys provide information and documentation of the existing condition of selected structures. These structures were selected for detailed investigations because of proximity, type, importance of the structure, potential structural risk, real value, or as a representative of a number of structures having low seismic resistance. In addition to recording actual structure condition, the surveys included descriptions of the type of construction materials and the construction practice utilized. Existing damage, such as cracks induced by aging, temperature expansion and contraction, settlement, or water, were documented by written observations, sketches and/or photographs. From this documentation, reports for internal use were prepared for each location. Concurrent with the structure survey, an evaluation of the soils foundation materials was made to predict amplification effects, or to identify any hazards from foundation material failures, slope failures, or similar earth-structure hazards. Condition surveys were found to be especially valuable for establishing the validity of post-shot damage complaints.

Two teams were involved in conducting condition surveys of selected structures for Project RULISON. Each team was composed of two members whose responsibility was to investigate structures and the soils-foundation conditions. These teams, like the structure inventory teams, operated from the field office established near the survey area.

Condition surveys were conducted at the following structure locations:

Structure Locations	Approximate Distance from GZ, km	Azimuth from GZ, degrees
Forshee Ranch	8	342
La Court Motor Lodge, Grand Junction	64	235
Hoaglund Ranch	8	354
Trahern Ranch	10	025
DeBeque School	23	250
Zediker Residence	10	307
DeBeque Bridge	24	250
Grand Valley Post Office	10	305
Arnette Ranch	8	295
Sattersfield Ranch	8	305
Grand Valley School	10	305
Wambolt Residence	10	307
Abandoned House	10	284
Smith Ranch	6	305
Battlement School	8	297
Grand Valley Water Tank	10	305
Richardson Ranch House	19	183
B. L. Smith Ranch	6	360
Barrick Ranch	6	334
Ed Sifer Ranch	5	330
Claude Hayward Cabin	1	012
Burtard Ranch	6	337
Nelson Ranch	6	334
Jefferson Residence & Garage, Rulison	8	010
Lemon Ranch	6	013
Sefcovic Ranch	6	017
Clem Ranch	5	326
Colorado River Bridge at Grand Valley	9	305
Gillard Ranch	6	334
Morrisania Community Center	6	335
Collbran Civilian Conservation Center	19	183
Hayward Ranch	6	331
Plateau Valley School	19	190

Structure Locations	Approximate Distance from GZ, km	Azimuth from GZ, degrees
Eames Orchard Inc.	6	340
Schwab Ranch	6	335
Valley Upholstery & Austral Oil Warehouse, Grand Valley	10	305
Television Relay Station	5	344
Sinclair Garage, De Beque	24	250
Residence	10	305
Moulton Insurance Building, Rifle	21	045
Jeep Bldg. & Estes Trucking, Rifle	21	045
Congregational Church, Collbran	19	185
IOOF Hall, Collbran	19	185
Post Office & Store, Molina	26	200
Research Station Bldg., Anvil Points	13	010
Union Carbide Plant near Rifle	18	040
United Methodist Church, Rifle	21	040
Kennon Ranch	13	184
Harvey Gap Dam (Special Survey)	32	049
Cameo Plant	45	225
Kochland Ranch	10	305
Wayne Wells	8	004
Blue Stone Ditch	22	254
Harris Reservoir	36	010
Ute Conservancy Plant, Palisade	52	220
Dwain T. Jackson, Grand Junction	64	237

Fifty-six condition survey evaluations were made for RULISON. Out to a radius of 35 kilometers from ground zero, in the area of potentially damaging ground motion, 51 condition surveys were performed; 5 surveys were conducted beyond this distance.

Each inventory team performed an average of two condition surveys a day. These survey investigations provided information and documentation of the actual condition of selected structure locations. The condition survey procedure was explained to the tenant and permission was usually granted for the survey.

The condition survey teams often began the investigation by making a sketch of the location and the relationship of structures. On this sketch, structure distribution, estimated structure dimension, and photographs were noted. Each structure sketch was numbered for reference to the associated text on general observations. The brief description for each structure and associated photographs documented actual structure conditions and indicated any potential hazards. This phase of the condition survey is illustrated by Figures 24 and 25.

The general observation sheets also gave information on the evaluation of foundation materials. These investigations generally described the surface materials; indicated depth of alluvium or soil to bedrock; estimated density and moisture content of the founding materials; pointed out fill treatment; noted the water table, seepage, and drainage; and indicated problems that were present or could arise concerning the structure-soils foundation system.

Another step performed in a condition survey procedure was to document a structure or structures in detail. Generally, this documentation was performed on the dominant structure of the location. Building information was recorded on a form, a building sketch made with photograph locations noted, and observations were recorded on elements of the structure which may be vulnerable to ground motion. Figure 26 is a typical form which indicates building information. Figure 27 is a ranch house plan-view sketch with photography indicated. Figure 28 is an observation sheet which reviewed

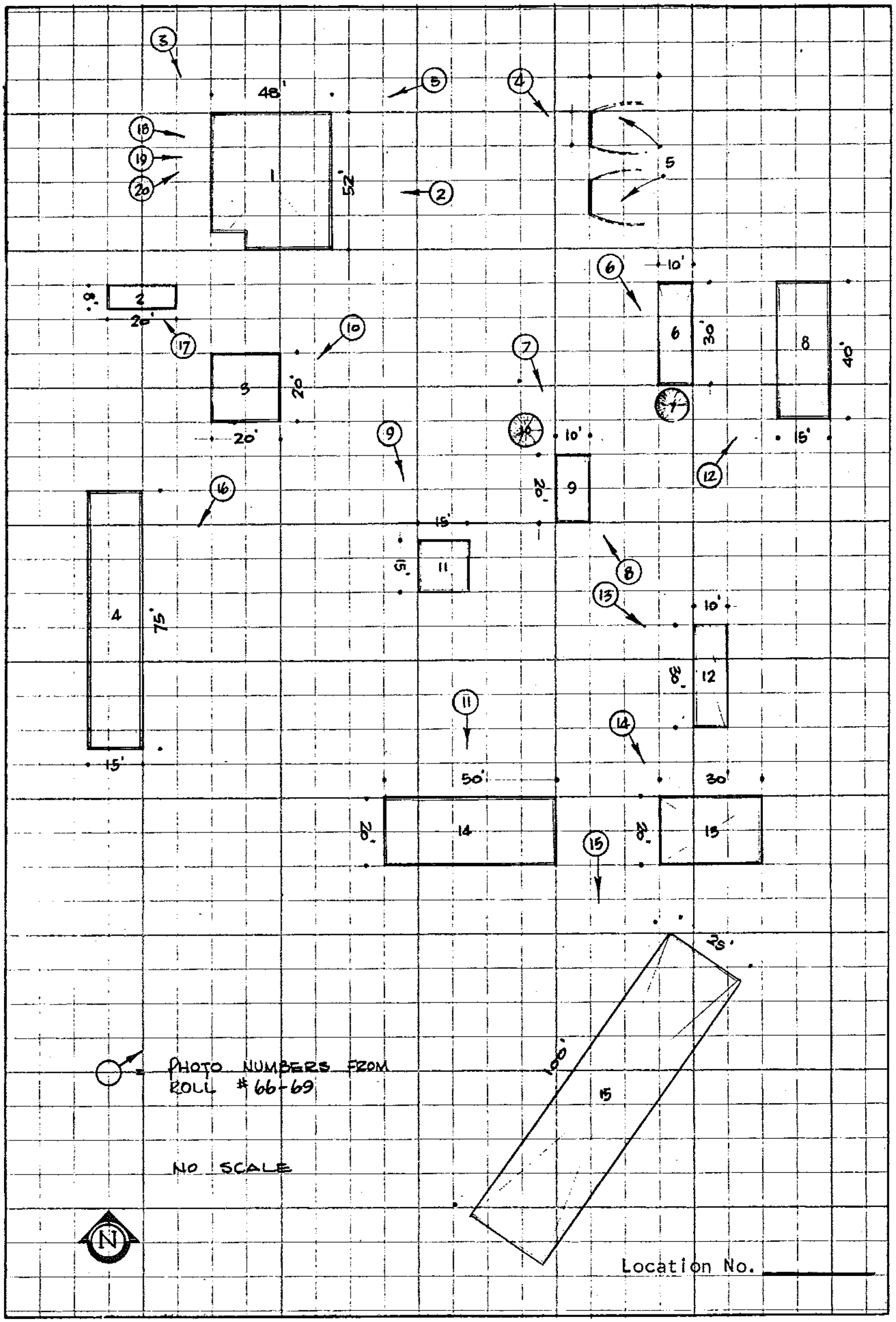


FIGURE 24

GENERAL OBSERVATIONS

Description of ranch (dimensions estimated). ---- 1. The main ranch house is wood frame resting on a rock foundation. It has two chimneys extending approximately 11' and 12' above the roofline. It has one small addition about 15 years old. Fair condition. 2. Mobile home with metal siding resting on the wheels and 12"x12" timber. Fair Condition. 3. Garage is wood frame resting directly on field stone piers -- floor is dirt. Part of the garage has a lean-to shed incorporated into its 20' x 20' size-common roof. The structure is in poor to fair condition. 4. Animal shelter constructed of wood siding on a wood frame and having a dirt floor. The structure is constructed like a lean-to with the opening facing west. The condition is fair. 5. At this location are two root cellars dug into the hillside. Both are constructed of rubble rock unmortared and both have log and sod roofs. Condition is poor. 6. Wood frame storage shed with a partial concrete wall dug into the hillside. Structure has a dirt floor and overall classification is poor. 7. Small metal fodder bin resting at ground level on railroad ties. Good condition. 8. Abandoned log structure in poor condition probably once used as a chicken shelter. 9. Storage shed constructed of railroad ties and chinked with mud. This structure rests on a concrete foundation which is about 2' high. Fair to good condition. 10. See description #7. 11. Log frame lean-to-like structure for hay storage -- light frame and wood siding -- poor condition. 12. Light wood frame constructed storage shed with wooden piers into the ground. Poor condition. 13. Wood frame animal shelter open on two sides. Poor condition. 14. This is an abandoned equipment-animal shelter of an open wood frame and no siding. The roof is near gone. Structure is near ruin. 15. Wood frame shelter for animals open on the west end and with a metal roof. Dirt floor and overall is generally in good condition.

There is a cistern approximately 300' north of the main house. It is about 12'x12'x8' deep. The water level is about 10" from the top of the vessel. The plaster on the cistern walls appears in good repair.

The founding is a moderate reddish-brown silty clay with some gravel (15-20%±). There is an occasional boulder from 2 to 3 feet in diameter. A residual soil

FIGURE 25

Loc. No. ________

GENERAL OBSERVATIONS

on alluvial fan material -- probably deep 150'± -- and dry. There is no evidence of expansive soil, some evidence of settlement. The cracks in the foundation are attributed to the quality of concrete, age, and probably lacking reinforcing bars.

FIGURE 25 (Cont'd)

Loc. No. ___________

BUILDING INFORMATION

Location No. ______ Lat. 38° 22' N Long. 108° 04' W

Location Name Ranch House

Owner ______ Year Built 1900±

Date Seen 10 July 1969 Observers C. Kensler

Number of Stories 1 + attic room Total Height 14'±

Length 52'± Width 48'±

Structural Frame Wood frame 2x4 studs

Exterior Walls Horizontal wood siding - 10" boards ship-lap

Ship-lap Thickness 6"

Interior Walls Plaster on lath

Thickness 4"

Ground Floor Rubble stone and some concrete No basement

(crawl space) Thickness 4"-6"

Intermediate Floors Wood joist on wood frame - attic-like room

Thickness 8"±

Roof Pitched wood frame with asphalt shingles

Thickness 5"±

Chimneys? (Type) Three - brick Height Above Roof 12', 11', 5'

Percent of Wall Openings - N 20 E 15 S 40 W 5

Total Construction Cost or Estimated Replacement Cost $ 19,500

Assessed Valuation Not available

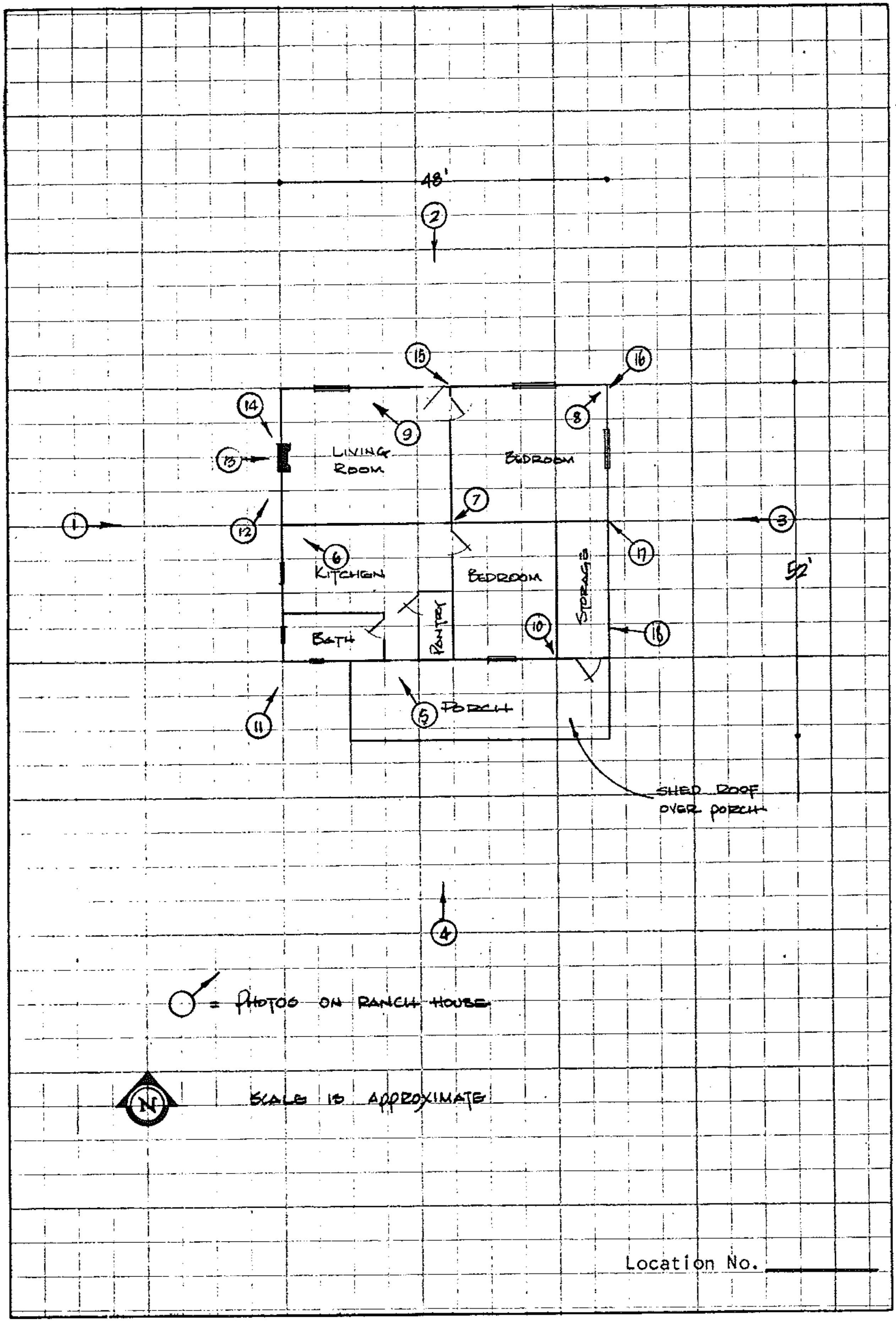
Photographs CX-135 Roll No. 67-69 Negatives 1-18

Brief Description of Hazards (Items which are susceptible to damage) -- Two brick chimneys (one has been cut-off) which are approximately 11' and 12' above the roofline. Both chimneys are only in poor to fair condition. The mortar is deteriorated and the chimneys moved when pushed only slightly. Interior walls are highly cracked.

Number of Buildings	3	10	2
Building Class Number	2	5	6
Total Cost Breakdown	$500	$6,000	$13,000

Loc. No. ______

FIGURE 26



48'
52'
LIVING ROOM
BEDROOM
KITCHEN
BEDROOM
STORAGE
PANTRY
BATH
PORCH
SHED ROOF OVER PORCH
= PHOTOS ON RANCH HOUSE
N
SCALE IS APPROXIMATE
Location No.

FIGURE 27

GENERAL OBSERVATIONS

The ranch house was picked for observation. The house has a mud sill which rests directly on a rubble rock foundation which is mortared in part. Most of the foundation was not observable. There is a front porch, back porch and an addition (bedroom) which have concrete floors. The front porch has a perimeter crack which is located at the sidewalk contact. The back porch has a thick (12") slab with hairline cracks. The bedroom concrete foundation has one vertical crack found at the crawl hole.

Chimney: 12' x 20" x 16": This chimney is found over the dining room. About 3'-4' from the top of the chimney there is a rigid guy-bar (1/4"-1/2" dia) anchored to the ridgepole. The chimney is in poor to fair condition and it has weathered mortar. See CX-135 Role #67-69

Chimney: 11' x 32' x 16": This chimney is found at the west elevation of the living room. The overall height of the chimney (ground to top) is estimated to be 21'-22' high. The chimney rests on a 1-2 course rubble rock foundation which has been leveled by concrete. This pad is in poor condition. The chimney below the roofline shows settlement cracks mainly in the mortar joints -- most of these show new patching. Above the roofline the chimney appears out of plumb (northward lean). The top 18 courses of brick are newer than below. The mortar and brick on these courses are in good condition. From these brick to the roofline the brick and mortar are in extremely poor condition. Patching and re-cracking is evident. See CX-135 Roll #67-69.

FIGURE 28

Loc. No. ________

the vulnerable elements of the ranch house.

Condition surveys, along with supplementary inspection information and predicted response spectra, were used to make prediction of the nature, extent, and cost of repair damage. Extremely hazardous structures were noted for further evaluation.

It has been found from RULISON and other off-site events that an efficient means for documenting a condition survey is by photographic coverage. Exterior photographs of a structure selected for a condition survey should show all elevations, height, geometry, general setting, and any obvious problems. Interior photographs should indicate column layout, partitions, material applications, and potential problems. Before the detonation the original condition survey team conducts a pre-shot survey to discover and record progressive deterioration or changes, if any. This pre-shot survey is usually scheduled a week before the event, and generally consists of a brief evaluation of the existing pre-shot condition of the structure. The condition surveys are then checked shortly after the event to document any damage to the structures.

Figures 29 and 30 show selected photographs of a chimney. These photographs indicate the pre-event condition of the chimney. The post-event photographs, Figures 31, 32 and 33 can readily be compared and the extent of damage easily detected. These kinds of pre-event and post-event photographic documentation help establish the validity of damage and aided in defining ground motion damage criteria.

During the event, personnel were placed as observers at locations where damage was predicted or where the location would afford a structure response of particular

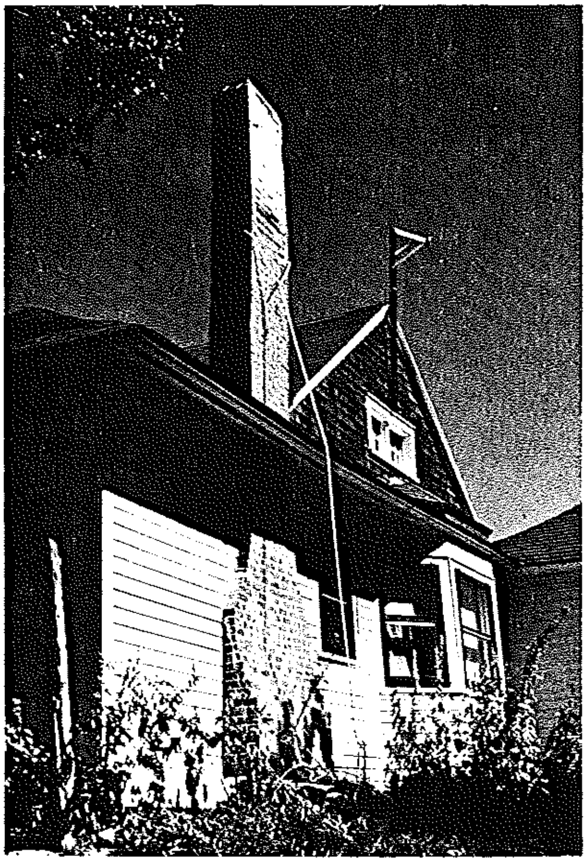


FIGURE 29. PRE-EVENT CHIMNEY CONDITION.

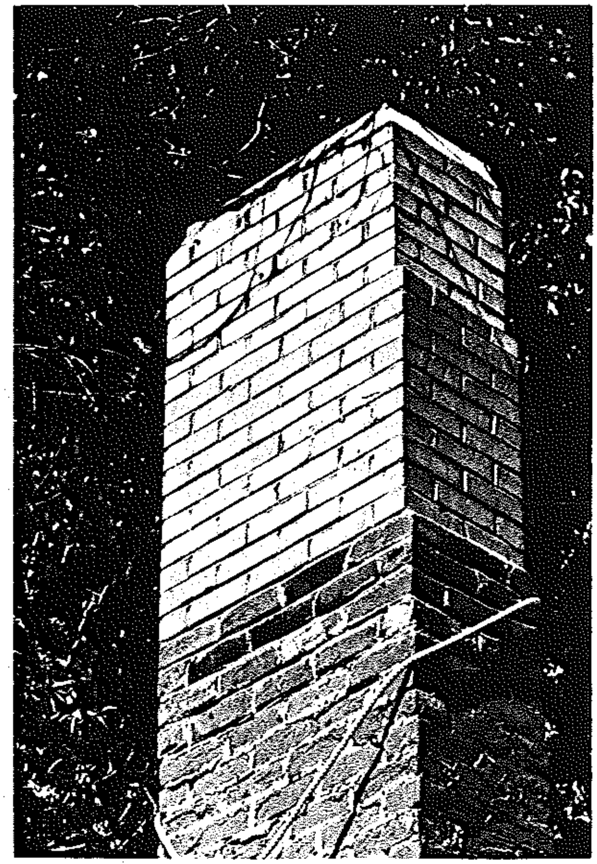


FIGURE 30. PRE-EVENT CONDITION SHOWING NEW AND OLDER BRICK AND MORTAR.

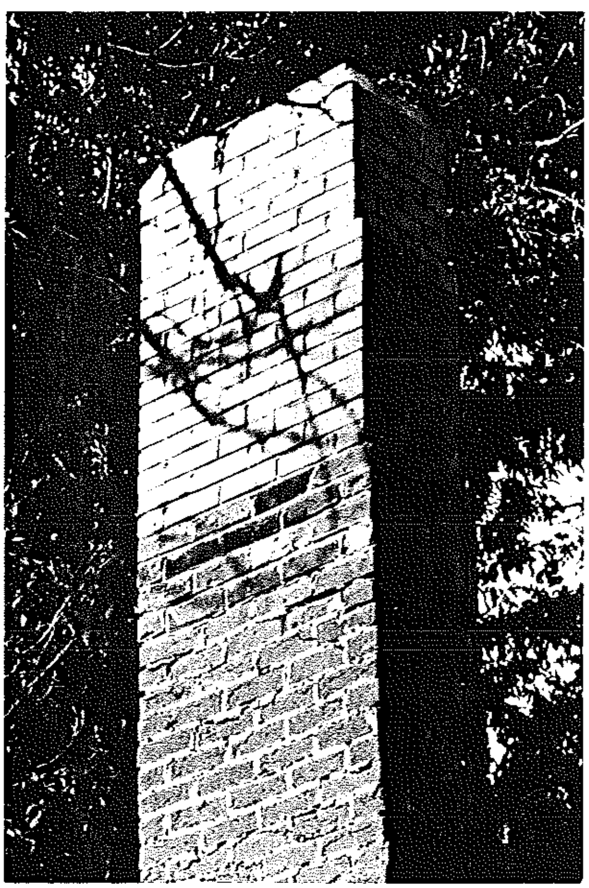


FIGURE 31. POST-EVENT CONDITION WITH SOME MORTAR DAMAGE TO THE OLDER SECTION OF THE CHIMNEY. COMPARE WITH FIGURE 30.

FIGURE 32. PRE-EVENT CONDITION OF THE CHIMNEY BASE AND FOUNDATION. NOTE THE NUMEROUS MORTAR PATCHES.

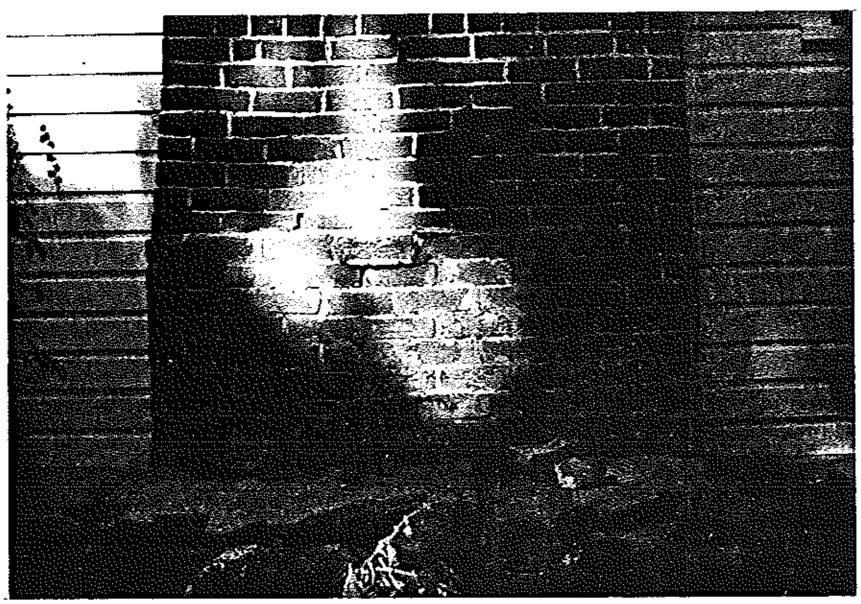


FIGURE 33. POST-EVENT CONDITION OF THE CHIMNEY BASE AND FOUNDATION. COMPARE WITH FIGURE 32.

interest. These observers had access to the internal (field copy) condition survey documentation. In addition to making perceptibility observations, the observers were required to re-survey and establish the condition and record changes, if any, just prior to the event. These observers recorded their comments on an observation data sheet as depicted by Figure 34.

Immediately post-event any damage which occurred in the vicinity of the observer station was documented for future reference. This documentation was recorded on observation data sheets and contained statements about the observed effects to the structure because of ground motion. Figure 35 shows an example of post-event observations. If no changes to the structure were observed, this fact was also noted. Damage or lack of damage was recorded by photographs.

Following the event a post-shot re-survey was performed by the condition survey teams which made the initial survey and all subsequent re-surveys. This inspection documented the changes and damage or lack of damage to the structure investigated. In addition to the condition survey teams one or two senior engineers and geologists were available to conduct any immediate post-shot damage evaluations.

OBSERVATION DATA SHEET

1. STRUCTURE ____________________

2. DATE 10 September 1969 TIME 1200 - 1430 Hours

3. NAME OF OBSERVER Chuck Kensler

OBSERVATIONS MADE FOR: PRE-EVENT X POST-EVENT ____ REGULAR ____

GENERAL OBSERVATIONS

All structures were inspected on the ranch. The ranch house was inspected on the exterior and it did not differ from the general observations made for the condition survey. Several sealing wax pads were applied to the chimney found at the west elevation of the chimney -- wax on broken mortar joints.

The interior was briefly inspected but mainly for heavy objects that may fall or be damaged because of the ground motion. The interior plaster cracks all indicated age.

The cistern was inspected and found to be in fairly good condition. The concrete walls are 5" thick and about 1" of plaster application.

FIGURE 34

OBSERVATION DATA SHEET

1. STRUCTURE ______

2. DATE 10 September 1969 TIME 1530

3. NAME OF OBSERVER Chuck Kensler

OBSERVATIONS MADE FOR: PRE-EVENT ____ POST-EVENT X REGULAR ____

GENERAL OBSERVATIONS

The living room chimney inspected on the exterior and the following was observed: (1) the rock and concrete chimney pad (base) has minor cracking and separation from the brick -- some pieces of concrete has chipped away (2) the bottom 12 brick courses or so has mortar which has been loosened in the joints and in some cases has fallen from the joints (3) many bricks are loose and have moved away from the house on these lower 12 courses or so (4) the roof is covered with loosened mortar in the vicinity of the chimney (one piece was laying 13'± from the house -- west of chimney) (5) between the 23rd and 24th courses of brick from the top, the mortar joint has lost much of its mortar (6) much of the mortar half way between the roofline and chimney top has loosened and/or has fallen out (7) new chipping or aggravation is apparent in a random pattern. This chimney was photographed post-event with roll #67-69 negatives #25-#37. All wax broken.

The dining room chimney lost some mortar -- most mortar appears to be missing about 3'-4' from the top -- at about the level where the guy ties into the chimney. This mortar is laying on the roof. This chimney was photographed post-event with roll #68-69 negatives #11 and #12.

The interior of the house was inspected immediately after the event and the following was observed:

FIGURE 35

OBSERVATION DATA SHEET

1. STRUCTURE ______________________________

2. DATE 10 September 1969 TIME 1530

3. NAME OF OBSERVER Chuck Kensler

OBSERVATIONS MADE FOR: PRE-EVENT ____ POST-EVENT x REGULAR ____

GENERAL OBSERVATIONS

Kitchen - (1) small plaster flakes lying around the room

(2) a calendar fell off the south wall over the counter -- nail pulled out

Dish Pantry - (1) cupboard doors were ajar and the cups were swinging on the hooks

(2) plaster flakes on the floor from vertical cracks

Living Room - (1) clock stopped at 3 p.m.

(2) plaster on the floor from a north wall "pop-out"

(3) picture overturned on the piano

(4) doors to bookcase open

Master Bedroom - (1) east-west ceiling crack released plaster dust and chips

In the garage 1/2 can (1 gallon size) of oil fell.

Some debris fell and sifted through the roof of the root cellar.

No damage could be observed on the cistern.

Page 2 of 2

FIGURE 35 (Cont'd)

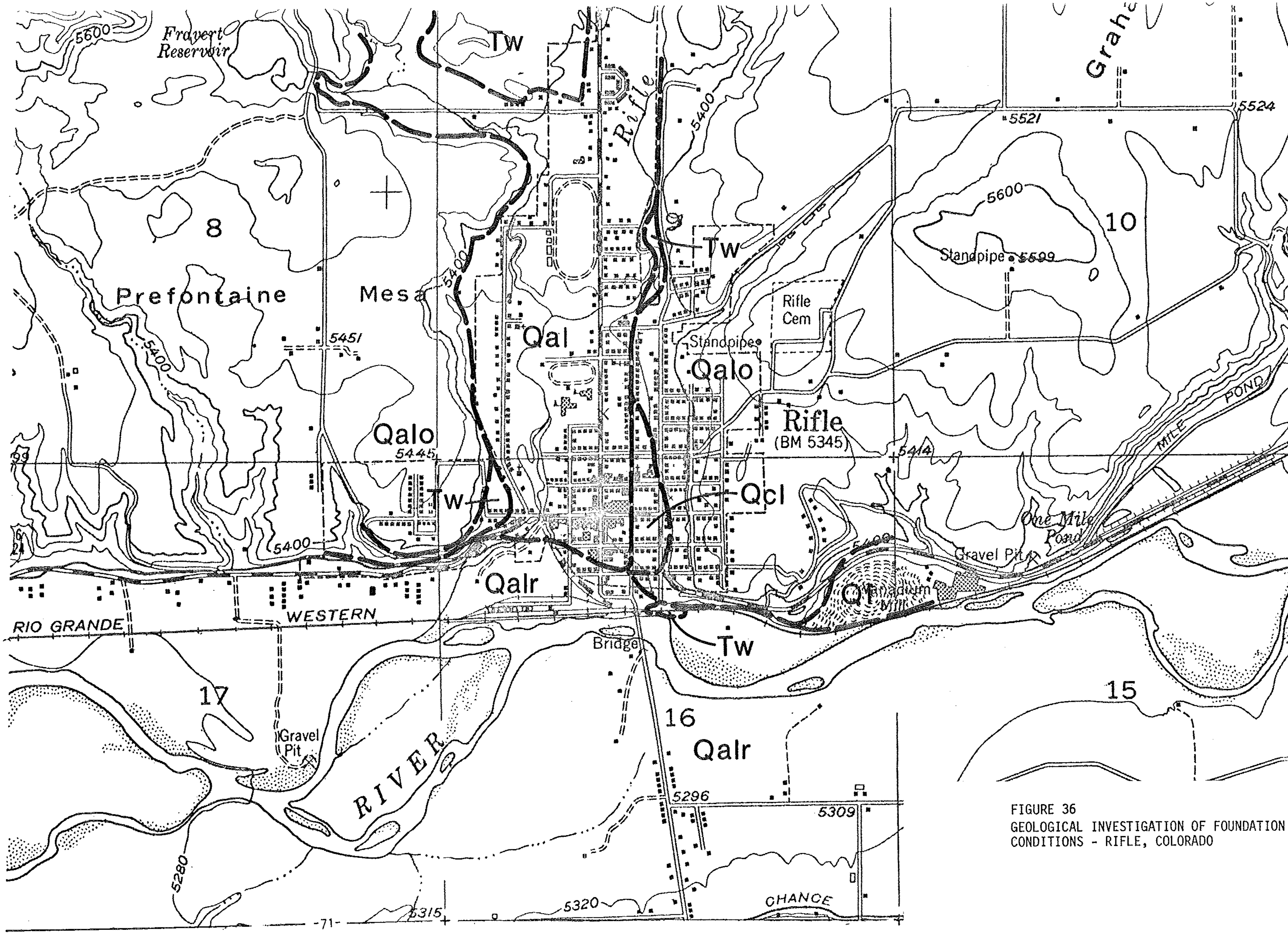


FIGURE 36
GEOLOGICAL INVESTIGATION OF FOUNDATION CONDITIONS - RIFLE, COLORADO

FOUNDATION CONDITIONS IN LARGER COMMUNITIES

Geological evaluations of foundation conditions were made for the communities of Rifle, Grand Valley, DeBeque, Silt, Morrisania Mesa, and Collbran. The following description of Rifle is typical of the investigations undertaken.

Table 6 describes the characteristics of foundation materials underlying Rifle; the data is shown graphically in Figure 36.

A considerable area of the town of Rifle lies in the valley of Rifle Creek. The downtown area is founded on stream alluvium deposited in scour channels in the Wasatch Formation and is locally subject to consolidation. Structures founded on this material show cracking from differential settlement. Settlement results from consolidation by penetration of water and is most severe in areas where clayey silt is the thickest. Settlement of heavier commercial structures results from both consolidation of materials normally above the water table and compression of materials below the water table.

The portion of Rifle that is built on the Prefontaine Mesa to the west and Graham Mesa to the east is founded on older alluvium composed of bedded gravels and silt. The silts are subject to high consolidation.

Structures at the base of the terrace on the east side of Rifle are founded on well-graded gravels and silt, which have accumulated down-slope as a result of weathering and stream undercutting. These talus deposits or colluvium are subject to differential consolidation depending locally on the amount of silt that is present. The section of the town founded on the flood plain on the Colorado River is underlain by river deposited beds of gravel and sand. The sand beds are subject to consolidation.

TABLE 6

FOUNDATION MATERIALS - RIFLE, COLORADO

Map Symbol	Description	Average Composition	Range in Thickness	Settlement Characteristics	Remarks
Qal	Stream Alluvium	Clayey silt and gravel	13' to 40'	Subject to consolidation	Underlies all of Grand Valley. Present in downtown area of Rifle
Qalr	River Alluvium	Gravel and sand	0 to 50'+	Sand subject to consolidation	Structures in portions of Rifle founded on this material
Qf	Fills, random fills, engineered fills and mill tail piles	Silt	0 to 25'	Highly variable depending on compaction during placement	Relatively few structures found on these units.
Qcl	Colluvium	Well graded gravels and	0 to 40'+	Highly subject to consolidation	Foundation material for structures at base of terrace on east side of Rifle
Qalo	Older Alluvium	Bedded gravels and silt	0 to 100'+	Silts subject to high consolidation	Present capping terraces, east and west sides of Rifle
Tw	Wasatch	Bedded claystone, siltstone and sandstone		Competent siltstones subject to sliding.	Underlies foundation materials in both Rifle and Grand Valley

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Page 72 is missing from this document.

INSTRUMENTATION

It is apparent from the preceding discussions that data acquisition depends greatly on the ability of people to collect information. However, instruments are also used advantageously in this effort. Following are descriptions and deployment of various instruments used. The objectives are:

- To monitor the ground motions for the structural response evaluation and the damage complaint investigation.
- To record the ground motions for documentation and detailed study.
- To monitor the movements of the structural elements for structural response evaluation and damage complaint investigation.

During the inventory and condition survey programs, possible locations for seismic instruments and various gages were selected. The potential sites were presented to the representatives of various agencies at a meeting on March 19 and 20, 1969. With this and other information from various agencies, 30 sites were selected with seventeen additional sites selected subsequently.

Most of the seismic instruments were L-7 velocity meters[7] which record motions on magnetic tapes. The systems were installed and operated by the Special Projects Party of the U.S. Coast & Geodetic Survey (USC&GS, now the National Ocean Survey). Data thus obtained were processed by USC&GS and Environmental Research Corporation (ERC).

The Sprengnether blastmeters, used as a back-up system at several locations, were operated by JAB personnel. The blastmeter is a portable self-contained three-component seismograph which records displacements on light-sensitive paper. The frequency range of the instrument as usually adjusted is 1 to 100 Hz.

Two types of passive gages were used to monitor the movement of the structural elements; 31 were displacement gages and 37 were scratch gages. Both types are installed and operated in essentially the same manner. Normally, they are mounted across a crack or between two structural elements to monitor the relative movements. These gages are inexpensive and simple to operate[8].

A displacement gage is shown in Figure 37. The two-part base is mounted on each side of a crack or on two elements. The movements of the elements -- opening or closing -- result in relative motion of a stylus attached to a rod anchored in the left-hand portion of the gage. As the stylus moves, it displaces two sliding bars on the right-hand component. At the time field measurements are to be made, the bars are locked in their displaced positions by means of two friction screws. After the displacement is measured with micrometer calipers, the friction screws are released, the sliding bars are returned to their closed position, and a reading is made in the closed position. Gage locations and measurements at event time are given in Tables 7 and 8.

The major components of the scratch gages are two-part base, a needle arm, and a glass plate coated with special emulsion (Figure 38). When the bases move, a needle which is attached to one base leaves a mark (scratch) on the glass which is attached to the other base. During the periodic inspection, the glass is removed and photographed, and measurements made on the enlarged photograph.

The instrument used to measure water surface oscillations (seiche or waves of translation) is an adaptation of a gage originally fabricated to measure long-period waves in harbor models (Figure 39). The float is installed in a stilling well connected to the lake or reservoir by a series of holes which serve as a hydraulic filter to eliminate the effects of short-period wind-generated waves.

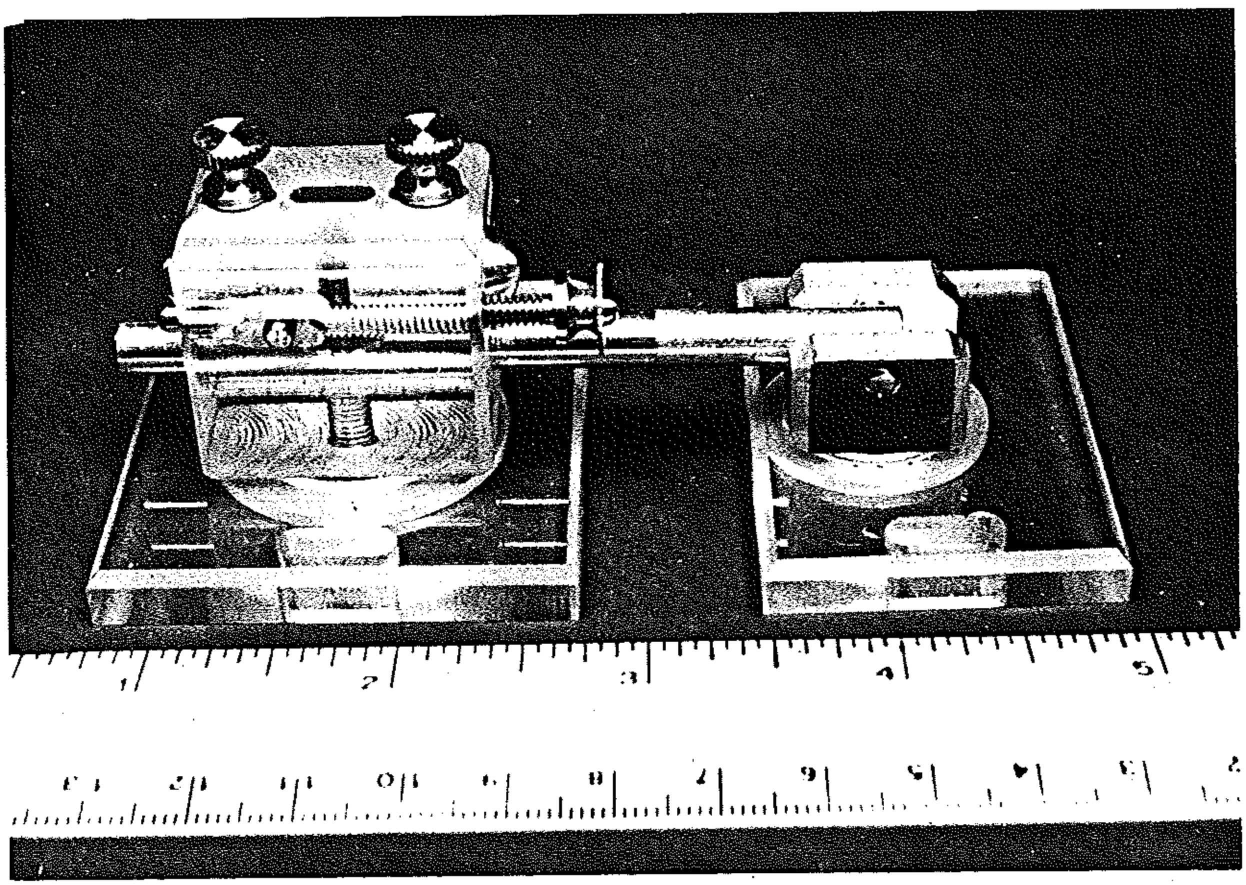


FIGURE 37. DISPLACEMENT GAGE.

TABLE 7 - LOCATIONS OF PASSIVE GAGES

Location	Approximate Horizontal Distance From GZ (km)	No. of Gages Displacement	Scratch
Ranch	5	-	2
Ranch	5	-	2
Ranch	6	-	2
Ranch	6	-	1
Ranch	6	-	1
Ranch	6	1	1
Morrisania	6	1	1
Ranch	7	-	2
Rulison	8	2	1
Ranch	8	2	2
Ranch	8	2	2
Ranch	9	-	2
Ranch	9	-	2
Grand Valley	10	5	4
Anvil Points	13	2	1
Plateau Valley	18	2	1
Union Carbide Plant	18	2	1
Collbran	19	1	1
Rifle	20	5	3
DeBeque	23	4	3
Molina	26	1	1
Cameo	43	1	1
	TOTAL	31	37

TABLE 8 - PASSIVE GAGE MEASUREMENTS

APPROX AZI-MUTH	APPROX DIST (km)	GAGE No.*	GAGE LOCATION	EVENT MOVE-MENT (in.)
330	5	SG- 87	Ext. - Bet. Stone Chim. & Shgle Siding	**
		SG- 88	Bet Flr Joist & Found. at Chimney in Bsmt.	**
335	5	SG- 89	Bet Roof Rafter & Log Siding	**
		SG-106	Bet Rf Rafter & Wd Siding	**
360	6	SG- 83	Ext. - N/Wall-Rafter to Stucco Wall	**
		SG- 84	Int. - W/Wall-Rafter to CMU Wall-Tackshed	**
335	6	SG- 86	Int. - Bsmt.-Bet Flr Joist & Wd Beam	**
337	6	SG- 90	Bet. Inter of two Wings-Frame	**
340	6	DG-115	Ext. - N/Wall-Shop-Stucco Wall to Wd Fr.	0.0018
		SG- 85	Ext. - N/Wall-Hse-Bet Log Rafter & Log Beam	**
335	6	DG-116	Int. - Stairs to Bsmt-Floor Beam to Brick Chimney	0.0016
		SG- 91	In Corn of Wd Folding Dr Frame	
345	7	SG- 92	Ext. - N/E Cor of Porch Gages-Perpendicular	**
		SG-107	to ea other Bet. Beams & Same Post	**
010	8	DG-117	Ext. - S/Wall-Acr Sep Plate & CMU Wall	0.0530
		DG-118	S/W Cor CMU Ret Wall-Acr Mort Jt Crack	0.0078
		SG- 94	Ext. - S/E Cor-Rafter to CMU	**
295	8	DG-128	Ext. - N/Wall-Jt Bet CMU & Fr.-Hse	Damaged
		DG-129	Ext. - S/Wall-Jt Bet CMU & Fr.-Hse	Damaged
		SG-100	Ext. - N/E Cor-Cor. of CMU Porch & Frame-Hse	**
		SG-101	Ext. - N/W Cor Garage-Wd Rafter to CMU	**
305	8	DG-130	Ext. - E/Wall-Acr Mort Jt Crk CMU-Shed	0.0024
		DG-131	Ext. - W/Wall-Acr Mort Jt Crk CMU-Shed	0.1276
		SG-102	Ext. - S/E Cor Hse-Bet Rafter & Wd Sid.	**
		SG-103	Ext. - N/W Cor Hse-Bet Rafter & Wd Sid.	**
025	9	SG- 93	N/E Cor-Porch Post to Beam	**
		SG-108	N/W Cor-Acr Inside Cor of Intersect. Walls	**
305	9	SG-104	Ext. - S/W Cor Shed-Rafter to Wd Post	**
		SG-105	Ext. - N/W Cor Shed-Rafter to Stucco Wall	**
305	10	DG-114	Ext. - E/Wall-Crk Bet 2 Bldgs	0.1116
305	10	SG- 81	Roof Beam to CMU Steeple	**

TABLE 8 (Cont'd)

APPROX AZIMUTH	APPROX DIST (km)	GAGE No.*	GAGE LOCATION	EVENT MOVE-MENT (in.)
305	10	DG-110	Int. - W/Wall-Science Lab-Acr Crack in Brick	0.0036
		DG-111	Int. - N/Wall-S/E Cor Auditorium-Acr Crack in Brick	0.0034
		DG-112	Int. - S/Wall-6th Gr. Rm.-Acr Crack in CMU	0.0226
		SG- 79	Ext. - E/Wall-Acr Cor Bet Old & New Bldgs Brick	**
		SG- 80	Ext. - Acr Cor Bet Old & New Bldgs Brick	**
305	10	DG-113	Ext. - N/Wall-Acr Patched Crk in CMU-Block Cracked	0.0020
		SG- 82	Ext. - W/Wall-Acr Crk in CMU	**
010	13	DG-119	Ext. - E/Wall-Acr Mortar Joint Crack CMU	0.0020
		DG-120	Int. - N/Wall-Acr Mort Jt Crk CMU	0.0126
		SG- 95	Ext. - S/E Cor Rec Hall-Rf Rafter to Wood Fr	**
185	18	DG-105	Int. - E/Wall N/E Cor-Plaster Crk	0.0006
		SG- 75	Int. - W/Wall-Plaster to Brick	**
190	18	DG-103	Int. - E Wing-Mort Jt CMU	0.0000
		DG-104	Int. - S/Wall-2nd Gr Rm-Acr. Cor Mort Jt Crk	0.0028
		SG- 74	Ext. - N/W Stairs Bet Gym & Shops Mort Jt Crk	**
040	18	DG-121	Ext. - N/Wall-Crack Mortar Joint CMU	0.0090
		DG-122	Int. - Across Cor 2 Perpendicular CMU Walls	0.0040
		SG- 96	Int. - Across Cor 2 Perpendicular CMU Walls	**
045	20	DG-126	Ext. - N/Wall-Crk Brick at Chimney	0.0014
		DG-127	Ext. - S/Wall-Crk Brick und Wind	0.0010
045	20	SG- 98	Ext. - N/W Cor-Boxed in Ceil Joists to Brick Wall	**
		SG- 99	Ext. - S/W Cor-Boxed in Ceil Joists to Brick Wall	**
045	20	DG-123	Int. - E/Wall-Crack CMU	0.0026
		DG-124	Int. - N office Wall-Crack at Beam	0.0260
		DG-125	Ext. - S/Wall-Crack Bet 2 Bldgs CMU	0.0010
		SG- 97	Int. - W/Wall & N/Wall-Cor Mezzanine	
250	24	DG-109	Int. - N/Wall-CMU Joint at Add.	0.0030
		SG- 78	Int. - S/E Cor Men's Rm-CMU Mort Jt Crk	**
250	24	DG-106	Ext. - E/Wall S/E Wing-Acr Mort Jt Crack CMU	0.0030
		DG-107	Ext. - S/Wall Gym-Acr Mort Jt Crack CMU	0.0042
		DG-108	Ext. - N/Wall-Acr Jt of 2 Glu-Lam Bm	0.0024
		SG- 76	Int. - N/Wall Gym-CMU Wall to Glu-Lam Bm	**
		SG- 77	Int. - N/W Cor Gym-Brick to Glu-Lam Bm	**
200	26	DG-102	Ext. - N/Wall-at Jt of Brick & CMU	0.0010
		SG- 73	Ext. - N/Wall-at Jt of Brick & CMU	**

TABLE 8 (Cont'd)

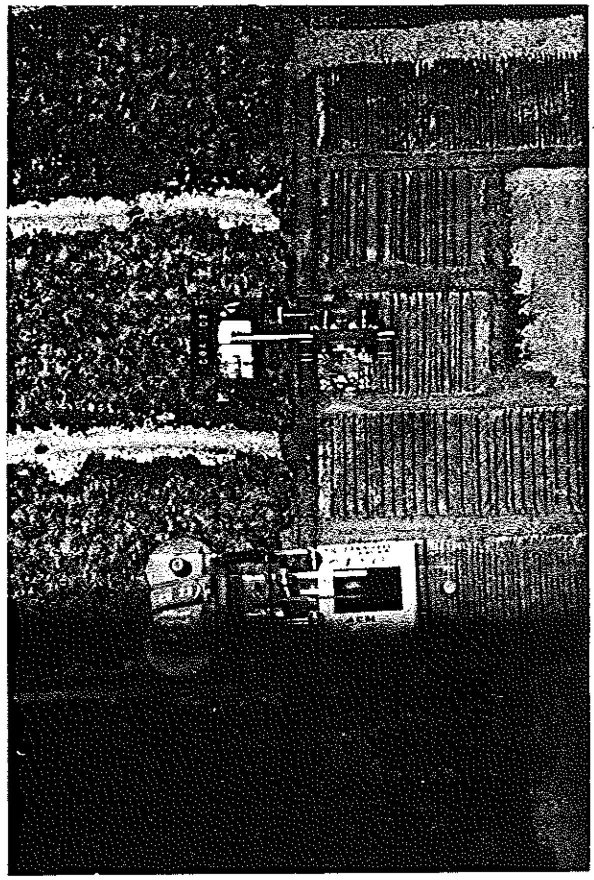
APPROX AZIMUTH	APPROX DIST (km)	GAGE No.*	GAGE LOCATION	EVENT MOVE-MENT (in.)
235	43	DG-101	Int. - E/Wall-Mort Jt Crk CMU Wall	0.0036
		SG- 72	Int. - N/Wall-Conc to CMU Wall	**
		Both in Same Stairwell		

* DG = Displacement Gage; SG = Scratch Gage

** = Film record obtained for later measurement

CMU - Concrete Masonry Unit
Mort - Mortar
Jt - Juncture
Ret Wall - Retaining Wall
Bet - Between
Glu-Lam - Glue Laminated

FIGURE 38. DISPLACEMENT GAGE (TOP) AND SCRATCH GAGE MOUNTED ON THE SAME CRACK, FOR COMPARISON OF READINGS.



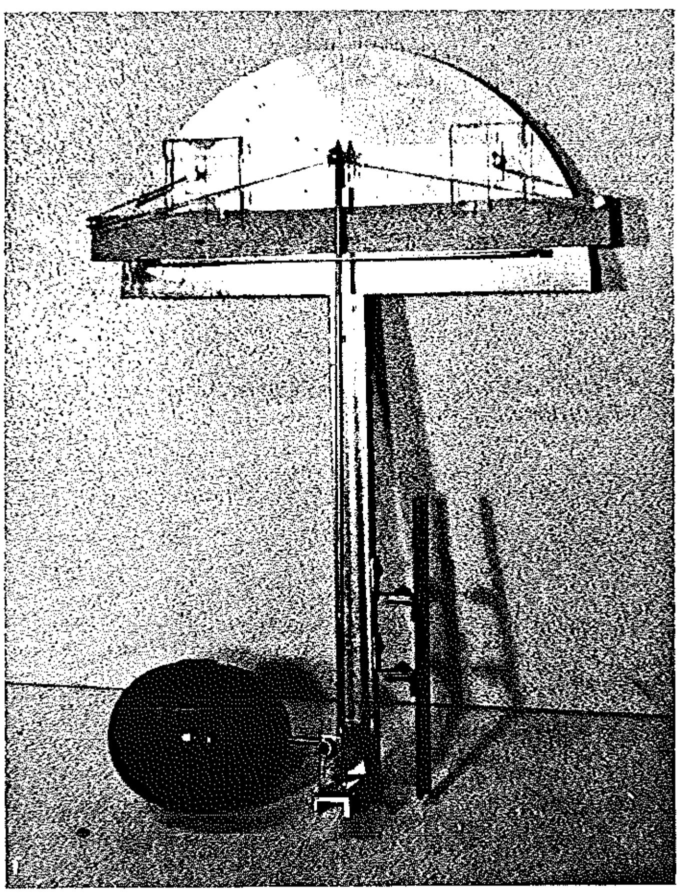


FIGURE 39. SEICHE MEASUREMENT GAGE.

IV. PRE-EVENT ANALYSES OF RESPONSE AND HAZARDS

GENERAL HAZARD ASSESSMENT

Ground motion predictions for the maximum credible yield and corresponding predictions of 5% damped velocity (S_V) were provided by ERC. These data were then used in developing the damage predictions and safety recommendations.

Because potential hazards to personnel were expected to exist within 7.4 kilometers as a direct consequence of predicted ground motion in excess of 0.3g, evacuation and other appropriate safety measures were taken by the AEC Director of Nuclear Operations (DONO). In the area from 7.4 to 14 kilometers possible damage to structures was expected to occur as a consequence of ground motion between 0.1 and 0.3g. Inhabitants in this area were requested by DONO to be outside and clear of their structures. These criteria for the safety of non-participating personnel have been used for previous AEC events. It was also recommended that school buildings be temporarily evacuated in Rifle, Collbran, and Plateau Valley during the event.

Rockfalls are a normal occurrence in many areas surrounding GZ. As a result of extensive investigation, these potential rockfall areas were identified. Ranch occupants, and highway and railroad users were advised to keep clear of these areas. Figures 40, 41, and 42 are examples of rockfall areas.

Based on ground motion forecasts and spectra, a distance of 25 kilometers was selected as the range of potentially damaging ground motion. Within this area of 25 kilometers from GZ all structures were located, inventoried, and evaluated for possible damage. Towns were treated independently and inventoried as individual units. Outside of the 25-kilometer radius and to a distance of about 100 kilometers,

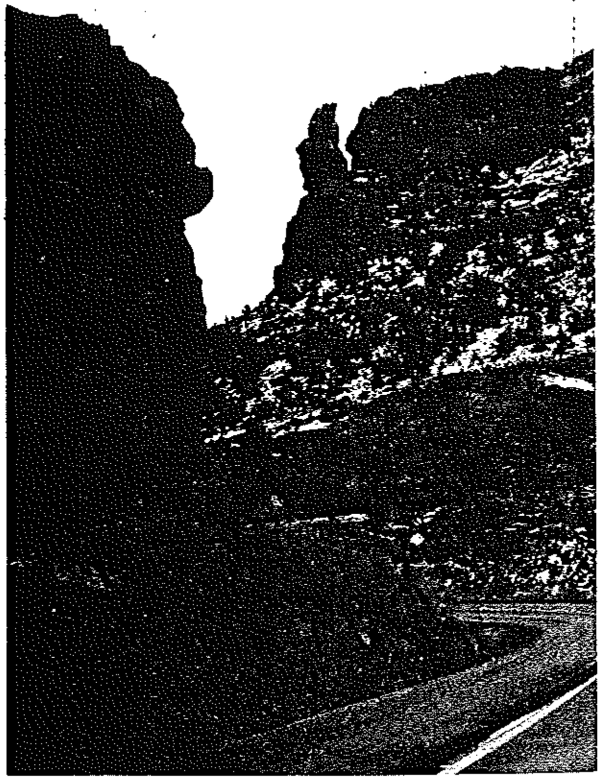


FIGURE 40. ROCKFALL AREA IN PLATEAU VALLEY, SOUTHWEST OF GROUND ZERO.

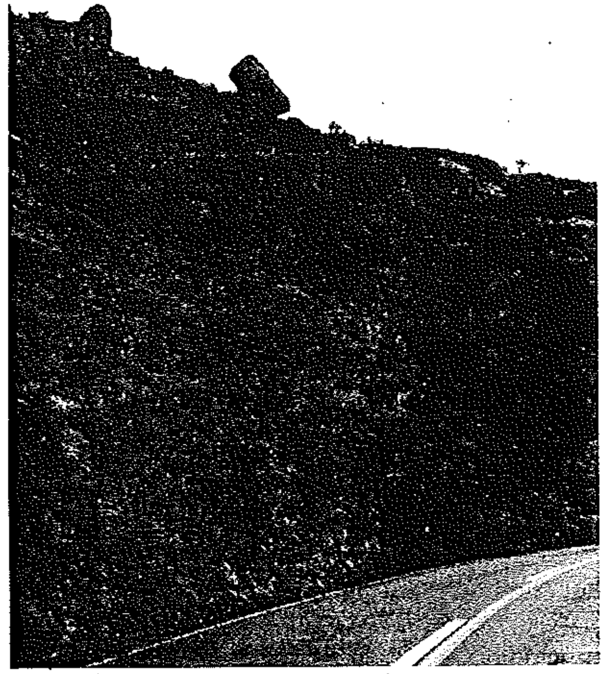


FIGURE 41. ROCKFALL AREA ADJACENT TO PLATEAU CREEK. THIS SECTION OF HIGHWAY 330 WAS CLOSED TO TRAFFIC DURING THE EVENT.

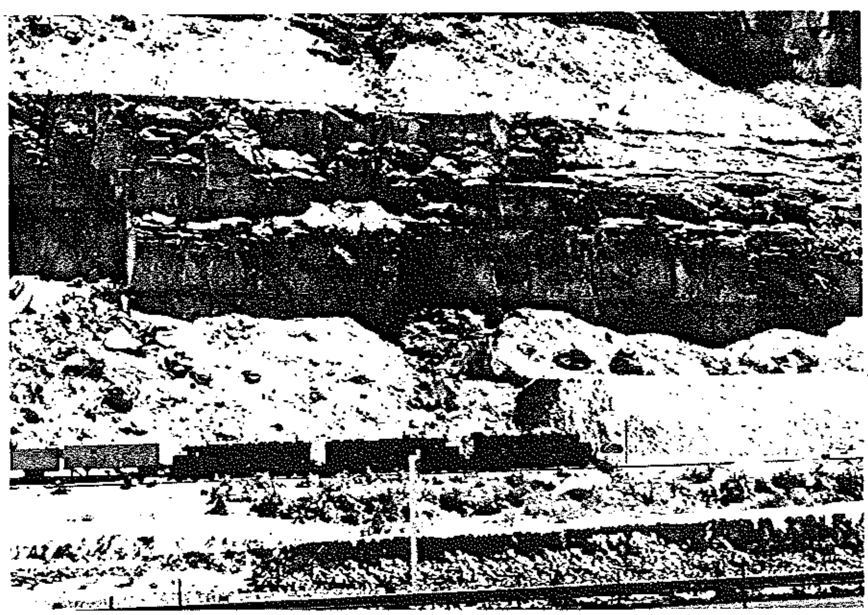


FIGURE 42. ROCKFALL AREA NEAR THE WEST END OF DEBEQUE CANYON. THE DENVER AND RIO GRANDE RAILROAD KEEPS EQUIPMENT IN THIS AREA (NEAR TUNNEL NO. 3) TO CLEAR THE TRACKS OF ROCK.

where ground motion was predicted to exceed 0.001g peak acceleration, all inhabited areas were visited and particularly vulnerable structures were noted and evaluated for possible damage.

Major industrial facilities outside of the 25-kilometer radius but within a 35-kilometer radius include the Oil Shale Research Center at Anvil Points, and the Union Carbide Plant at Rifle. The major dams are Rifle Gap Dam, Harvey Gap Dam, Bonham 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 those that do contain water have inoperative outlet control works. 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 four major dams, Harvey Gap above the town of Silt presented an apparent hazard in view of its age and obvious disrepair of outlet works, and because of the high water levels in the reservoir in early spring. However, when the detonation date was changed from May 1969 to September 1969, the reservoir was nearly empty and no hazard was present.

Safety hazards are defined to include hazards to either persons or property. Hazards to persons are predicted to exist either as a direct consequence of the imposed ground motion, or indirectly, as a consequence of other damage. Examples of direct consequences would include physiological or psychological response to the motion. An example of physiological response would be the loss of balance of someone on scaffolding, with increased danger of falling. A psychological response could also lead to injury if it initiated an over-excited reaction; e.g., rushing outside a building and falling as a consequence. Indirect consequences would include damage to occupied buildings, to dams with downstream habitations within possible flooding areas, or to inhabited or traveled areas below slopes from which rockfalls or landslides could be triggered by the ground motion.

Motion effects on property without a consequent injury to persons could include minor to moderate damage to buildings and contents; to earth structures including dams, canals, slopes, and fills; to roads and railroads; to special classes of structures such as towers and tanks; to hydraulic structures; to bodies of water and water supplies; and to cultivated areas and agricultural facilities.

EVALUATIONS OF SPECIFIC HAZARDS

General

The following paragraphs delineate specific hazard areas, with brief discussions as to the mechanisms. The inventory and evaluation data are as of the time of the inventory.

4.6 miles

Direct ground motion hazards were predicted to exist within a radius of 7.4 kilometers of GZ because peak horizontal ground accelerations (at 60-kt yield) were predicted to equal or exceed 0.3g within this area. From earthquake experience, it is found that a Modified Mercalli Intensity of IX corresponds roughly to this peak acceleration. It is further shown from considerable experience that ground motion corresponding to this intensity may cause persons to lose their footing and to fall, with a clear possibility of injury as a consequence. Actual RULISON experience indicates this criterion was too conservative; i.e., observers experiencing motion up to 0.5g did not sense any loss of balance nor imminence of falling.

The physiological response is primarily defined as the possible consequence of loss of balance of persons working in precarious locations. Utility and bill-board workers on ladders or platforms, painters on scaffolding, and construction workers on buildings and bridges are examples. The area of concern is difficult to define. However, no problems have been found to occur in Las Vegas at ground accelerations up to about 0.005g.

A potential problem of psychological response was considered to exist in Rifle and Collbran schools. School children, being young and impressionable, are probably particularly sensitive to alarm when experiencing ground motion, and some additional probability of over-reaction may be present. Rifle and Collbran schools, in particular, are locations at which such problems were expected to exist, and it was recommended that these schools be evacuated for the event.

General Structural Population to 7.4 km from Ground Zero

Peak horizontal ground acceleration out to 7.4 kilometers from GZ was predicted to be 0.3g or more. Spectral acceleration for structures of 0.2-second period, at 5% damping, was estimated to be 0.8g. At these levels of motion, some slight shifting on foundations might occur. Damage to chimneys might also occur as a result of differential motion or banging of the chimney against the house. Other damage could occur to bric-a-brac, tall standing objects (e.g., a grandfather clock), and to hanging mirrors and pictures. In some locations it was recommended that chimneys be removed, bracing installed, and certain utility services be shut off to prevent damage. Figures 43 and 44 indicate examples of remedial measures taken to prevent damage. Figure 45 is an example of wood frame construction; Figure 46 is an example of adobe construction.

General Structural Population, 7.4 to 14 km from Ground Zero

Damage of the extent which could pose a potential hazard to persons was considered a possibility to structures in the range from 7.4 to 14 kilometers. This region includes the town of Grand Valley, the Anvil Points Research Station, and a number of small ranches.

FIGURE 43. A TALL, NARROW CHIMNEY BEFORE REMOVAL. THE MORTAR IS DETERIORATED, ESPECIALLY THE TOP TWELVE COURSES. SEE FIGURE 45.

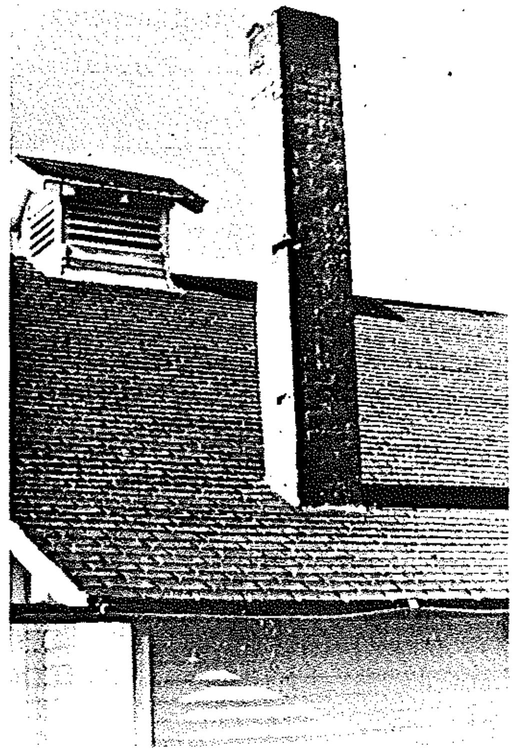
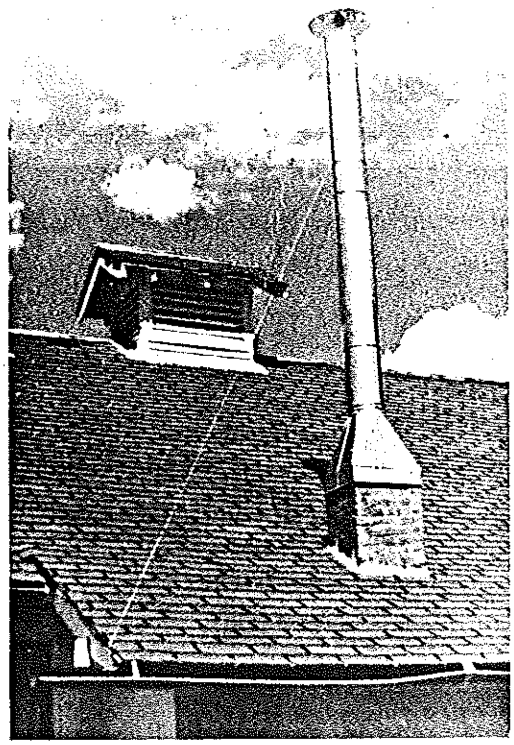


FIGURE 44. TO PREVENT DAMAGE FROM GROUND MOTION, SEVERAL FEET OF BRICK CHIMNEY WAS REMOVED AND REPLACED WITH A METAL FLUE. SEE FIGURES 43 AND 45.



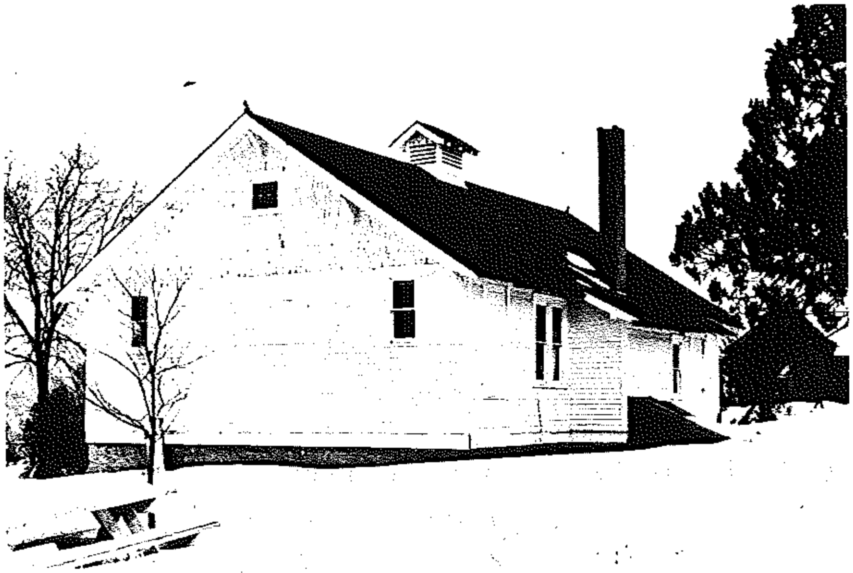


FIGURE 45. AN EXAMPLE OF WOOD-FRAME CONSTRUCTION LOCATED APPROXIMATELY 7 KILOMETERS FROM GROUND ZERO. NOTE THE CHIMNEY HEIGHT. SEE FIGURES 43 AND 44.

FIGURE 46. AN EXAMPLE OF ADOBE CONSTRUCTION.

The community of Rulison, for which the project was named, is an aggregation of many small farms, cabins, and isolated structures, located within a radius of about 9 kilometers from ground zero. Generally the structures are of wood frame construction, with a few masonry buildings.

Within this area, it was recommended that people be outside and two building heights away from structures.

The town of Grand Valley is located about 10 kilometers northwest of GZ. Structures in the commercial area are generally old brick 1- and 2-story buildings, partially occupied. The largest structure is the school, which is constructed of brick. There are a few brick veneer houses and a number of all-metal mobile houses; the rest are of all-wood construction. Figures 47, 48, and 49 are three structures located in Grand Valley.

The peak 5% damped spectral acceleration prediction for Grand Valley was 0.4g for structures with a period of 0.2 seconds; peak horizontal ground motion was predicted to be about 0.13g. Under these conditions only moderate damage was anticipated, mostly in the older 2-story commercial structures.

Anvil Points Research Station

This facility, shown in Figure 50, is located approximately 13 kilometers north of GZ. It was constructed in 1945 by the Bureau of Mines as an experimental research center, but is now in a caretaker status. In addition to the plant is the housing area which has many wood frame residential structures. The plant has several concrete block warehouse buildings, a 2-1/2 story administration building, and several metal-covered buildings. Process buildings include a crusher plant, retort structures, a cracking tower, several guyed stacks, and many large steel petroleum tanks. Near the highway there is a large transformer substation and a pumping plant.

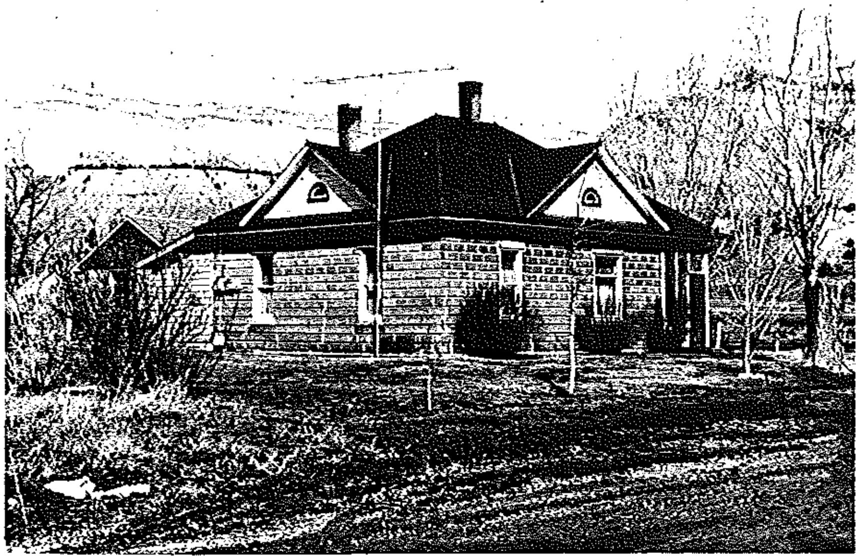


FIGURE 47. A RESIDENTIAL STRUCTURE CONSTRUCTED OF CONCRETE BLOCK. NOTE PATCHED CRACKS AND CHIMNEYS.

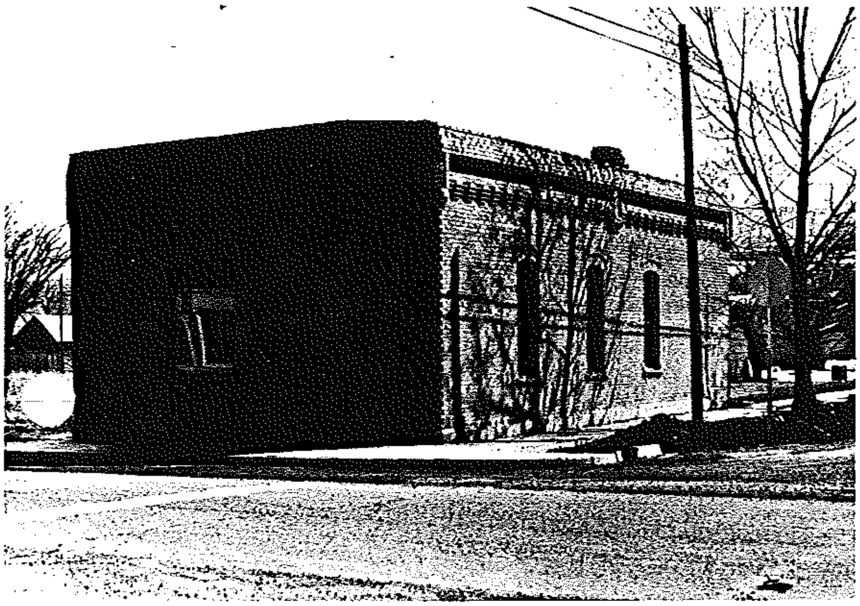


FIGURE 48. TYPICAL BRICK CONSTRUCTION. NOTE THE CHIMNEY AND PARAPET.

FIGURE 49. THE GRAND VALLEY POST OFFICE, PRE-EVENT. THE STRUCTURE IS BRICK WITH A STUCCO APPLICATION.

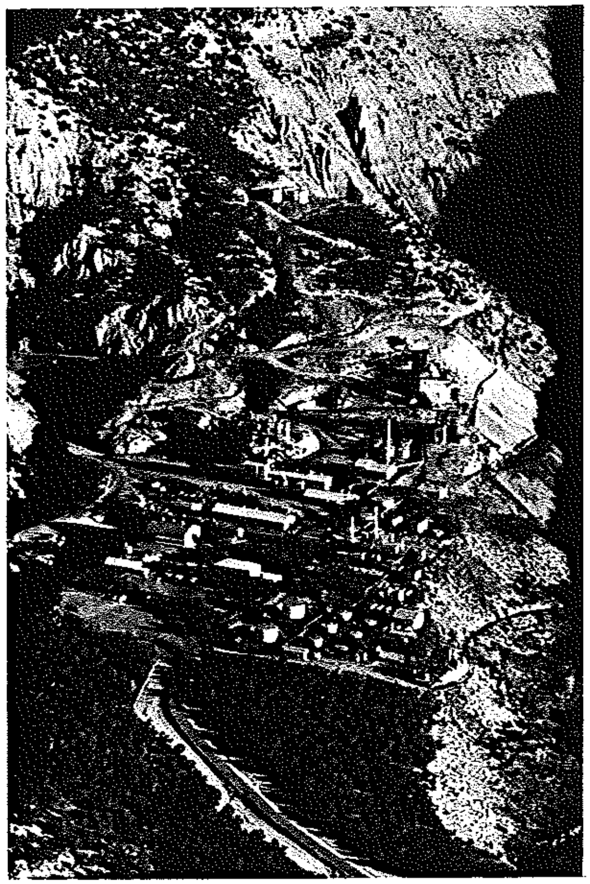


FIGURE 50. ANVIL POINTS RESEARCH STATION LOCATED AT THE BASE OF THE ROAN CLIFFS.

Spectral acceleration for the Anvil Points tower and retort structures at 5% damping was predicted to be approximately 0.3g; therefore, some slight overstressing might occur in bracing members, in anchor bolts, and foundations. Full storage tanks might spill over due to liquid motion. Failure of tower structures was not anticipated but it was suggested that maintenance personnel check all anchor bolts and guy wires for tightness and adequacy. Some extension of existing cracks might occur in the concrete block warehouse structures, the administration building, and the residential structures.

At the several small ranches within this area, the peak horizontal ground accelerations were predicted to be from 0.1g to 0.3g, and 5% damped spectral accelerations at the periods of typical structures in the area could range up to 0.4 and 0.5g. At these levels moderate damage might occur. Typically, such damage might include cracked and fallen plaster, damage to brick chimneys, and falling bric-a-brac and other precariously situated objects.

Microwave Tower

A microwave installation was noted about 14 kilometers northwest of GZ. This installation, owned by Mountain States Telephone Company, consists of dish-type antennas mounted on a square tower, and an equipment stack. While spectral acceleration was predicted to be relatively high, damage to the structures was improbable, because these facilities are exposed to and designed for high wind and snow loadings much larger than expected forces from RULISON ground motion.

Ranches in Plateau Creek Area

There are many ranches south of GZ, at an average range of 14 to 18 kilometers from GZ. These ranch buildings are generally of wood construction, but a few ranch houses in the area near Collbran were noted to have brick veneer exteriors. Several of the ranches were unoccupied and may possibly be used as summer ranch quarters only. Peak horizontal ground accelerations were estimated to be less than 0.1g. Predicted spectral accelerations at 5% damping ranged up to about 0.3g; minor damage, such as plaster cracking, might occur at these accelerations.

Union Carbide Plant

This plant, located about 18 km northwest of GZ, processes vanadium and uranium ore. Among the important structures are the 200,000-gallon water tank elevated 100 feet above ground, the 360-foot-long x 9-foot diameter kiln, the 12- to 20-foot-high wood-stave tanks with diameters varying from 36 feet to 60 feet, and the large concrete-block-walled steel-framed process buildings. Figures 51 and 52 are general views of the facility.

Spectral accelerations at 5% damping in the 0.2- to 0.3-second period range were predicted to be about 0.14g; horizontal ground motion was predicted at about 0.07g or less. At these levels some minor additional cracking of the concrete block filler walls of the process buildings was possible. Other features of the plant were expected to respond well. Spillage of acids and other liquids due to sloshing in tanks was also considered possible but unlikely to occur.

A mill tailings pile composed of silt size particles and a settlement pond which is retained in a fully saturated condition behind earth embankments are located adjacent to the plant. The saturated silty material might tend to liquefy under dynamic load, but this was believed unlikely to occur. It was recommended that persons be away from the downslope areas of the tailings pile during the RULISON event. Figure 53 is an overall view of the Union Carbide facility.

Collbran

Collbran, about 19 km south of GZ, and its small suburb of Plateau

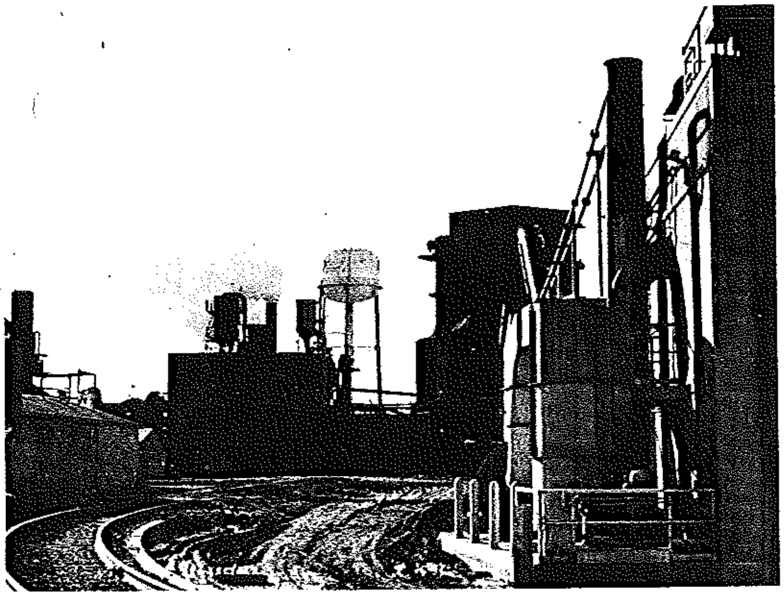


FIGURE 51. UNION CARBIDE PROCESSING PLANT WITH A 200,000-GALLON WATER TANK ELEVATED 100 FEET ABOVE THE GROUND.

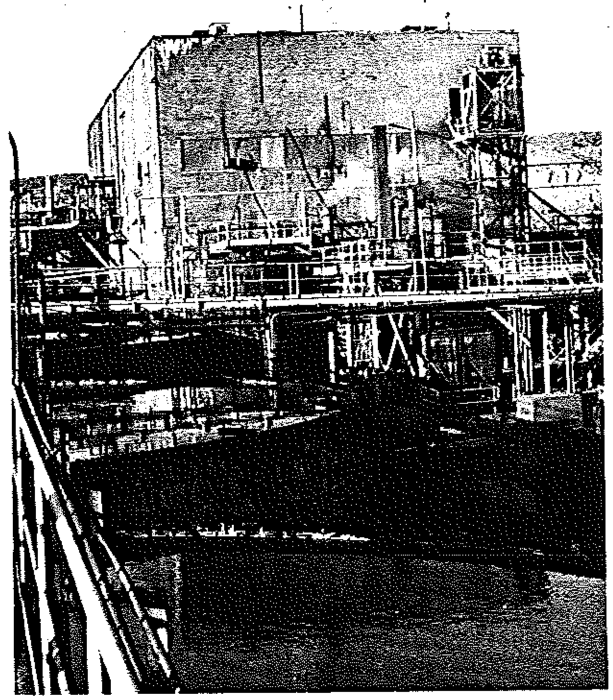


FIGURE 52. UNION CARBIDE CONCRETE BLOCK BUILDING AND WOOD-STAVE TANKS.

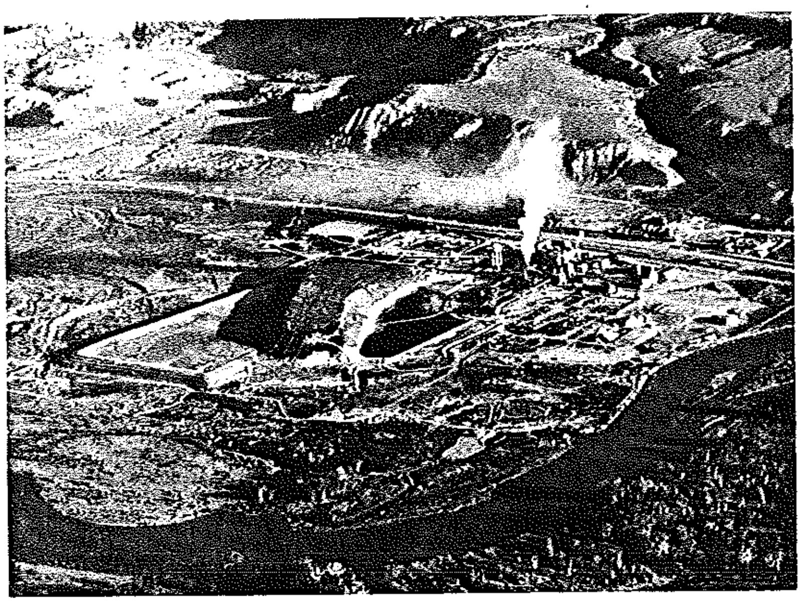


FIGURE 53. UNION CARBIDE PLANT WEST OF RIFLE. NOTE THE MILL TAILING PONDS.

City, is the center of an agricultural community. There is a large one-story brick school in Plateau City of recent construction, a Civilian Conservancy Corps camp with many permanent metal buildings as well as trailers, and the commercial section of Collbran with several older concrete block and brick buildings in generally fair condition. Residential structures are generally wood frame with many 2-story homes in evidence.

Peak horizontal ground motion at this range was predicted to be less than 0.05g, and spectral acceleration at 5% damping ranging up to about 0.18g. Minor damage such as cracking of interior plaster and extension of concrete block cracks was considered possible.

Rifle

This is the largest town close to GZ (approximately 20 kilometers northeast of GZ). The commercial district and many of the homes are situated in the valley, and some of the newer homes have been built on terraces above the town. Commercial structures are generally of brick 2-story construction (Figures 54 and 55). Residential construction is primarily wood frame and wood siding, although a number have brick veneer siding. There are quite a few mobile homes in camps in and near Rifle. Predicted peak horizontal ground accelerations were less than 0.06g, but spectral accelerations at 5% damping might be over 0.2g.

Motion at Rifle at these levels was expected to possibly cause damage such as cracking in plaster finishes, minor masonry damage, etc.

DeBeque

Buildings in the town of DeBeque, located about 23 kilometers southwest of GZ, range from small wood structures to wood frame

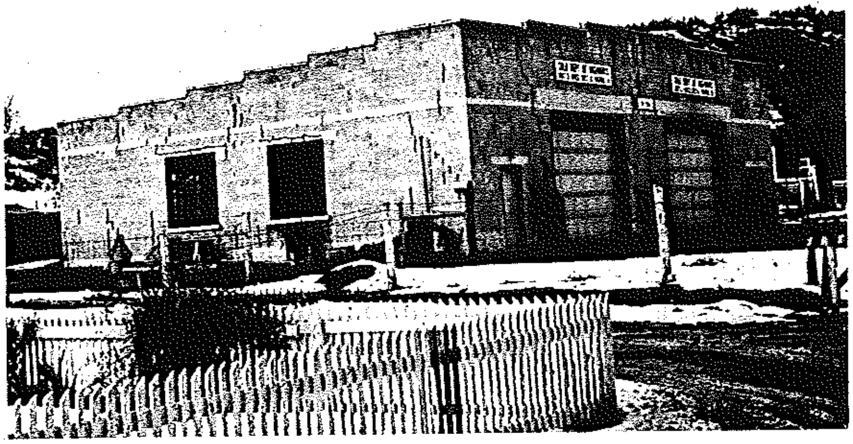


FIGURE 54. HIGHWAY MAINTENANCE BUILDING IN RIFLE. NOTE THE PATCHED CRACKS IN THE MORTAR JOINTS AND CINDER BLOCK UNITS.

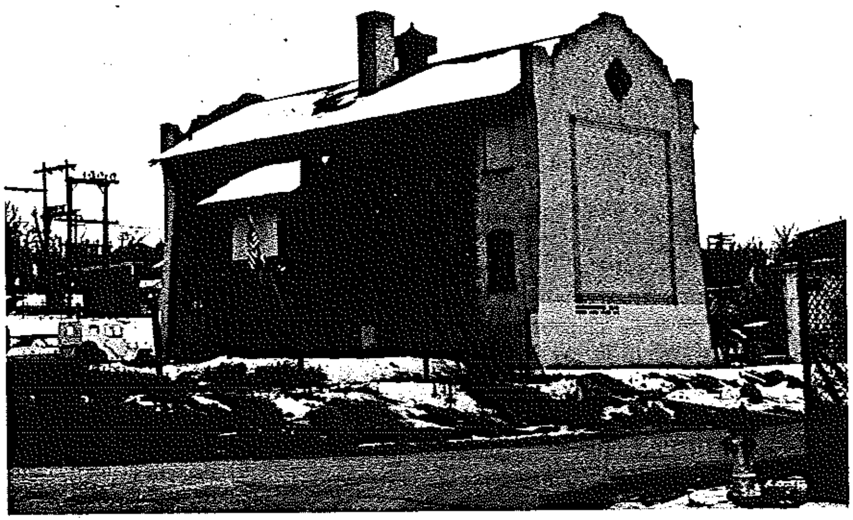


FIGURE 55. BRICK SCHOOL ADMINISTRATION BUILDING IN RIFLE.

homes to 2-story brick commercial buildings. (Figures 56 and 57). Some of the 2-story structures, such as the old brick DeBeque High School and the IOOF Meeting Hall, are unused. The new DeBeque School is a modern 1-story concrete block and brick structure located at the north edge of town.

Estimated peak horizontal ground accelerations were less than 0.03g; 5% damped spectral accelerations ranged up to about 0.1g. It was considered that these motions might cause some minor damage in plaster walls and in brick and block 2-story buildings.

The Oil Shale Corporation (TOSCO) Facility

A steel tower at the TOSCO facility 29 kilometers northwest of GZ was inspected in March 1969, and a structural evaluation was conducted, using available data.

The tower is approximately 200 feet high and 50 feet by 50 feet in plan, with 9 supporting columns. This tower has had a history of differential settlement. Foundation material consists of 5 to 6 feet of compacted fill which is underlain by about 170 feet of talus. The tower leans out of plumb at the rate of 2 feet per year when the plant is operating, and about 0.5 feet per year when not in operation. The tower has been regularly surveyed and replumbed by base adjustment.

Attempts have been made in the past to correct the foundation tilt by applying horizontal forces at the top of the structure, using "dead-men" anchored into the adjacent cliffs and pulleys attached to the top of the structure supporting suspended dead weights. Adjustments have also been made at the base of the columns by use of jacks. According to TOSCO management, the differential settlement had apparently slowed or stopped, probably because of inactivity of the TOSCO facility. Some of the reduction in settlement may be due to consolidation of the foundation material. Our analysis was based on an assumed dynamically stable foundation, which is a

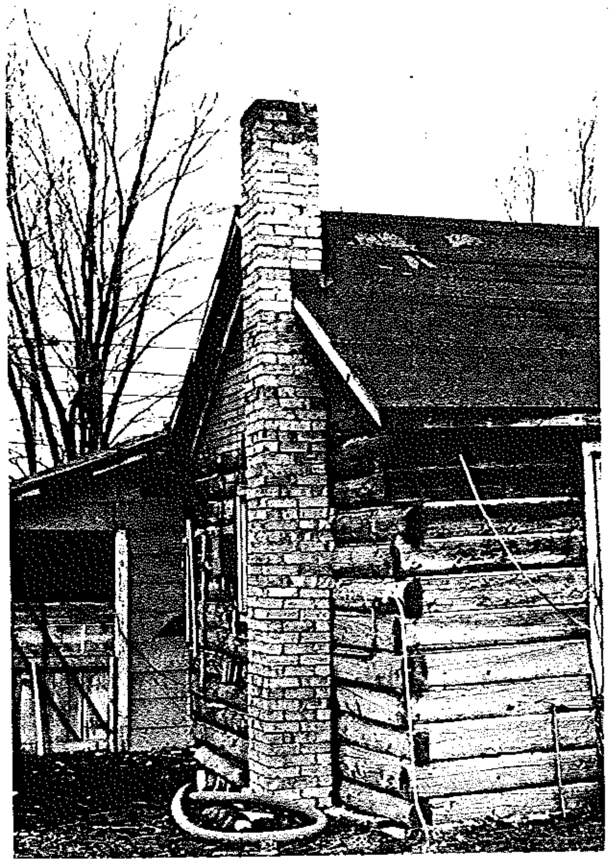


FIGURE 56. A LOG RESIDENCE IN DEBEQUE. NOTE THE MORTAR PATCHING ON THE CHIMNEY.

FIGURE 57. MESA COUNTY ROAD DEPARTMENT SHOP BUILDING, CONSTRUCTED OF CUT STONE.

reasonable assumption because of the very low levels of ground motion anticipated at this location.

A brief structural-dynamic study was made, based on rough field measurements obtained from a field trip on March 21, 1969. Photographs, structural drawings, and other necessary information for a definitive analysis were unavailable because of being company-classified as proprietary data. Therefore, the results of this study are approximate at best.

The results of the structural evaluation, using available data, were as follows:

	Range of Values	
Period (approximately)	1.20 sec	0.83 sec
Max. Allow. Design (x1.33) Base Shear Coeff.	0.018g	0.036g
Max. Pred. RULISON Base Shear	0.004g	0.008g
Max. Pred. Top Story Accel.	0.007g	0.013g

Max. Allowable Design (x1.33) Base Shear = 60^k

Max. Pred. RULISON Base Shear = 13^k

It was concluded that event-caused motion from RULISON would account for stresses less than 25% of those allowable. Therefore, no special precautions were recommended, other than evacuation of the facility because of rockfall hazard.

Silt

Silt is a small town located east of Rifle, approximately 30 kilometers northeast of GZ. Structures are generally 1-story wood frame buildings with wood or stucco exteriors. Near the highway are several unoccupied masonry structures which are in poor condition. These masonry structures show evidence of settlement. Peak ground accelerations were estimated to be less than 0.04g; 5% damped spectral accelerations ranged up to about 0.07g. Minor damage to stressed plaster of stucco surfaces and some slight extension of masonry cracks were considered possible. Figure 58 shows one of the few 2-story structures in Silt.

Mesa

Mesa is a small agricultural community in Plateau Creek Valley about 32 kilometers southwest of GZ. Structures are predominantly wood-frame with wood or stucco exteriors. Peak ground accelerations were estimated to be less than 0.04g; 5% damped spectral accelerations were 0.07g or less. Very slight damage, such as extension of cracks in brittle finish coats, was considered possible.

Other Communities

Perceptible motion (possibly generating some damage complaints) but no significant probability of damage was predicted for communities at greater distances than those discussed, barring the occurrence of unpredicted and anomalously strong ground motion. Included in this category were New Castle, Glenwood Springs, Grand Junction, Delta, Montrose, Cameo, Palisade, and Aspen. If long-period motion was generated with sufficient amplitude (which appeared unlikely in view of the predicted spectral distribution) response motion at barely perceptible levels might be experienced on upper levels of Denver and Salt Lake City high-rise structures.

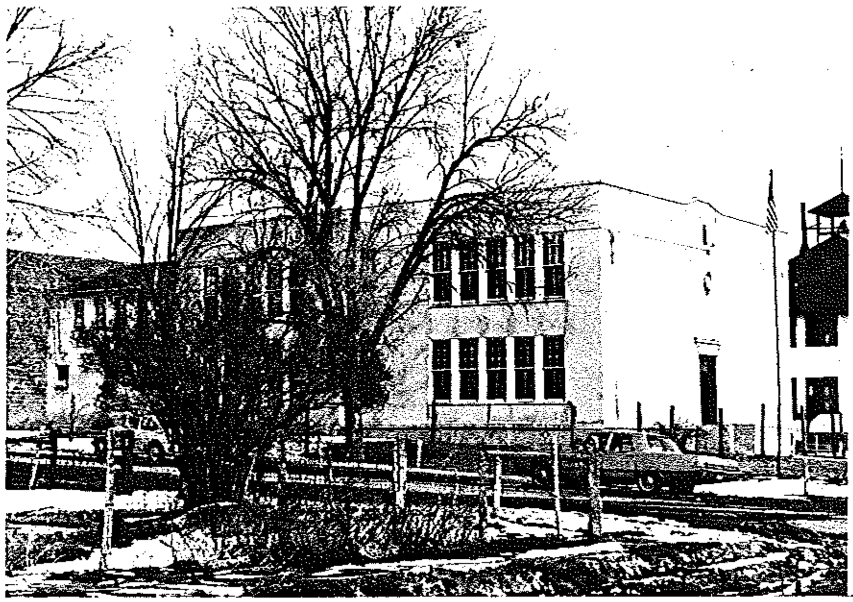


FIGURE 58. TWO-STORY ELEMENTARY SCHOOL IN SILT. NOTE THE OLDER WOOD-FRAME SCHOOL UNIT IN THE BACKGROUND.

INVESTIGATION OF EARTH STRUCTURES

Early in our earth structure hazard evaluation we observed and were concerned about the old Harvey Gap earth dam. Our initial evaluation and concern were expressed in early progress reports and led to a much more extensive study of the possible potential hazard presented by the Harvey Gap Dam. A separate study and report (Reference 9) was prepared by Drs. H. B. Seed and J. L. Sherard, assisted by Woodward-Clyde and Associates. After a May 1, 1969 safety review meeting in Las Vegas, predictions of reservoir levels were obtained and maximum potential downstream flooding areas calculated. Additional investigations of the Battlement Mesa reservoirs and Beaver, Gunnison, and Ute Dams were also conducted. An evaluation was made of the potential hazard presented by water wave generation in reservoirs. It was concluded that probable wave heights would not constitute a hazard.

Harvey Gap Dam and Reservoir

Harvey Gap Dam and Reservoir, also known as Grass Valley and Grass Valley Antlers, was originally constructed in 1891. The dam was of the earth-fill type 49 feet in height above the foundation with crest length 580 ft; width of crest 10 ft; width of base 225 ft; downstream slope 2:1; and upstream slope 3:1. The original dam failed in 1895 and was rebuilt in 1909. In 1921 the dam was rehabilitated and raised to a height of 60 feet with a crest length of about 800 feet. The gross reservoir capacity was increased to 5058 acre-feet with a high water surface area of 206 acres. The present operator is the Farmers Irrigation Company. Until Rifle Gap Dam was completed in 1967, Harvey Gap Reservoir was the largest development in the immediate area, and supplied water for irrigated lands on Harvey Mesa north of the town of Silt.

The Seed, Sherard, and Woodward-Clyde & Associates study concluded that a remote probability of damage to the Harvey Gap Dam existed, and recommended certain precautionary measures. These were amplified by the Safety Panel (NVOO Panel of Safety Consultants), an independent board of experts who regularly reviewed the progress reports made for the Effects Evaluation Safety Studies. The Safety Panel recommended certain action for specific situations of reservoir water level. The study contained recommendations for provisions for timely evacuation if water level was 15 to 20 feet below the dam crest, and no immediate evacuation requirements if the water was more than 20 feet below the crest of the dam.

Damage to downstream stock-watering ponds, utility lines (gas, electric, telephone), irrigation ditches, roads, the Denver and Rio Grande railway, irrigation ditches and cultivated lands, as well as farm buildings, could accompany serious flooding. The probability of such flooding was sufficiently remote, in view of the predicted very low water levels at shot time, that no serious effort to estimate these damages was made.

A survey program to determine whether or not movement occurred during the RULISON event was planned. Regardless of water level at shot time, the dam would be visually observed and monitored.

Based on discussions with persons in the area familiar with water usage and reservoir levels, it was predicted that the reservoir water level in September (to which time the RULISON event had been postponed) would be about 40 feet below the dam crest, assuming normal summer rainfall and runoff from the local drainage area, and that the reservoir would be almost dry. This was the case, as it actually happened.

Battlement Mesa Reservoirs

These reservoirs include a number of small dams and impounded bodies of water on Battlement Mesa, a few kilometers southeast of ground zero (Figure 59). The reservoirs empty into Battlement Creek which flows northerly past ground zero and across Morrisania Mesa to empty into the Colorado River.

Our detailed study of the outflow characteristics, assuming a one-hour outflow and a typical flow hydrograph on the basis of dam failure experience, with full reservoir calculations, indicated that no flooding would occur outside the normal creek channels. Since there were no inhabited locations in or near the channel, and since it was expected that the entire area would be evacuated for the event period, being inside the 0.3g evacuation area, no hazard to persons would be presented by this flooding if it should occur.

Rifle Gap, Vega and Bonham Dams

The careful construction techniques known to be employed by the Bureau of Reclamation, review of construction specifications, and the assurances expressed by Bureau of Reclamation personnel concerning the stability of these dams under the predicted dynamic loading, were taken as adequate assurance that no hazard was posed by these dams. Additional investigations, which were conducted by the NVOO Panel of Safety Consultants, were reassuring with regard to the dynamic stability of dam foundation materials.

Beaver, Overland, Ute and Harris Dams

Additional studies were made of the hazards posed by Harris, Overland, and Beaver Dams, at distances of about 34, 45, and 74 kilometers respectively from the RULISON ground zero.

Beaver Dam might have posed a hazard to inhabited areas as a consequence of failure; however, the estimated RULISON ground

FIGURE 59. BATTLEMENT RES-
ERVOIRS LOCATED ABOVE AND
SOUTHEAST OF GROUND ZERO.

motion at 70 kilometers was at such low levels (peak ground acceleration predicted to be 0.005g) that no significant effect on the dam stability was expected. Therefore, no hazard to downstream areas was anticipated as a consequence of RULISON ground motion, nor was leakage of the dam expected to increase.

Overland Dam and Ute Dam impound water, but no problem was anticipated in downstream areas, as there were no permanent residents. Evaluation of the effects of predicted ground motion at at these dams indicated that no significant effect on the stability of the dams would be created. Therefore, no hazard to persons in downstream areas (campers, fishermen, etc.) was anticipated as a consequence of RULISON generated ground motion.

Harris Dam had a seepage problem in the foundation of the right abutment. Because of the small size of the dam, its relatively small capacity, and the lowering water level during the summer, the dam presented no special problem.

Canals

Natural instability because of saturation under static operating load conditions is characteristic of much of the canal system in the area. Some additional instability might be caused as a consequence of the ground motion created by RULISON. Definitive studies and forecasts were not possible because of extensive systems in the area and a great variety of foundation conditions. Specific areas of slope instability were noted by the Bureau of Reclamation on Relocated State Highway No. 325 near Rifle Gap Dam, the Leon-Park Feeder Canal, and the Southside Canal. Figure 60 shows a view of Southside Canal. Also, slopes under the Bonham pipeline from Stations 30+00 to 40+00, 174+00 to 189+00, and 202+00 to 240+00 were showing evidences of similar slope instability, particularly during wet seasons. Because of the expected dry conditions and improved slope stability at the

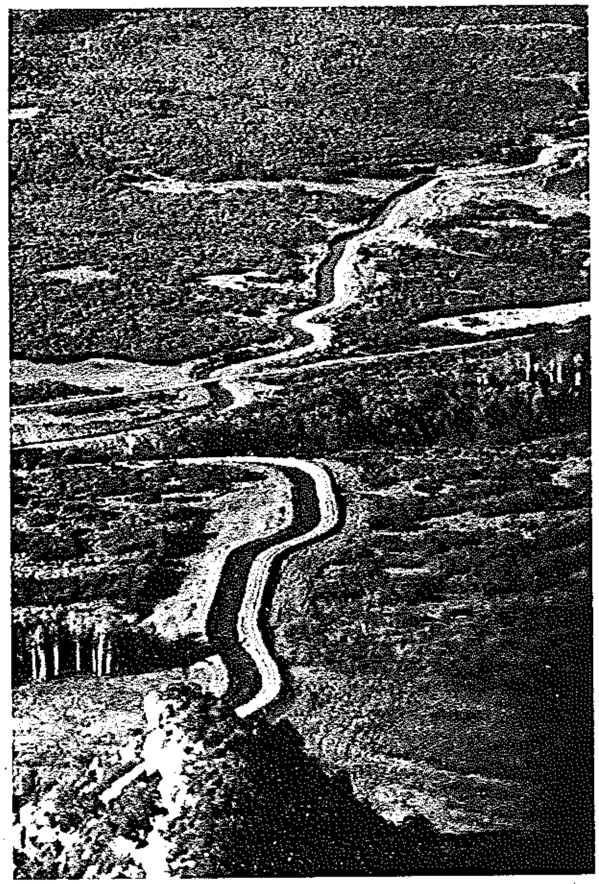


FIGURE 60. SOUTHSIDE CANAL HAD SOME AREAS WHERE SLOPE INSTABILITY WAS NOTED.

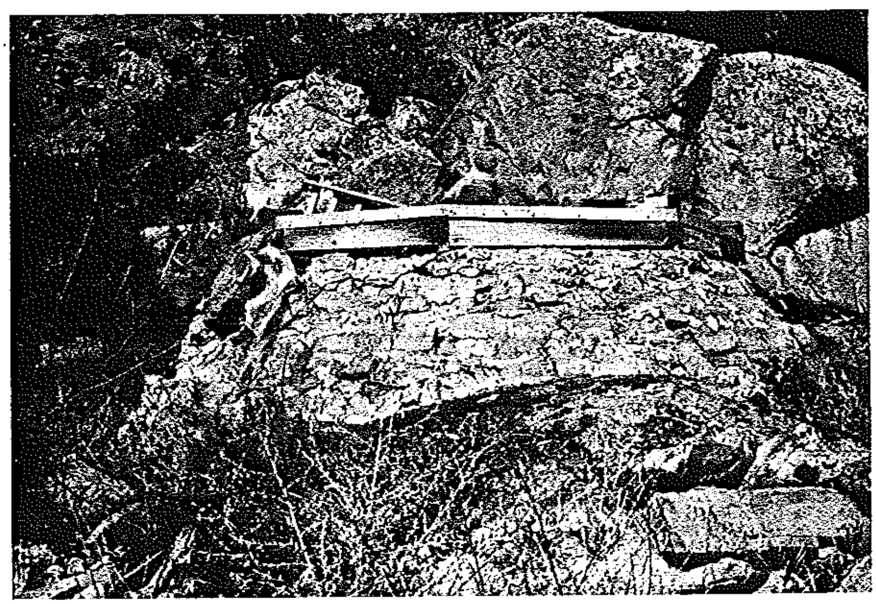


FIGURE 61. MOST CISTERNS IN THE STUDY AREA WERE TOTALLY UNDERGROUND BUT CONSTRUCTION WAS SIMILAR TO THIS. IN THIS CASE A HOLE WAS DUG, LINED WITH ROCK, THEN PLASTERED. OFTEN A HOLE WAS DUG AND THE SIDES DIRECTLY PLASTERED.

planned September shot date no event-associated failures were anticipated.

Tunnel No. 3 of the Grand Valley Project

This tunnel had shown evidence of static instability, largely because of its location in an old massive landslide. A portion of the tunnel was relocated into adjacent undisturbed rock after failure by sliding in 1950, but remaining portions (in the vicinity of the east portal) are still located within the landslide area.

It seemed unlikely however that damage would occur because of the generally low level of motion predicted for this area, in view of general seismic experience with similar slopes in earthquake areas and at the Nevada Test Site.

Vega Wasteways

A wasteway structure below Vega Dam has been endangered by a flow-type landslide which caused extensive damage in 1966. Ground motion might cause added instability. Triggering the slide into rapid action seemed unlikely, however, at the relatively low levels of motion predicted for the area, particularly later in the summer when slopes had an opportunity to dry out.

Bodies of Water and Water Supplies

The general region of the RULISON event is low in water yield. Although the watershed area represents about 25 percent of the Colorado River Basin in Colorado, the average yield is less than 9 percent of the total. As a consequence, the inhabitants of the mesas must store water in cisterns and tanks for their needs. Sources of water are rain, snowmelt, pumped ground water truck delivery, and canals.

Numerous cisterns constructed both in rock and alluvium are located in the immediate vicinity (4 to 10 km) of the shot point. Figure 61 is a view of a cistern. It was considered possible that the RULISON event might cause minor damage to some of the cisterns although no extensive damage was predicted. No preventive measures were recommended since only limited minor damage was expected to occur.

Cultivated Land and Agricultural Facilities

Field investigations had identified some locations of slope instability above agricultural lands, specifically in the Plateau Valley, Plateau Canyon, and Parachute Creek areas. Damage to some portions of these lands by rockfall or landslide, or by flooding caused by temporary damming of creeks by slides, had been considered a possible but unlikely source of economic loss. Temporary loss of access to farmlands, caused by road blockage, or loss of crops through damage to water supplies was also a remote possibility.

Rockfalls and Landslides

The geologic section exposed in the canyon walls is a thick sequence of flat-lying interstratified sandstones and clay shales. The sandstones are hard and strong, jointed, thin bedded to massive, and separated by fissile, very thin to thick bedded soft weak clay shale. Slopes exposed by stream action are undercut along the soft clay shale beds which removes support from beneath overlying sandstone beds. Blocks of rock which are bounded by joint surfaces become detached and fall or slide downslope. The blocks are dislodged by loss of strength of the clay shale through lubrication or wetting from snow melt, or from precipitation and expansion due to freezing. Larger rock masses or pinnacles may collapse. Mass wasting of the clay shale also has taken place in the form of slumps and flows particularly in areas of springs and seeps, thus creating additional sandstone rock fall hazards by removal of lateral confinement and underlying support. Another effect of removal of lateral confinement is the consequent differential settlement and downslope gliding of large detached blocks and masses of sandstone on and into underlying compressible weathered clay shale beds. These sandstone masses and blocks may glide downslope for considerable distances before tilting past their respective centers of gravity and tumbling down the slope surface to the valley floor. Figure 62 shows rock on Interstate Highway I-70.

Dip slope failures (failure of layers along the plane slope of the geological formation) of large intact rock masses as well as individual joint bordered blocks are also observed in the area. These failures occur where dip slopes have been undercut by stream action; excavations for buildings, highways, and railroads; and at tunnel portals.

The frequency of slope failures is highest at the time of the fall freeze, lowers slightly throughout the winter, and rises again with the spring thaw. This is followed by a relatively quiet period through the summer until about mid-August when many landslides are triggered by precipitation runoff from cloudbursts. The cloudburst season is usually followed by a short period of slope stability until winter storms and ground freezing again start the cycle. It was considered remotely possible that the RULISON event could induce minor slope failures at certain localities.

DeBeque Canyon - Rockfalls and landslides consisting of large masses of intermixed sandstone blocks and clay shale are a chronic occurrence in DeBeque Canyon. Figures 63, 64, and 65 show rockfalls. These slope failures periodically block portions of Interstate Highway I-70 and the main line of the D&RG RR for a distance of 14 miles along the Colorado River. The canyon starts just west of the town of DeBeque, and the canyon floor hazard area extends for about 22.5 kilometers almost con-

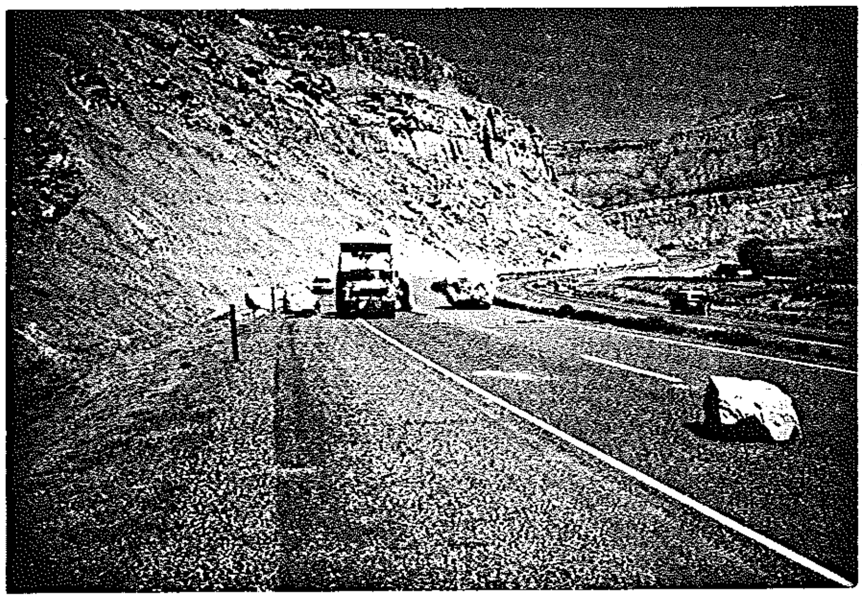


FIGURE 62. ROCKFALL FROM THE BOOK CLIFFS ALONG I-70 NORTH OF PALISADE. THIS ROCK FALL OCCURRED DURING THE LATTER PART OF APRIL 1969.

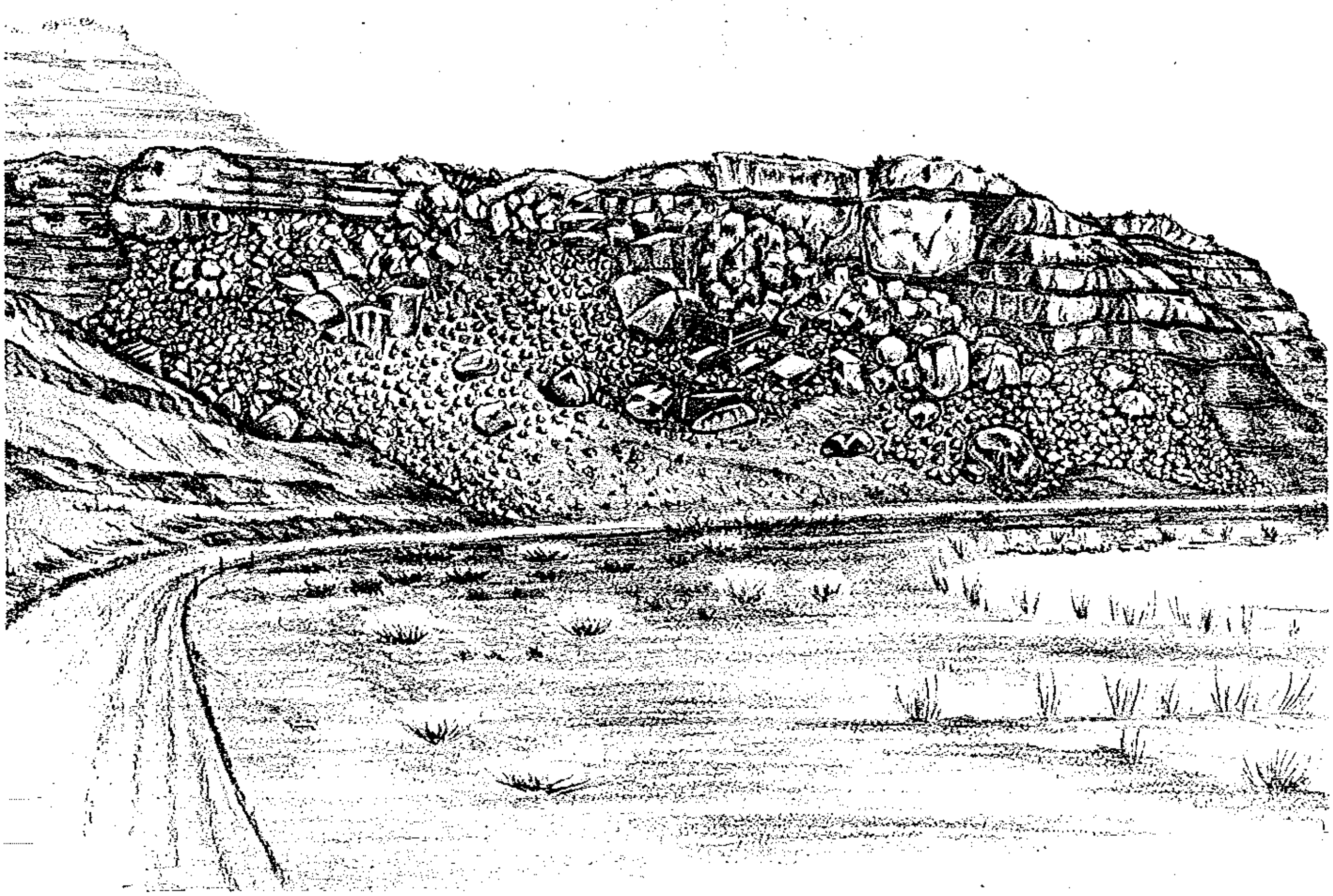


FIGURE 63. VIEW OF DEBEQUE CANYON, COLORADO LANDSLIDE, SHOWING FEATURES OF SLOPE INSTABILITY IN THE CANYON. INTERSTATE HIGHWAY 70 IS SHOWN EXTENDING FROM THE LOWER LEFT-HAND CORNER ACROSS THE TOE OF THE SLIDE. THE COLORADO RIVER IS BELOW THE HIGHWAY TO THE RIGHT OF CENTER.

THE RIM ROCK COLLAPSE IS BELIEVED TO HAVE TAKEN PLACE IN 1929. THE SLIDE CONTINUES TO BE A HAZARD, AS IT IS A SOURCE OF ROCK FALLS ONTO THE HIGHWAY AND A CHRONIC HIGHWAY MAINTENANCE PROBLEM. COMPARE THIS FIGURE WITH FIGURE 64.

FIGURE 64. DEBEQUE SLIDE TAKEN FROM AN AERIAL PHOTOGRAPH. COMPARE WITH FIGURE 63.

FIGURE 65. A ROCKFALL AT THE EAST END OF DEBEQUE CANYON DURING EARLY 1969.

tinuously west to a point just east of the town of Palisade. There are no residences in the main portion of the canyon. Two diversion dams are present in the western portion of the canyon. A steam power plant is located at Cameo, and several coal mines are operating in the vicinity. There is a network of active and abandoned canals in the western portion of the canyon, and some residences in wide portions of the canyon between Cameo and Palisade. A restaurant-gas station-garage which operates the year round is located in the vicinity of Cameo. With the exception of the highway, railroad, and canals, the remaining structures were considered to be relatively free from the normal small-scale rockfall hazard. The highway could become impassable as a consequence of rockfalls or slides in the canyon.

Plateau Valley - Rockfalls are a particular hazard in Plateau Canyon along State Highway 65 from the confluence at the Colorado River east to the vicinity of the Mesa road fork with State Highway 330. Several large slump-type landslides and canyon wall collapses have also occurred in this reach of the valley since paved roads were built. The western half of the area contains a few ranches, several of which could be damaged by rockfalls because of their proximity to the valley walls. It was concluded that a remote possibility of hazard to personnel occupying these ranches might result from the RULISON event. Therefore, it was recommended that personnel living on Highway 65 at locations 2 kilometers east, 4 kilometers east, and 5 kilometers east of the intersection of Highway 65 and I-70 be evacuated.

The portion of Plateau Valley extending along State Highway 330 to the town of Collbran and beyond to Vega Dam showed evidence of many flow slides and slumps which have taken place in silt and clay shale beds in and at the base of the valley walls within the past few decades. There are also numerous landslides and block slump areas adjacent to Plateau Creek in the vicinity of Collbran. These have occurred in silt and clay shale bluffs undercut by the creek. Structures in portions of Plateau Valley east of the fork with State Highway 65 are for the most part relatively free from rockfall hazards.

A remote hazard to structures by flooding would exist if Plateau Creek should be dammed by a massive slump or slide. This has taken place in the past at several localities, and Plateau Creek is currently in danger of being blocked through natural sliding. Minor slides and rockfalls were remotely possible; however, it appeared unlikely that the proper combination of circumstances would occur to cause damming of the creek.

Collbran-Silt Road - An improved road extends along a tributary valley from Plateau Creek east of Collbran over a drainage divide north along Snake Creek and Reservoir Creek to the town of Silt which is located on the north side of the Colorado River on Interstate 70 (US 6/24). The area between Plateau Creek and the confluence of Snake Creek and Reservoir Creek contains many slumps and flows, several of which are active. The valley bottom is occupied by ranch houses and summer homes. This area is relatively free from rockfalls but subject to flooding from damming of the creek bed by flows and slides. This occurrence, however, was believed unlikely to occur as a consequence of RULISON ground motion. The area north of the confluence of Snake and Reservoir Creeks is relatively free of hazards from slope failures.

Parachute Creek - Rockfalls occur frequently at many locations along the valley formed by Parachute Creek. The confluence of the creek with the Colorado River is just west of the town of Grand Valley. The creek extends in a northwest direction through the Roan Cliffs, then turns north to slightly northeast where several forks draining the Roan Plateau join the trunk stream.

An extensive oil shale development has been constructed at the confluence of the trunk stream and its various forks. One such facility is referred to as TOSCO (The Oil Shale Corporation).

Natural rockfalls are a constant hazard to personnel, and have, on several occasions, damaged and destroyed company structures. The operators were well aware of the hazards and expressed a willingness to cooperate during the RULISON event. It was recommended that the facility be evacuated and all persons removed to areas free of rockfall hazard during the event.

The Union Oil facility, located on Parachute Creek south of the TOSCO facility, has several metal storage buildings, but is generally inoperative. While rockfalls were possible, there did not appear to be any particular hazard to personnel or facilities as a result of the RULISON event.

The Parachute Creek area towards Grand Valley contains several ranch houses and the access road to TOSCO. The ranch houses are situated towards the center of the valley formed by the trunk of Parachute Creek; however, the road, for the most part, is at the extreme eastern edge of the valley below the canyon rim and is exposed to rockfalls. It was recommended that travel on this road be restricted during event time.

Interstate 70 from Grand Hogback to Dotsero - Large portions of I-70 and the Denver and Rio Grande Railroad from a point 8 kilometers east of Silt, extending east through New Castle and Glenwood Springs to Dotsero, are normally subject to rockfalls, flow and slump type landslides. Rockfalls and landslides along bedding planes and joint surfaces are also frequent. A number of such failures occur during any one year.

The Roaring Fork River, extending for some distance southeastward from its confluence with the Colorado River at Glenwood Springs, is subject to similar slope stability problems. No closure was recommended however because of the lack of any serious hazard to persons.

Denver and Rio Grande Railroad (D&RG RR) - In addition to portions of the D&RG RR previously discussed, the following locations were designated by the Division Civil Engineer as chronic landslide and rockfall areas:

(1) Niger Hill - 9.7 kilometers east of DeBeque

(2) Webster Hill - 6.4 kilometers west of Rifle. This portion of the track was scheduled for relocation. Construction started in late May 1969. (Figure 66).

(3) Track which had recently been relocated from the north to the south side of the Colorado River immediately west of Glenwood Springs parallel to I-70. In view of the expected dry condition of slopes at shot time no particular hazard from slope instability was expected as a result of the RULISON event.

Grand Hogback at Rifle Gap and Harvey Gap Dams - Numerous old landslides were noted adjacent to the left abutment at Harvey Gap Dam as well as rockfalls and landslides downstream from the facility along the canyon walls southward to the Colorado River Valley. The dam and reservoir did not appear to be hazarded by these slides; however, the road and coal mine structures in the canyon through the Grand Hogback were vulnerable to both rockfalls and landsliding. The same observations applied to the road through Rifle Gap, which contains no other structures. However, recently relocated portions of the roads up East Rifle Creek (State Highway 325) and West Rifle Creek were slumping toward the reservoir, and recommendations were made that adjacent land and water areas be kept clear of persons at shot time. See Figures 67 and 68 of Rifle Gap Dam.

Mine Dumps - Mine dumps and tailings piles in the area are un-

FIGURE 66. WEBSTER HILL CUT-SLOPES FOR THE DENVER AND RIO GRANDE RAILROAD RELOCATION. THIS PHOTOGRAPH WAS TAKEN A FEW DAYS BEFORE DETONATION.

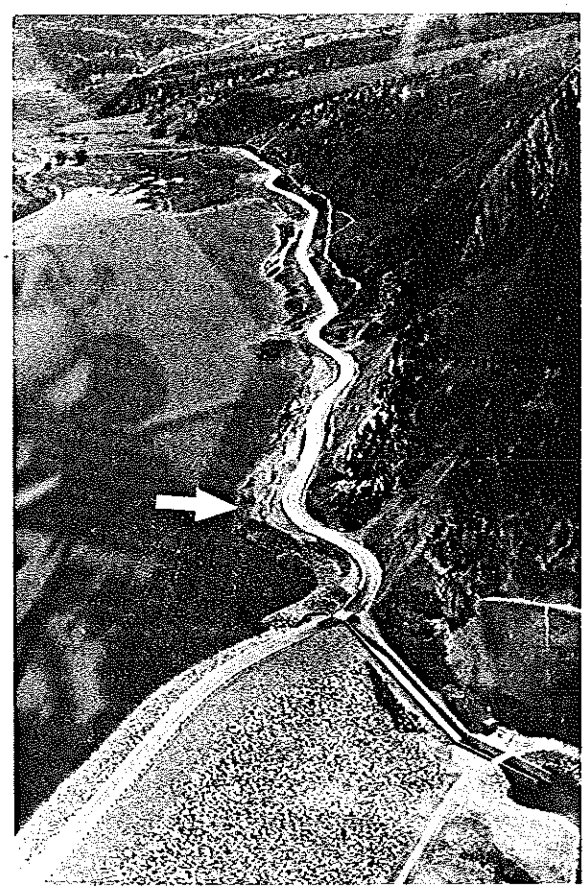


FIGURE 67. RIFLE GAP DAM AND RESERVOIR SHOWING RELOCATED STATE HIGHWAY 325. THE POINTER INDICATES THE AREA OF FIGURE 68.

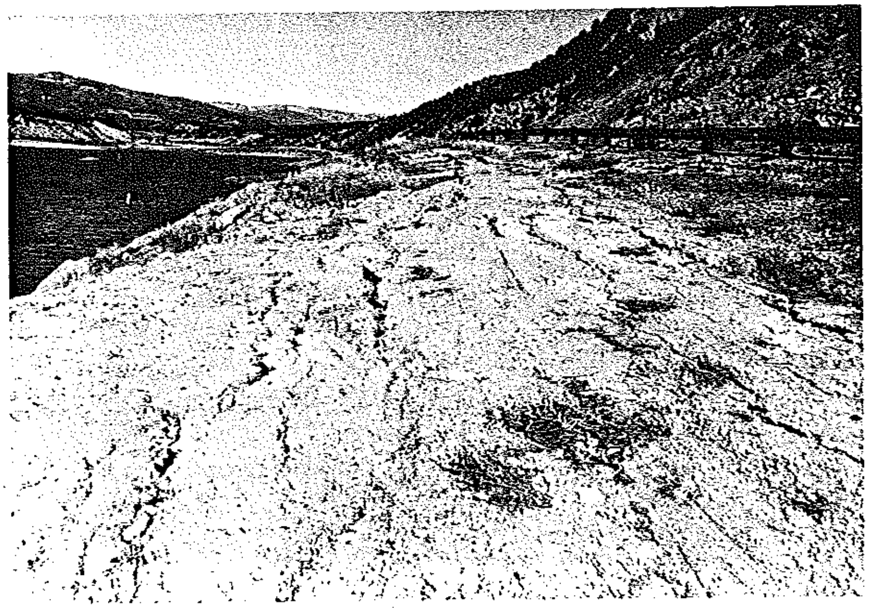


FIGURE 68. AN AREA BETWEEN RELOCATED STATE HIGHWAY 325 AND RIFLE GAP RESERVOIR THAT SHOWS DISTRESS. SEE FIGURE 67 AND SLUMPING CAN BE OBSERVED.

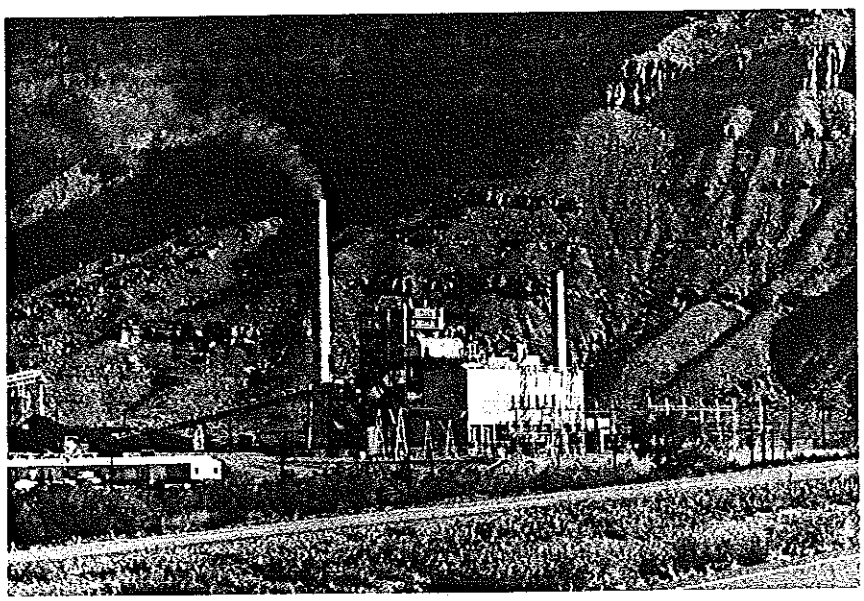


FIGURE 69. CAMEO PLANT WITH A STRUCTURAL FRAME OF REINFORCED CONCRETE AND STEEL. BOTH STACKS ARE OF REINFORCED CONCRETE. ONE STACK IS 150 FEET AND THE OTHER IS 200 FEET HIGH.

stable and have a history of failure under normal load conditions. Dynamic loading, as for instance from RULISON ground motion, possibly could increase the instability of such earth structures. The region involved extends to perhaps no more than 25 kilometers from GZ. No particular hazard to persons existed; it was planned that all mines would be closed during the RULISON event, which further reduced any probability of hazard to persons.

Utilities

Some concern was expressed for turbines and substations associated with the Cameo Plant. (Figure 69). No effect from the RULISON ground motion was expected. It was possible that some temporary power outages might occur if the swaying motion caused uninsulated pole-mounted lines to swing together. However, it seemed unlikely that such problems would not have already arisen, and been solved, as a consequence of the same kinds of motion from high winds. Operating personnel were contacted with regard to ground motion and its possible effect on minor equipment housed in substation buildings and were advised of adequate preparation measures, to be implemented at shot time. The supervisor's panel in the Grand Valley Substation was braced by Public Service Company, prior to the event.

Water Wave Studies

A non-recording float gage to measure seiche or surge was installed in Rifle Gap Reservoir at a point approximately 0.6 mile west of the right abutment of the dam. The instrument was manned by a JAB observer. Computations were made of the surface wave that would be generated, based on our pre-shot predictions of the ground motion response in the dam and reservoir area. Computed wave amplitude was 3.0 cm based on a fundamental period for the dam of 0.31 seconds, average acceleration of 0.10g, and horizontal particle velocity of 4.6 cm/sec. The observed amplitude of the surface wave of translation was 3.3 cm.

V. STRUCTURAL EFFECTS

PERCEPTION OBSERVATIONS

During the event, observers were stationed at specific locations surrounding ground zero to record their perception of motion resulting from the detonation and to provide immediate observations of any damage which might be sustained by the structures at those locations. It should be noted that people will perceive ground motion at levels well below those that will cause damage.

Observers indicated their perception to ground motion using the following criteria.

Perceptibility Observation Criteria

I. *Not felt.*

II. *Questionable.*

III. *Felt - Direction of motion uncertain. Non-observers do not notice or question.*

IV. *Felt - Observers can assign at least one plane of motion. Noticed by some observers.*

V. *Felt distinctly - Observer can define directions of motion with clarity. Most non-observers at rest will feel or react to the motion.*

VI. *Felt by all - Sense of balance affected. Non-observers may exaggerate reports of motion experienced.*

In the vicinity of ground zero the perception effect was a sharp, strong vertical motion. As the distance increased from ground zero, ground motion rapidly decreased.

At a point 5 kilometers northwest of ground zero (inventory location number G-046) a perception of VI was reported. This location was the nearest observer station to ground zero. The motion felt was primarily vertical with a very minor horizontal motion. The vertical component was probably about one-half inch, causing a lantern to fall from a hook. A hanging pot on a 3-foot-long chain did not swing, confirming the lack of horizontal motion at its frequency. There were paint flecks on the floor beneath the first floor windows and in an upstairs bedroom at the wall corners. A large bottle of hand lotion fell from a shelf. There was no other observable damage.

A perception of V was assigned by an observer 7 kilometers north-northwest of ground zero (inventory location number G-110). The motion was felt as a quick roll, up then down. The ground seemed to shake quite a bit after the initial shock. No distinct second shock was felt. It was hard to determine vertical displacement, but it was probably about an inch. Two dogs owned by the tenant were quite disturbed for a few moments following the initial shock. The tenant at the location assigned a VI for perceptibility. He said he felt as if he were lifted about 9 inches and dropped. A third person at this location gave a IV perceptibility and reported that a rock slide occurred south of the location and halfway up the hill. The ground could be seen rolling from the direction of ground zero, apparently raised several inches. The rolling motion was felt rather sharply.

A V perceptibility was assigned by the observer at a location 6 kilometers north of ground zero (inventory location number G-033). The motion was strongly felt at approximately 1500 + 6 seconds. The motion was mainly vertical with a north-south orientation, and the magnitude of the vertical component almost obscured the horizontal. Dust clouds were seen rising from the exposed cliff faces toward ground zero, and a few could be seen across the valley above the steeply eroded and exposed faces of the Roan Cliffs.

A perception of V was felt 6 kilometers west-northwest of ground zero (inventory location number G-052). The observer stood facing southeast toward ground zero, approximately 30 feet northwest of the house. He felt a very distinct and sharp vertical motion, almost as if being raised off the ground. The house appeared to move, which may have been an illusion caused by reflections in the windows. He heard glass and a loose storm door rattling. He did not feel any horizontal motion.

Another V perception report was made from a point 11 kilometers northwest of ground zero (inventory location number G-129). The motion was felt distinctly as two shocks with aftermotion for approximately 15 seconds. Walls appeared to move back and forth, and some dust was thrown into the air.

Observers at Anvil Points, about 13 kilometers north-northwest of ground zero, reported that shocks lasted approximately 10 seconds. All eight people in the area felt the motion distinctly. Dust was raised from the area just below the Roan Cliffs north of the Bureau of Mines installation. A perception of V was assigned to this location.

An observer 12 kilometers west-southwest of ground zero, (inventory location number M-001) gave a perceptibility report of VI. Here the motion was felt about 3 seconds after the shot from a southeast direction. The motion and sound seemed to arrive simultaneously. The motion was vertical with a duration of 12 seconds. A soft drink can fell off a fence post. Dust fell from the chimney's mortar joints. A window came open. Most of the cabinet doors came open. Plaster fell from old cracks. Cups were swinging on hooks. Some bric-a-brac fell or was moved. A clock stopped at 3 p.m. Dirt sifted from the roofs of root cellars. All sealing wax patches on existing house cracks (to determine if movement occurred) were broken. A half-full can of linseed oil fell from a shelf. Trees swayed.

The observer located 12.5 kilometers south of ground zero (inventory location number 502-69-25) gave a perception report of V. It was reported that rock slides occurred north to northeast of the ranch house on talus slopes on Green River shale. The first motion was sharp, followed by a rolling motion in a north-northeast to south-southwest direction. The observations were made while standing next to an automobile.

At the Union Carbide plant near Rifle, 18 kilometers northeast of ground zero, a V perceptibility was reported. The motion was felt almost immediately. It was a strongly perceptible impact-type motion of relatively short duration -- 5 to 10 seconds at most. The motion seemed to be predominantly vertical. Guards over kiln bullgear and thermocouple sliprings vibrated noticeably. Lights on gooseneck stands stayed in visible motion the longest. A Sprengnether blastmeter installed to record ground motion showed normal traces after 20 to 30 seconds.

At a location of 18 kilometers south of ground zero (inventory location number M-200) a IV perceptibility report was made. The following was recorded:

Shot time :	1500 MDT
1st arrival:	6 sec
Description:	1 to 2 cycles
2nd arrival:	12 sec
Pendulum 1 :	0.4 sec
Pendulum 2 :	1.0 sec

Both pendulums were too long to measure motion.

COMPARISON OF PREDICTED AND ACTUAL EFFECTS

General

The JAB pre-shot predictions of damage occurrence were quite accurate. Damage of the type predicted usually occurred at the locations expected.

Table 9 presents a comparison of damage predictions and actual effects. This table is related to the ERC-predicted PSRV spectra at the design yield of 40 kt.

Instances of falling masonry in Grand Valley indicate that our recommendation to the AEC Director of Nuclear Operations that people be evacuated from the area or outside of the house and two building heights away from the house was well advised, as was the pre-shot removal or rebuilding of 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. (See Figure 70). As with chimneys in most old homes in rural areas, many of these chimneys are unlined. 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. (See Figures 71 and 72).

Structural Response

Within 7.4 Kilometers of GZ - The peak horizontal ground motion within 7.4 km of GZ was predicted to be in excess of 0.30g for the maximum credible yield of 60 kilotons. Depending on the location, the actual values of peak horizontal ground motion did exceed 0.30g.

A comparison of the records for the Eames Orchard and the Lemon Ranch, both within 7.4 km, shows that the periods of the peak motions are similar. The difference in motions is however appreciable, particularly for the vertical component.

TABLE 9

COMPARISON OF DAMAGE PREDICTIONS AND ACTUAL EFFECTS

(Based on ERC-predicted PSRV at design yield of 40.0 kilotons)

Name	Approximate Distance & Direction From GZ (km)	Predicted Effect	Actual Effect
Rulison	9 N	Moderate damage	Minor to moderate damage
Grand Valley	10 NW	Moderate damage	Minor to moderate damage
Anvil Points	13 N	Moderate to minor damage	Possible minor road damage
Microwave	14 NW	No damage	No damage
Ranches	14-18 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
DeBeque	23 SW	Minor damage	Minor damage
TOSCO	29 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	Slight damage
Mesa	32 SW	Minor damage	Minor damage
Harvey Gap Dam	32 NE	No prediction	No damage
New Castle	40 NE	No damage	No damage
Glenwood Springs	56 E	No damage	No damage
Grand Junction	65 SW	No damage	Minor claim
Delta	75 S	No damage	No damage

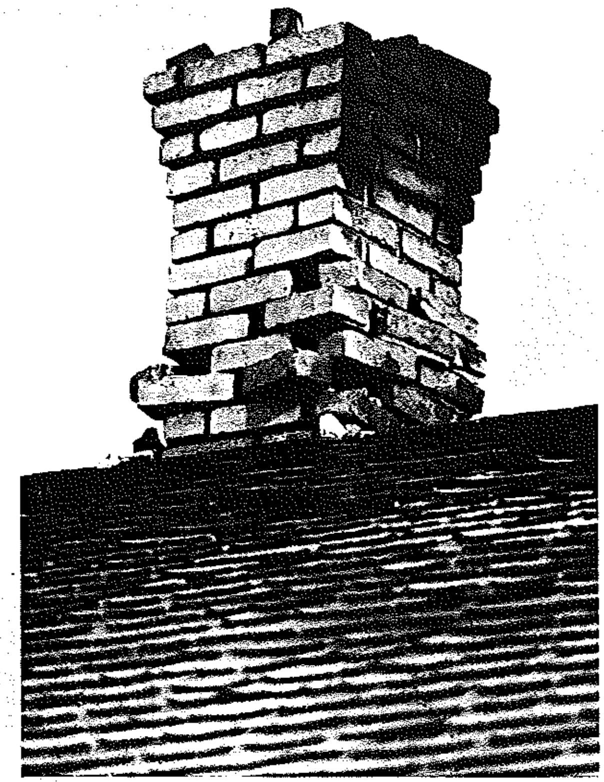


FIGURE 70. Cap bricks have fallen from this chimney. This chimney also appears to have rotated.

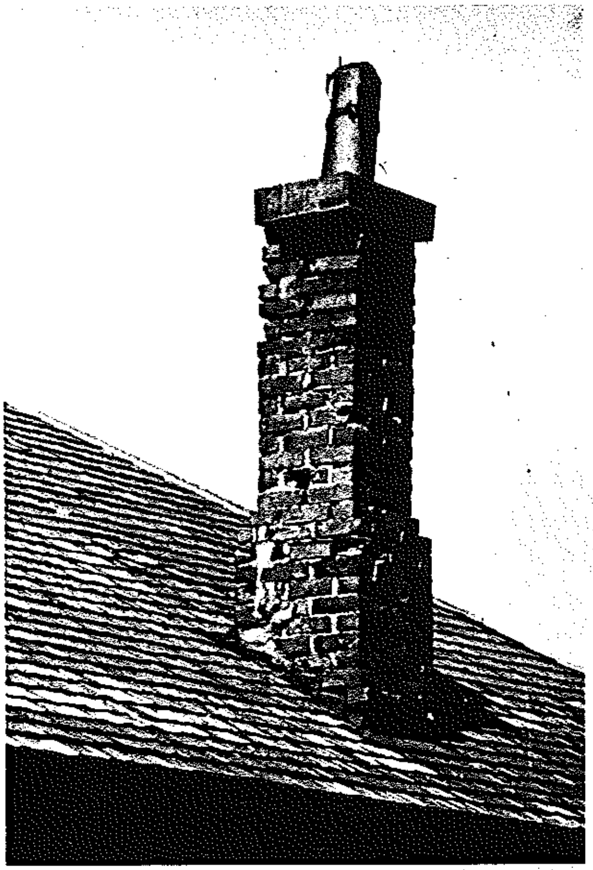


FIGURE 71.

The pre-event condition of this chimney indicates mortar deterioration and patching. Compare with Figure 72.

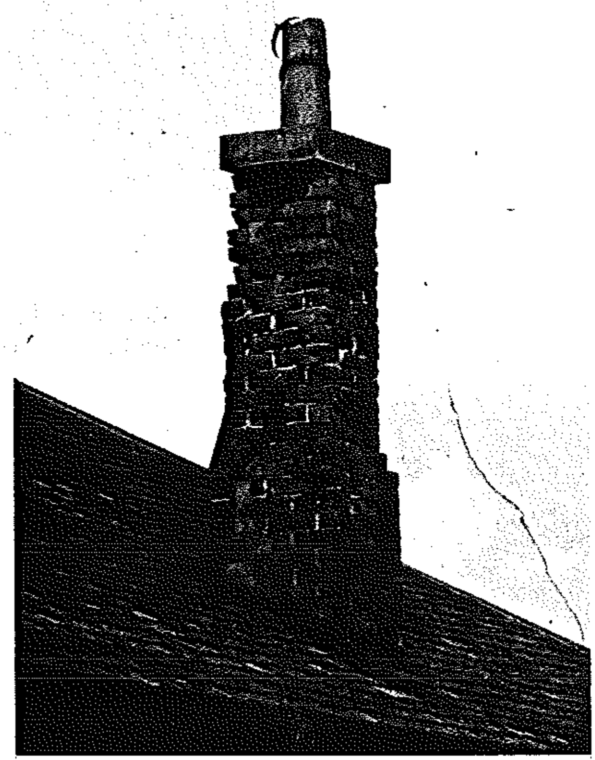


FIGURE 72. The post-event condition of this chimney shows that the chimney has moved because of ground motion. Compare with Figure 71.

Similar motion observations were reported at the Schwab Ranch, 6.4 km northwest of GZ, and at the Smith Ranch, 6.4 km northwest of GZ.

In the hills surrounding GZ some dust was raised on the slopes as a result of minor rockfalls and slides at close-in areas of Battlement Mesa. The observer at the Lemon Ranch reported a rock slide to the south of his location and halfway up the hill.

7.4 Kilometers to 14 Kilometers From GZ - The aggregation of structures called Rulison, the town of Grand Valley, the Anvil Points Research Station, and many small ranches on Morrisania, Holmes, Battlement, and Taughenbaugh Mesas are within the range of 7.4 to 14 km of GZ. There are also three steel truss bridges over the Colorado River at Grand Valley west of Grand Valley and at Rulison.

A comparison of the observers' reports of motion direction and intensity and actual damage shows the effect of the horizontal component of motion. Chimney damage and wall cracking occurring within the 7.4- to 14-km range appear to coincide closely with observer reports of strong perception in that area.

Beyond 14 Kilometers From GZ - Motion in the Rifle area (18 to 20 km) was strongly perceptible, predominantly vertical, and generally lasted from 20 to 30 seconds. At Collbran (18 km) the perceived motion was less intense but similar in direction. A review of ground motion data again confirms the motion perceptions and damage observations of the observers.

The TOSCO tower structure was instrumented for structural response with two horizontal component L-7 seismic instruments located at the southwest corner of the top full story of the tower. Three components of motion (2 horizontal, one vertical) were recorded on the ground 100' southwest of the structure and one vertical component was also located on the ground nearby.

A review of the paper copies of the recorded motion shows that the peak response of both structure and ground motion was at a period range of 0.25 to 0.30 seconds. The structure also responded at a period of roughly 1.0 seconds.

The 1.0+ second period response was approximately 0.8 cm/sec, which at a 1.0 second period results in a peak fundamental mode top story acceleration of 0.005g. This is about one half the predicted range 0.007g to 0.013g for maximum top story acceleration in the fundamental mode.

The 0.25 to 0.30 second period range appears to be either the 2nd or 3rd mode response or a combination thereof. The peak measured responses in this period range are approximately 7 cm/sec along the major axis and 3.5 cm/sec along the minor axis. The top story accelerations at this period range are calculated to be approximately 0.10 to 0.15g, or from 2 to 3 times the predicted values.

In summary, the 1st mode response was less than predicted and the 2nd and/or 3rd modes were greater than predicted. It appears that the 2nd and/or 3rd modes were the critical modes for the response of the TOSCO tower to the RULISON event, and that resultant stresses may have been in the range of standard allowable design code stresses.

If future events are planned which would result in ground motion equal or greater than RULISON, it would be advisable to make a detailed analysis of this structure and the RULISON structural response records. Such an analysis would require that the structural details of the structure, including the dead load weights be obtained, and would entail computer processing of the magnetic tape records obtained at the tower.

Rockfalls and Slides

Rockfalls resulting from the event-related ground motion were small in size and few in number. No extra efforts by highway maintenance personnel were required.

At New Castle there was a rockfall into an irrigation ditch 0.2 mile west of the Elk Creek Bridge on Highway 6/24 and 0.1 mile northwest of the highway. The rockfall was witnessed during the event. The area has had many rockfalls resulting from intensely fractured rocks upslope on the Grand Hogback. These rockfalls are a continual maintenance problem for this section.

Talus slopes developed from debris weathered out of the Green River shale showed minor movement throughout the area near the TOSCO installation in response to the event-generated ground motion.

Talus slopes undercut by the road in Parachute Canyon ravelled. Small quantities of talus debris and an occasional small block of Green River shale were reported at scattered areas of roads in the canyon.

Immediately following the event, a small rockfall was noticed on State Rt. 65 in Plateau Canyon. The occurrence of this rockfall was unobserved. It was known to have taken place within a time span of two hours around shot time. The area is one of frequent large and small rockfalls. This particular rockfall was easily cleared by maintenance crews and not reported to their supervisor until several days after the event.

Large blocks of rocks were observed rolling downslope in the vicinity of the Rifle Gap Reservoir. Several fragments fell on State Rt. 325 just east of the dam. Along the slope of the Grand Hogback west of the dam, rocks moved at two locations but did not reach downslope as far as the road.

No rockfalls were observed in DeBeque Canyon. Minor rockfalls and dust slides were observed on high points of Battlement Mesa and on the face of the Roan Cliffs.

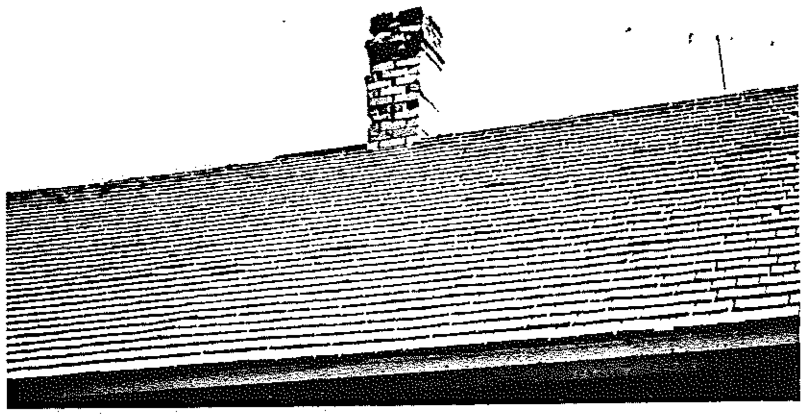
A case of incipient landsliding was examined on Buzzard Creek, 0.7 mile east of the Collbran Community Park and Arena. A crack in the slope on the north side of the creek was reported shortly after the event. This creek crossed a driveway which was traveled by the property owner just prior to and shortly after the event. The crack is more than 100 yards long and is located about halfway up the creek valley slope parallel to the bank. The width varies from a series of discontinuous parallel hairline openings to a single opening of 0.5 foot or more. Some vertical as well as horizontal component movement has resulted in an apparent tension-type crack more than 10 feet deep. The nature of the widespread hairline cracks implies that the plane of failure extends much deeper. Seepage was noted at the base of the area slightly above creek level. The bank area on both sides of the crack is also swampy and has the hummocky characteristics of old landslide areas.

Structure Damage

The data obtained from Project RULISON offers an opportunity to gain insight into the nature and cause of damage to buildings from event ground motion.

The damage to low-rise buildings from the RULISON event is of particular interest because of the applicability of the resulting data to effects prediction for similar future events. Project RULISON also provides the best and, to a large extent, the only example of real building damage in a populated area from an underground nuclear explosion. The only other instance of extensive minor damage, the SALMON event near Hattiesburg, Mississippi on October 22, 1964, was not well documented with respect to motion recording in Hattiesburg. Figures 73 through Figure 85 are examples of credible damage due to Project RULISON.

FIGURE 73. Chimney damage in Grand Valley, approximately 10 kilometers northwest of ground zero.



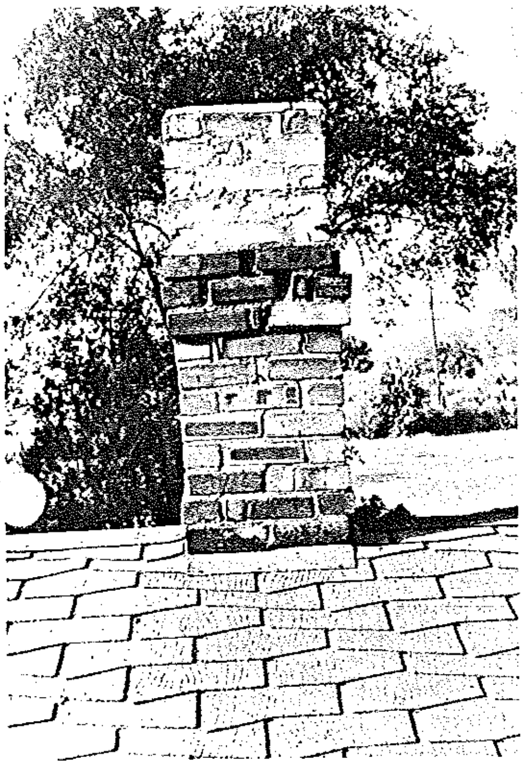


FIGURE 74. Damaged chimney near Grand Valley, showing deteriorated mortar damage.

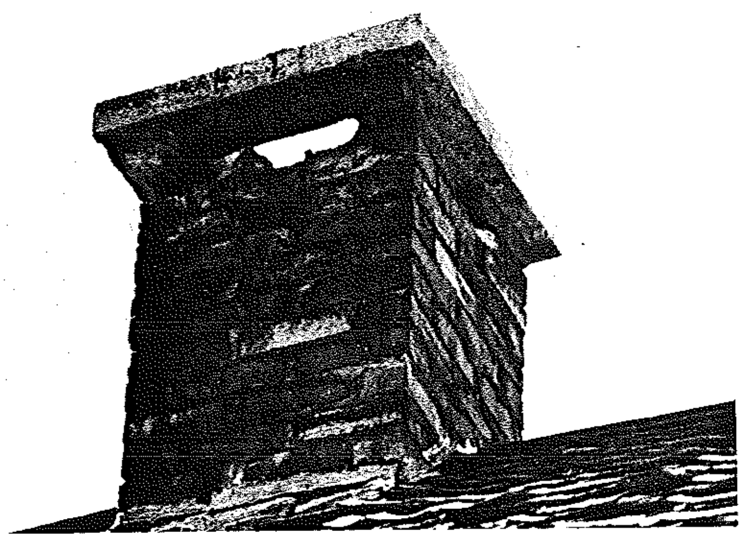


FIGURE 75. Chimney damage on Morrisania Mesa, indicating loose bricks that have fallen into the chimney.

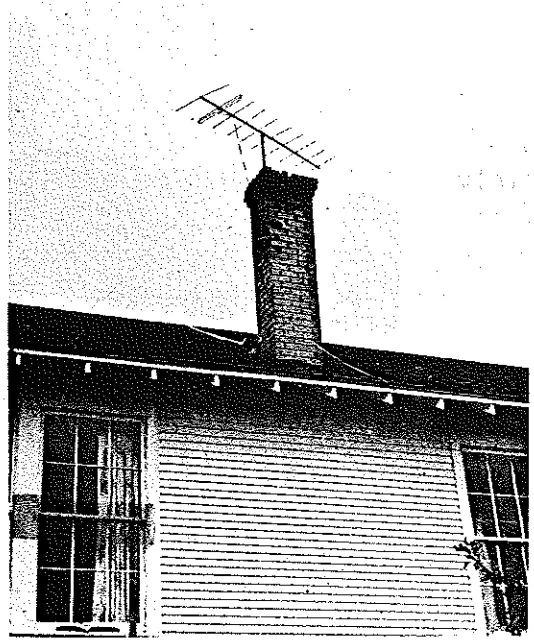


FIGURE 76. Chimney damage at Kansas Mesa south of Collbran.

FIGURE 77. Two chimneys displaying damage to the cap bricks. This location is in Rifle, approximately 20 kilometers northeast of ground zero.

FIGURE 78. Reworking of interior plaster crack at the wall-ceiling juncture.

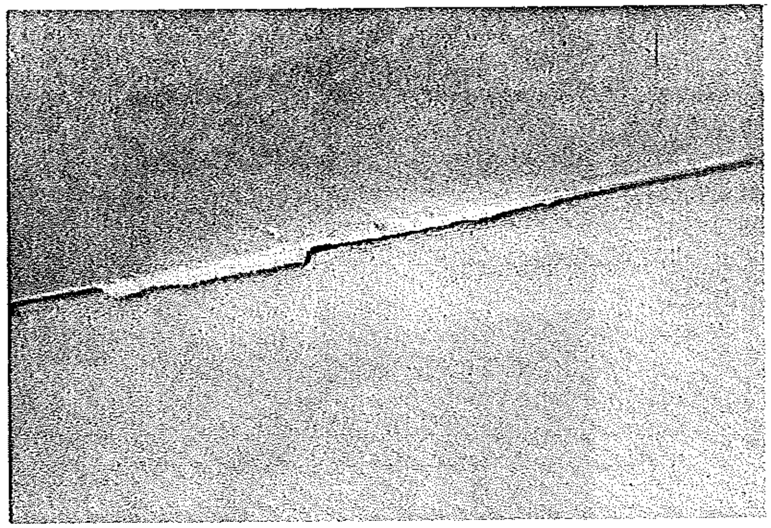


FIGURE 79. Interior plaster cracking and spalling at a door frame.

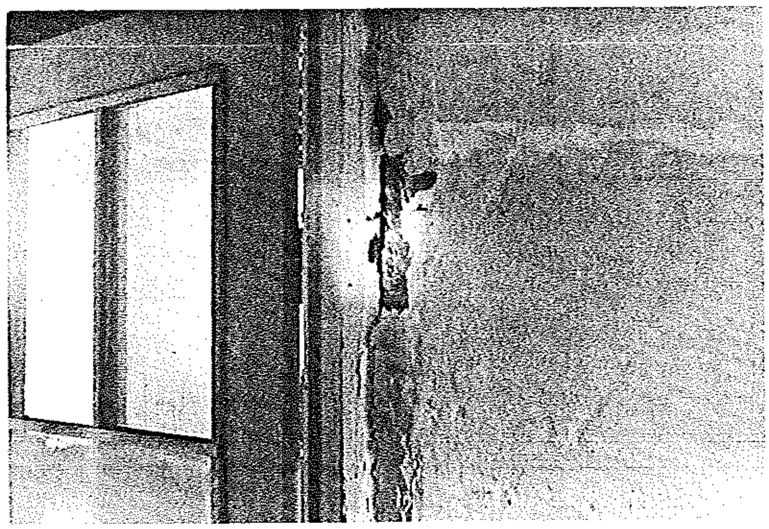


FIGURE 80. Interior plaster cracking of a partition wall.

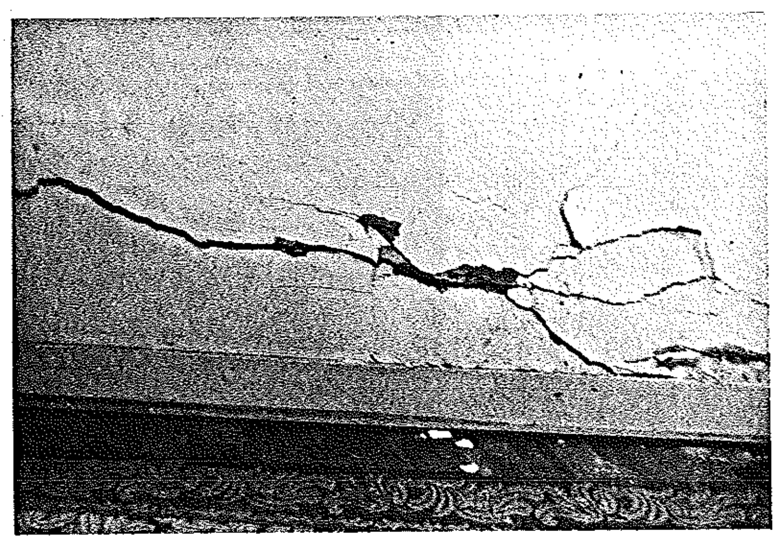


FIGURE 81. Reopened diagonal cracks on the interior wall of a stone house.

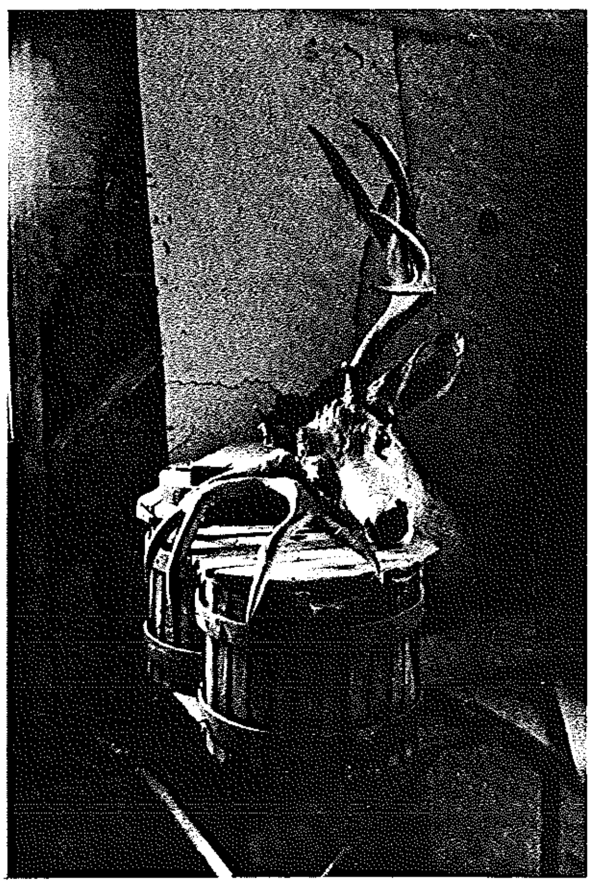


FIGURE 82. Damage also occurred to items that were hanging on walls and were displaced.

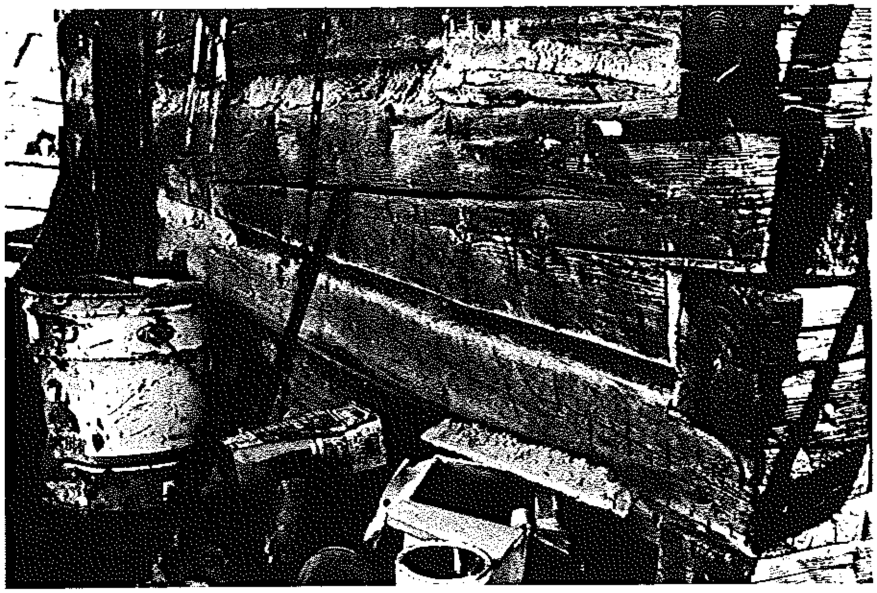


FIGURE 83. Within 1 kilometer of ground zero a log cabin had some chinking dislodged.

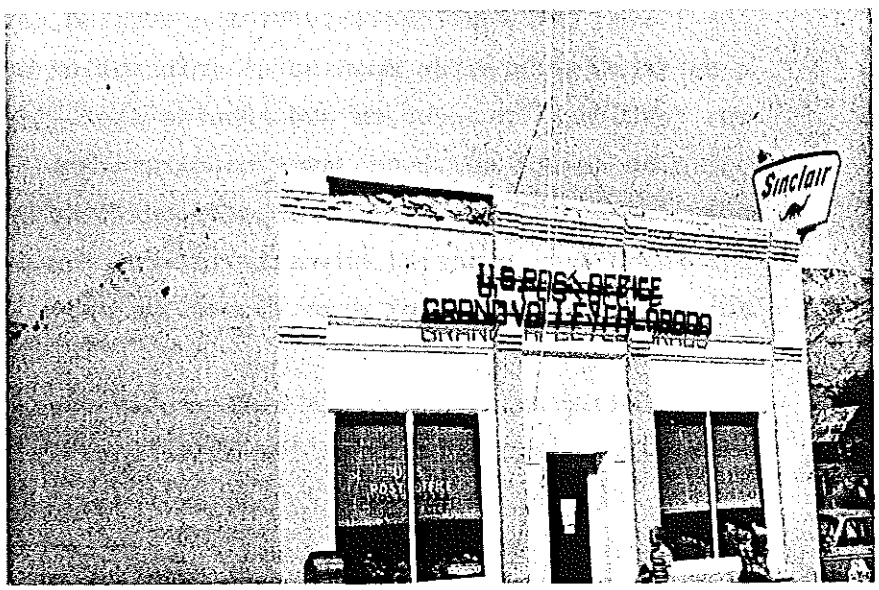


FIGURE 84. At Grand Valley the Post Office had brick damage to the parapet. For a pre-event comparison see Figure 49.

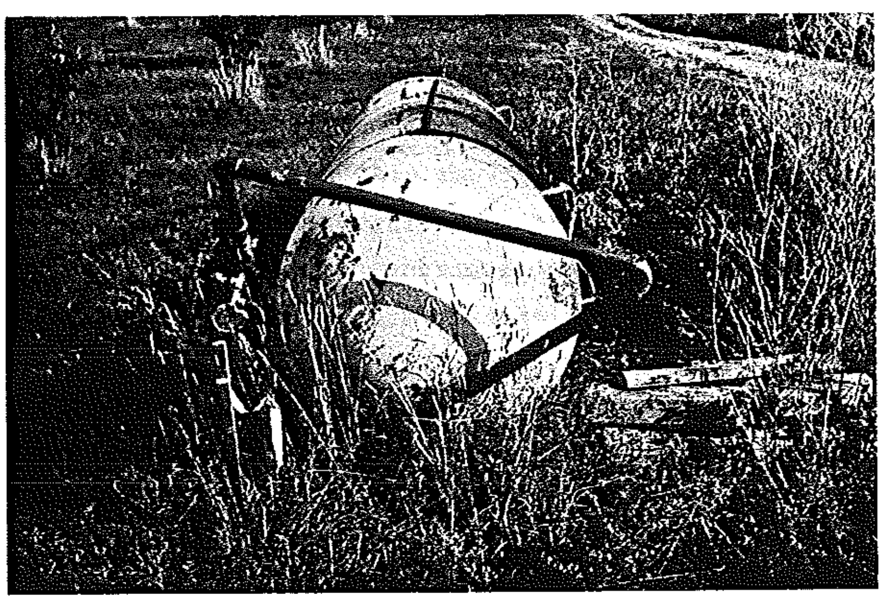


FIGURE 85. This figure shows a horizontal butane tank which was rolled over during the event.

In this report the following definitions are used:

> *Complaint - Any complaint made concerning property damage, whether or not formalized as a claim.*
>
> *Credible Damage Complaint - Any property damage complaint that has been defined as credible by JAB or GAB (General Adjustment Bureau) investigators, or one that has been paid.*

The limits and applicability of the RULISON data must be clearly understood to provide meaningful information and to avoid erroneous results. An accurate and precise statistical correlation of building damage and ground motion parameters requires comprehensive information, including a total building count in the area, the foundation material characteristics, the number of damaged buildings, the types of damage, and the applicable ground motion.

For the RULISON event, these criteria can be satisfied most practically by considering the five major towns in the area -- Grand Valley, DeBeque, Rifle, Silt, and Collbran. The damage complaint data included in this report are those received by March 31, 1970. Of the total property damage complaints received by that date, half of them were received from these five towns. The buildings in the towns represent a considerable percentage of the total building count for the RULISON area, and a significant amount of structure damage was claimed from these towns. For the purposes of analysis it is necessary also to assume that the one or two ground motion recordings obtained in a particular town can be applicable to the entire town. Damage patterns tend to substantiate this assumption.

A summary of ground motion data for the towns is presented in Table 10. The information in Table 10 includes peak vector ground motion acceleration, velocity, and displacement; the table also includes 5% damped response spectra peaks of acceleration (S_a), velocity (S_v), and displacement (S_d) for the period (T) range below 0.3 seconds (range of fundamental periods for low-rise structures).

Table 11 presents building counts and damage data for the period ending March 31, 1970. While later data are available, no further updating has been attempted since damage data were incomplete prior to September 10, 1970 and analysis of these data is still in progress.

Figures 86 through 93 show response spectra for Grand Valley, for 2 stations in DeBeque, for 3 locations in Rifle, and for stations in Silt and Collbran.

Figures 94 through 97 show graphically the relationship of peak vector ground acceleration and velocity to complaints (Figures 94 and 95) and credible damage complaints (Figures 96 and 97) with complaint data in the form of percent of building count. "Complaint" and "credible damage complaint" are defined earlier on page 138. Building count data are set forth in Chapter III and in Table 11. Although only a few data points are available for each plot and considerable scatter is seen, there is an indication of a direct relationship between motion amplitude and damage.

Figures 98 through 101 show the same relationships except that peak horizontal component spectral acceleration is used instead of peak vector ground acceleration (Figures 98 and 100), and peak horizontal component spectral velocity is used instead of peak vector ground velocity (Figures 99 and 101). Spectral acceleration and velocity peaks were taken from the period range below 0.3 seconds, since this period range includes the fundamental period of vibration for the great majority of RULISON structures. One more data point is available for each of these latter plots since

TABLE 10

PROJECT RULISON GROUND MOTION AND SPECTRAL MOTION

LOCATION	SLANT, RANGE, km	PEAK VECTOR GROUND MOTION A, Accelera-tion, g	V, Velocity cm/sec	D, Displace-ment, cm	PEAK HORIZONTAL COMPONENT SPECTRAL MOTION, 5% Damping, 0 to 0.3 Seconds Sa, Spectral Acceleration, g	Sv, Spectral Velocity cm/sec	Sd, Spectral Displacement, cm
Grand Valley	10.6	0.550	8.27	0.236	1.00	21.0	0.60
Rifle							
Union Carbide	18.0	0.174	3.57	0.139	0.50	8.3	0.14
Church	20.2	0.096	3.13	0.106	0.33	6.3	0.14
Top of Hill	20.2	0.137	3.77	0.410	0.21	5.0	0.22
De Beque							
Station #1	22.8	0.102	2.20	0.099	0.22	4.5	0.13
Station #2	22.8	0.162	4.68	0.206	0.43	10.3	0.40
Collbran	18.8				0.13 *	5.1 *	0.23 *
Silt (radial *compound*)	29.8	0.034	1.34	0.068	0.10	5.0	0.22

* Spectra based on short ground motion record (power failure 2.4 seconds after shot).

TABLE 11

BUILDING COUNT AND DAMAGE DATA (AS OF MARCH 31, 1970)

	BUILDING * COUNT	COMPLAINTS	PERCENT OF BUILDING COUNT	CREDIBLE DAMAGE COMPLAINTS	PERCENT OF BUILDING COUNT	TOTAL DOLLAR DAMAGE
Grand Valley	146	86	58.8	77	52.7	$ 15,044
Rifle	759	82	10.8	75	9.9	18,995
De Beque	102	13	12.7	6	5.9	1,320
Collbran	127	15	11.8	6	4.7	1,864
Silt	194	4	2.1	4	2.1	235

* Data from Section III. Note exclusions.

GRAND VALLEY, HARD ROCK, STATION R25, 10.6 KM

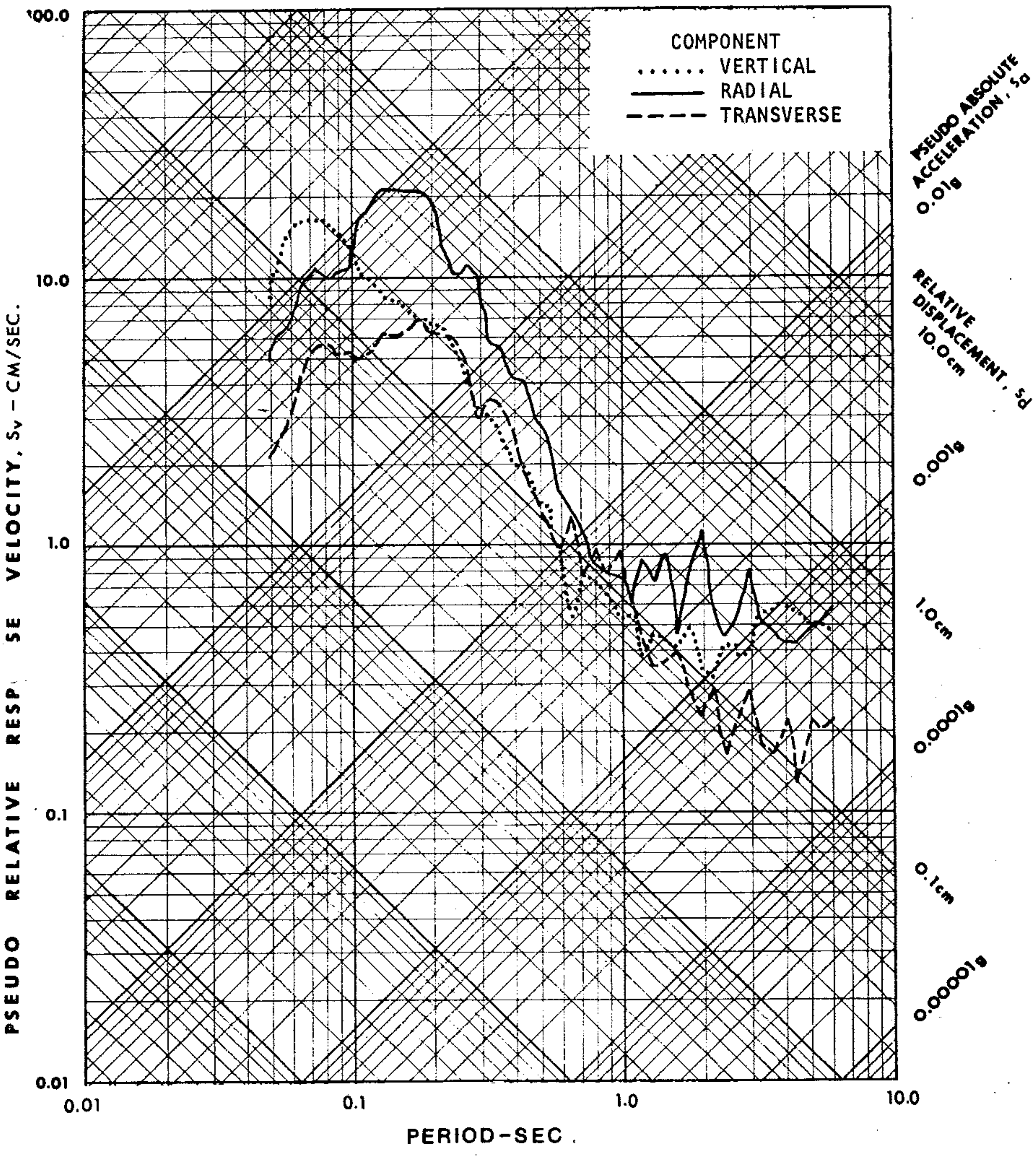


FIGURE 86. OBSERVED 5% S_V SPECTRA, RULISON EVENT[2]
(Source: NVO-1163-197[2])

DEBEQUE SCHOOL NO. 1 (100'), HARD ROCK
STATION R 12, 22.8 KM

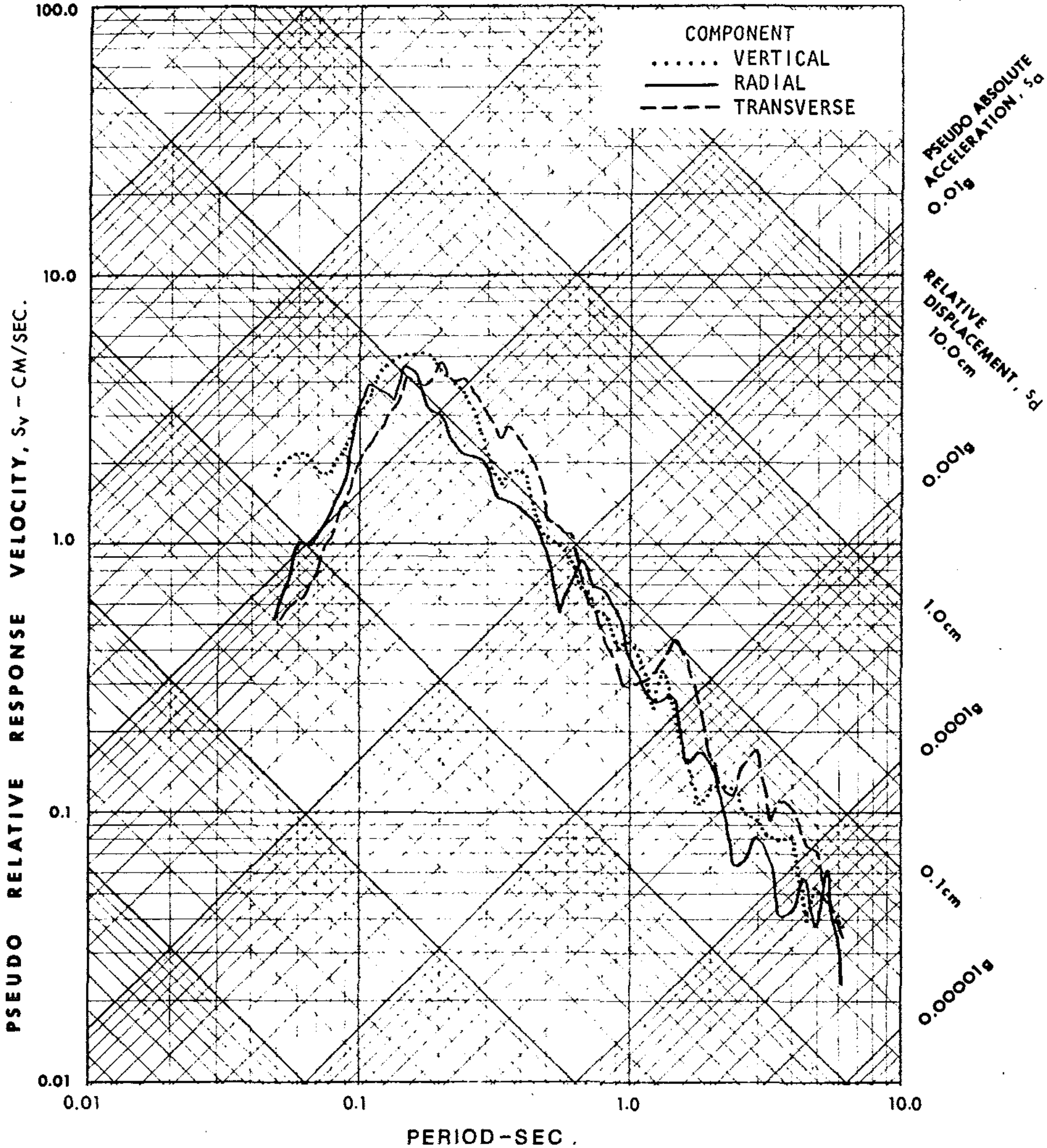


FIGURE 87. OBSERVED 5% S_V SPECTRA, RULISON EVENT[2]
(Source: NVO-1163-197[2])

DEBEQUE SCHOOL NO. 2 (1000'), HARD ROCK
STATION R 13, 22.8 KM

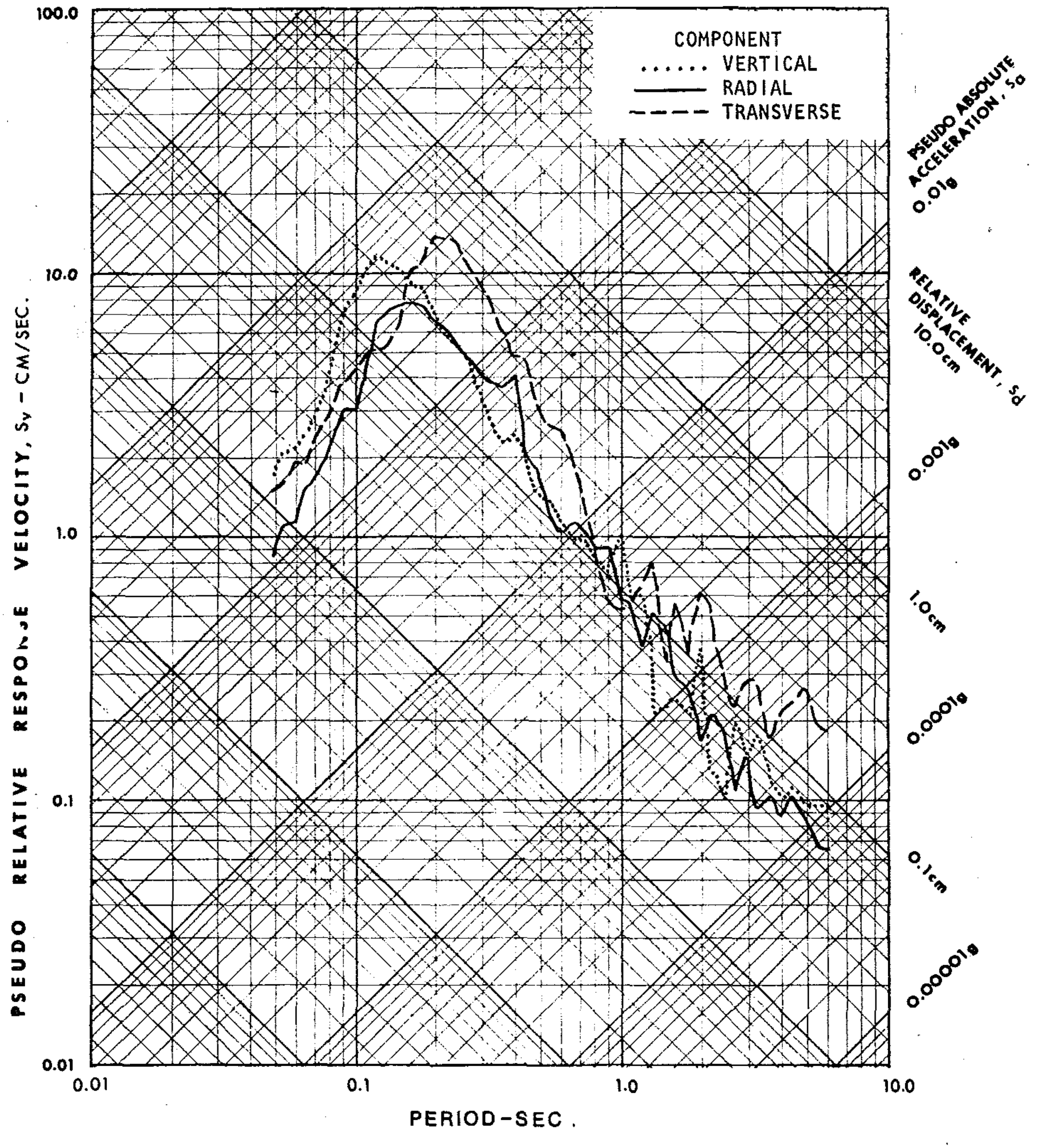


FIGURE 88. OBSERVED 5% S_V SPECTRA, RULISON EVENT(2)
(Source: NVO-1163-197(2))

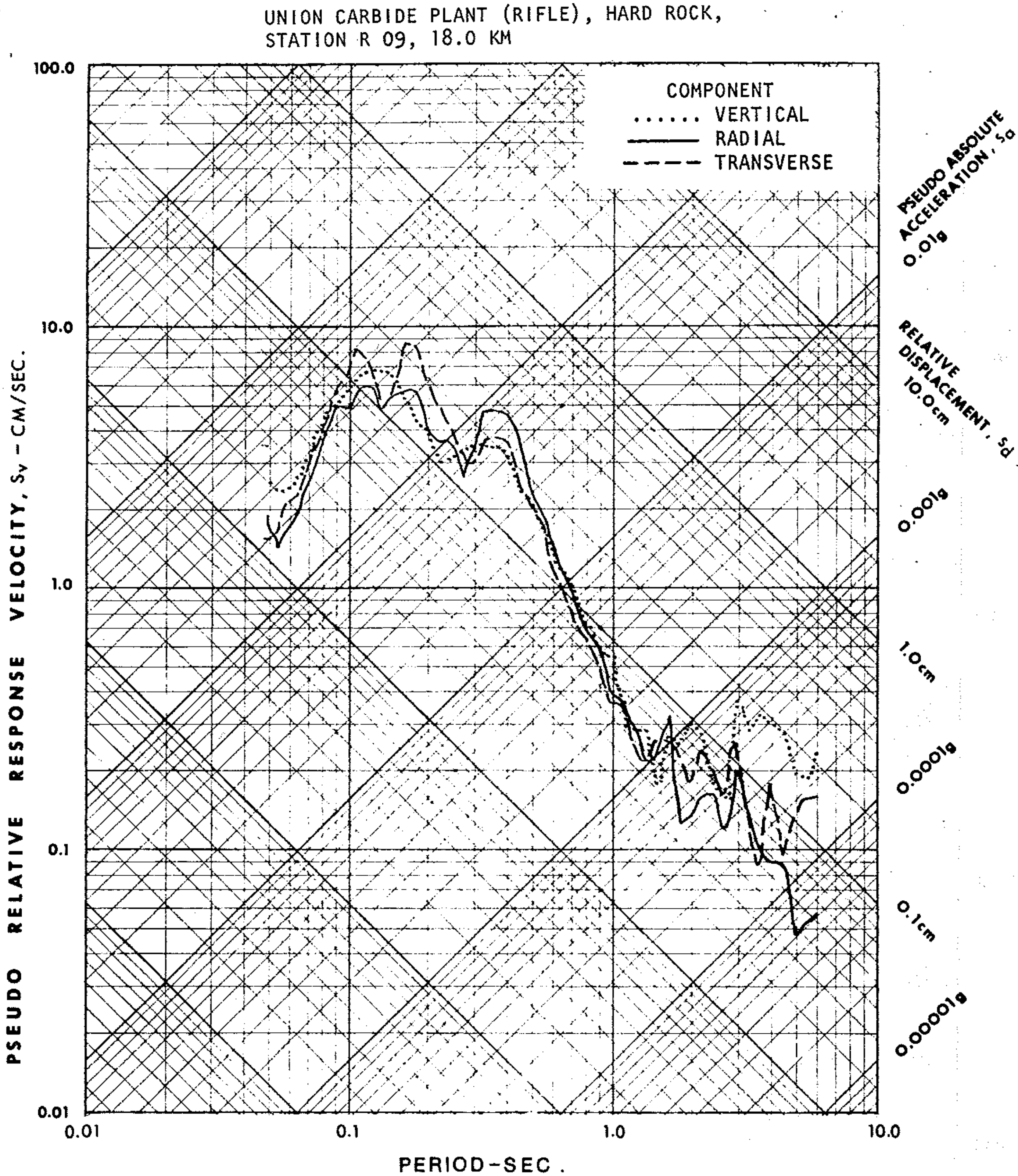


FIGURE 89. OBSERVED 5% S_V SPECTRA, RULISON EVENT (Source: NVO-1163-197[2])

RIFLE (TOP OF HILL), HARD ROCK,
STATION R 27, 20.2 KM

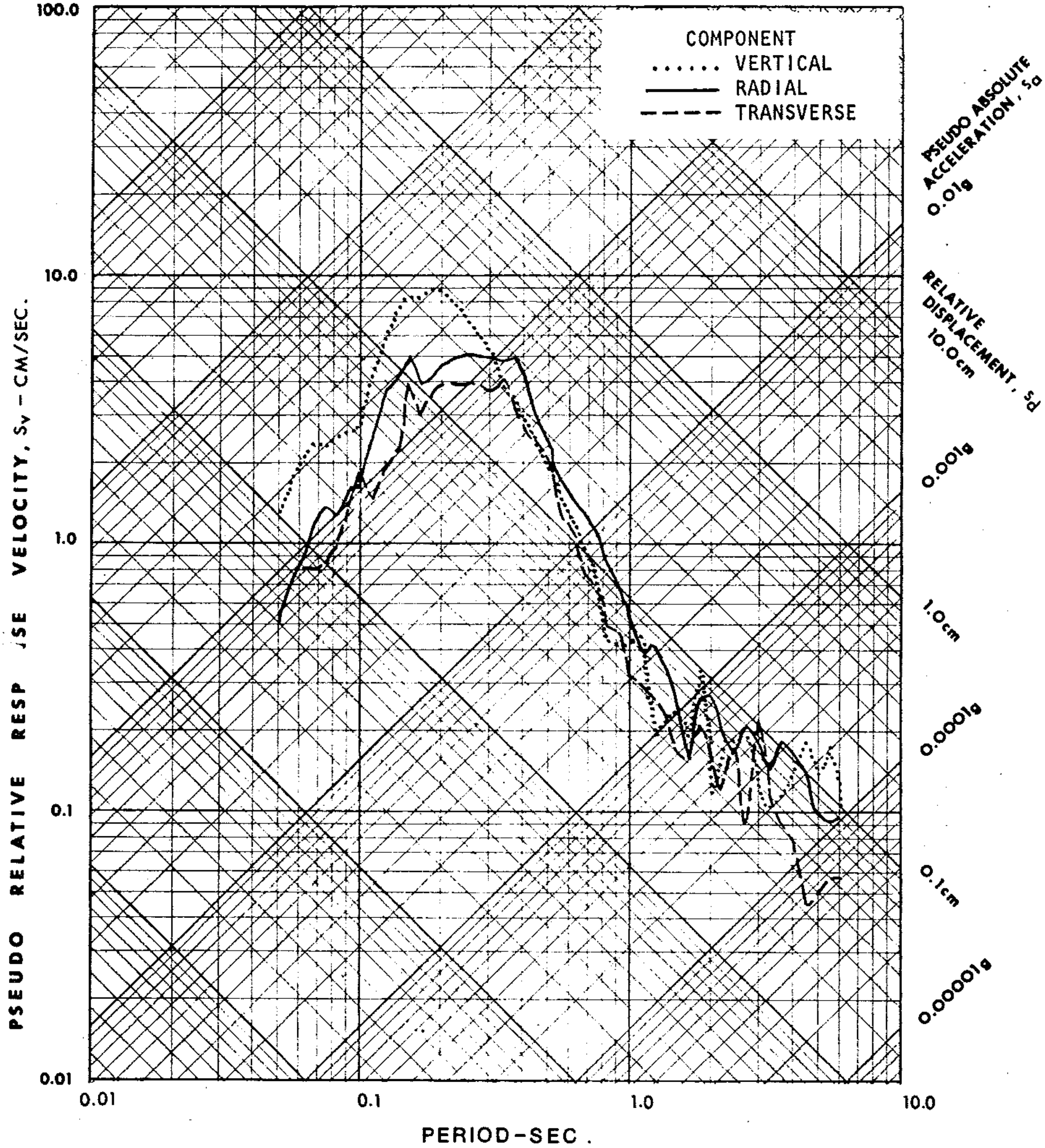


FIGURE 90. OBSERVED 5% S_V SPECTRA, RULISON EVENT (Source: NVO-1163-197[2])

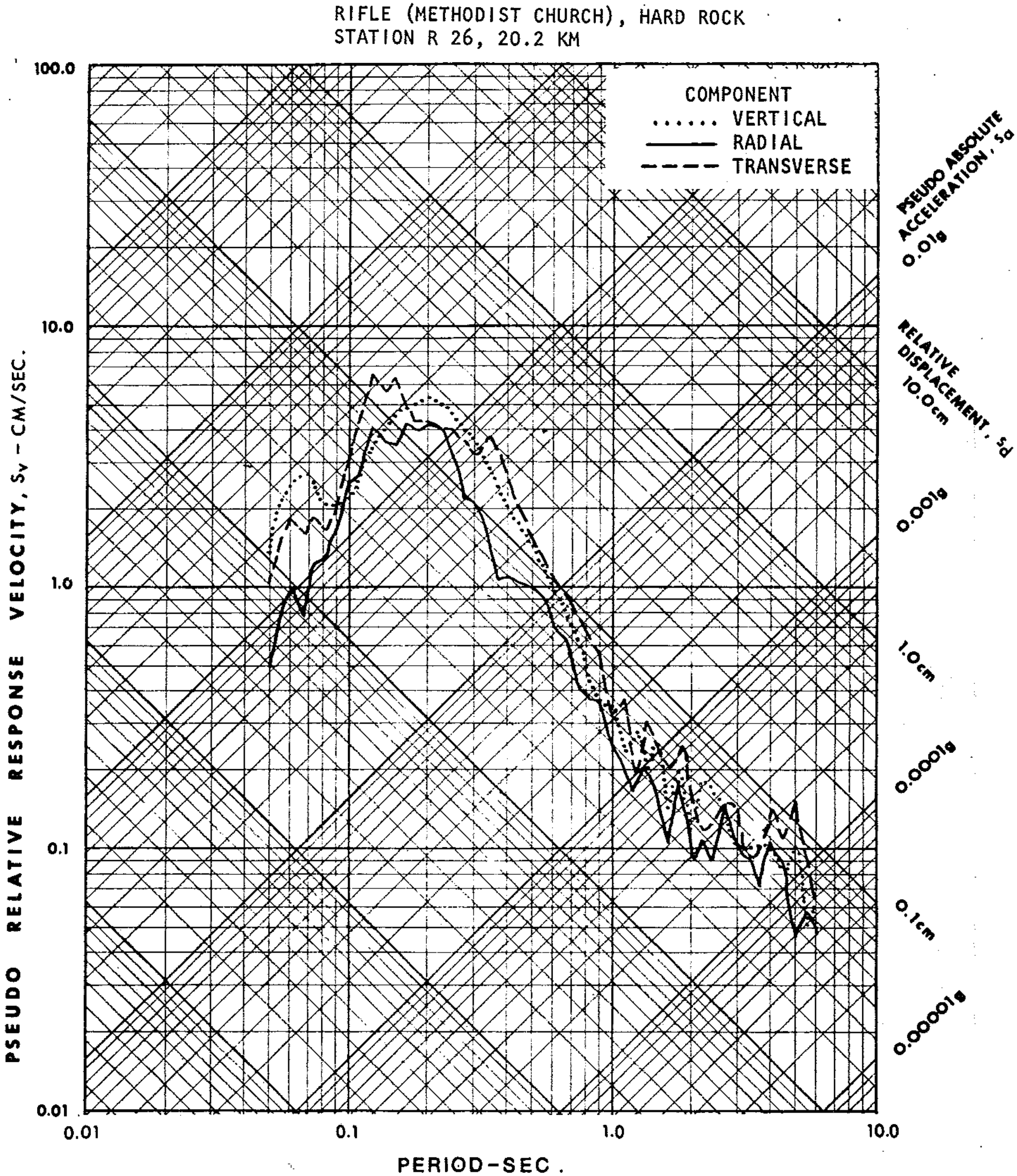


FIGURE 91. OBSERVED 5% S_V SPECTRA, RULISON EVENT (Source: NVO-1163-197[2])

SILT, HARD ROCK, STATION R 14, 29.8 KM

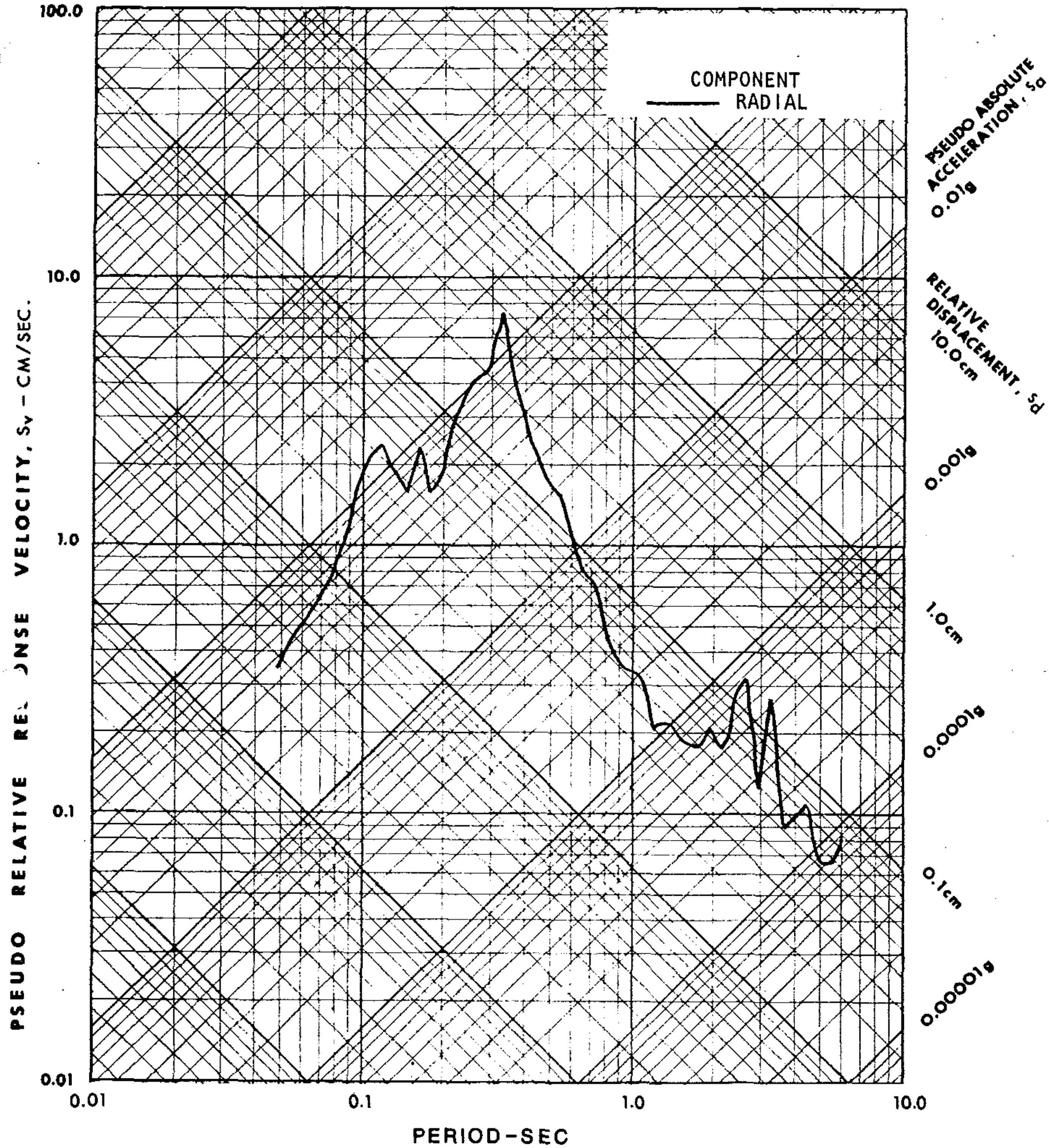


FIGURE 92. OBSERVED 5% S_v SPECTRUM, RULISON EVENT (Source: NVO-1163-197[2])

COLLBRAN, 18.8 KM

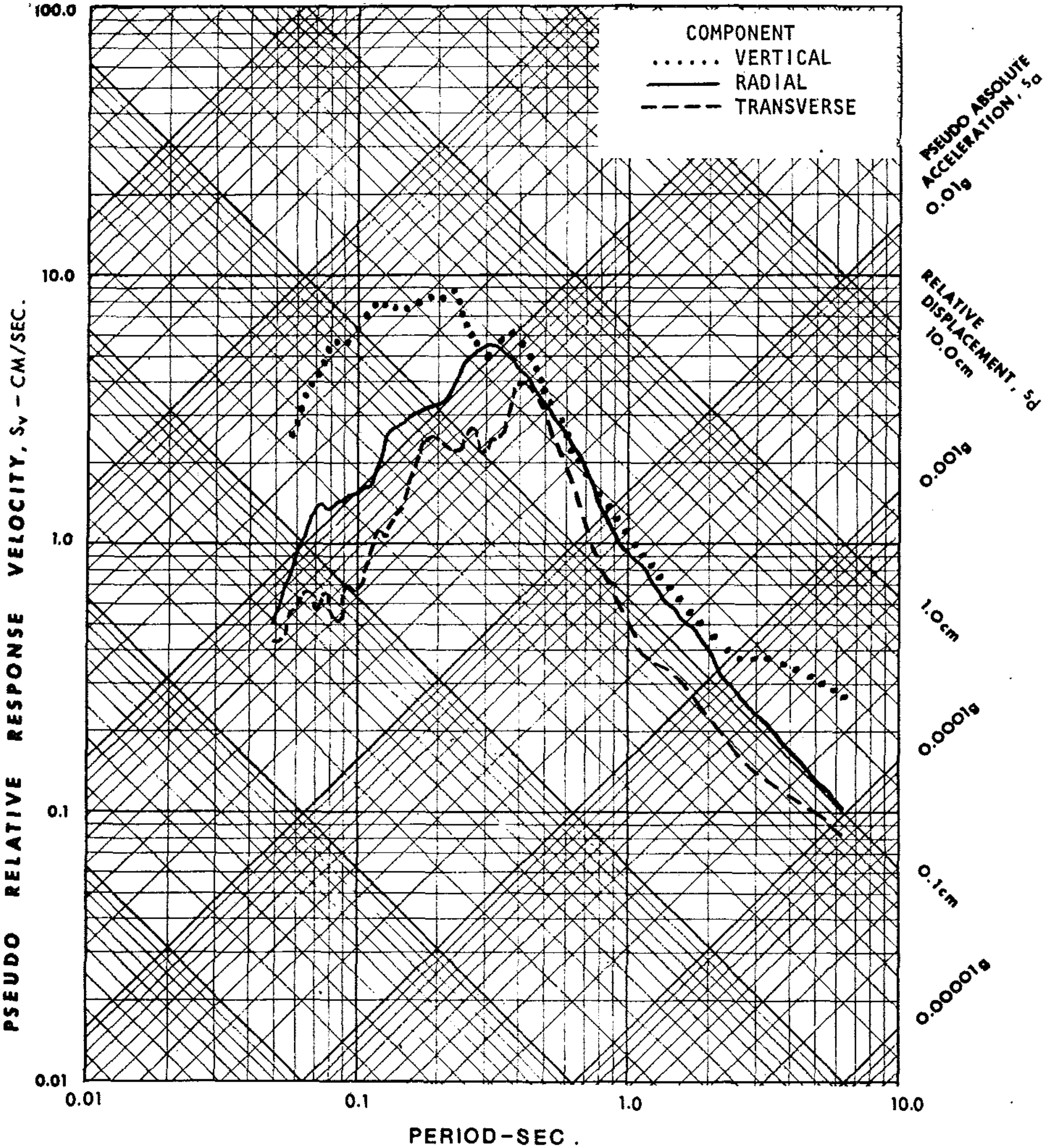


FIGURE 93. OBSERVED 5% S_V SPECTRA, RULISON EVENT

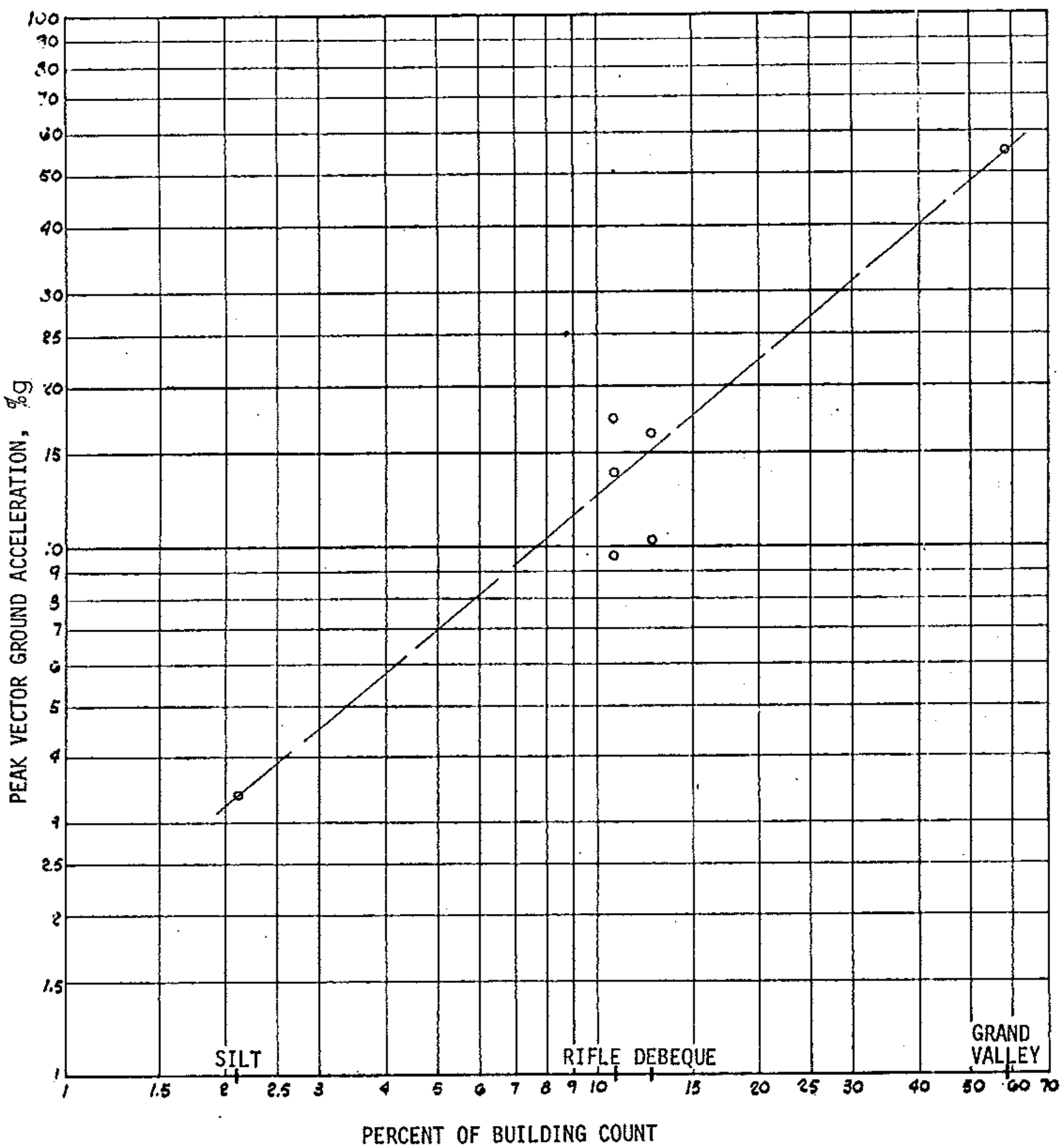


FIGURE 94. COMPLAINTS (PERCENTAGE OF BUILDING COUNT, TABLE 11) VS. PEAK VECTOR GROUND ACCELERATION

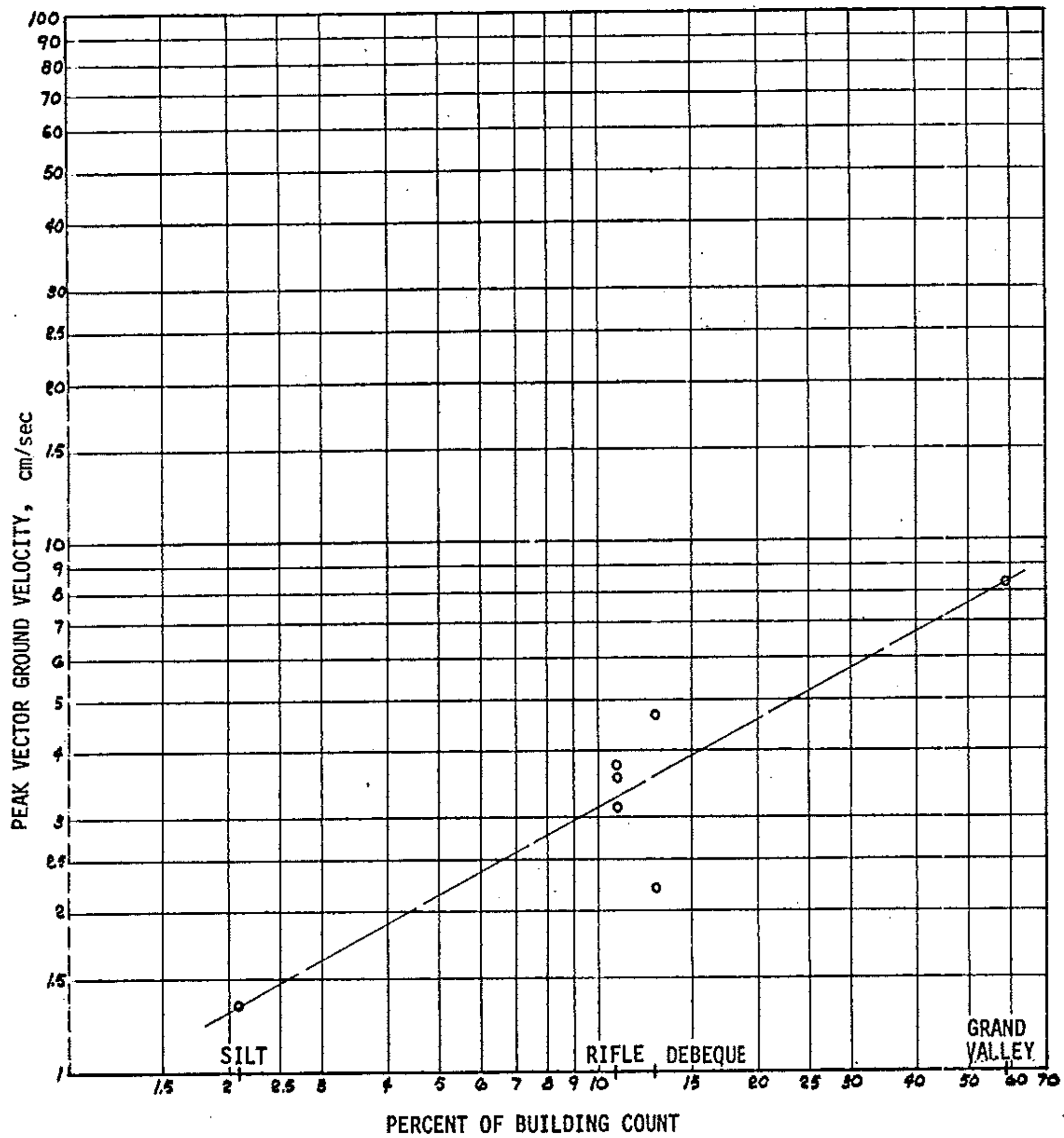


FIGURE 95. COMPLAINTS (PERCENT OF BUILDING COUNT, TABLE 11) VS. PEAK VECTOR GROUND VELOCITY

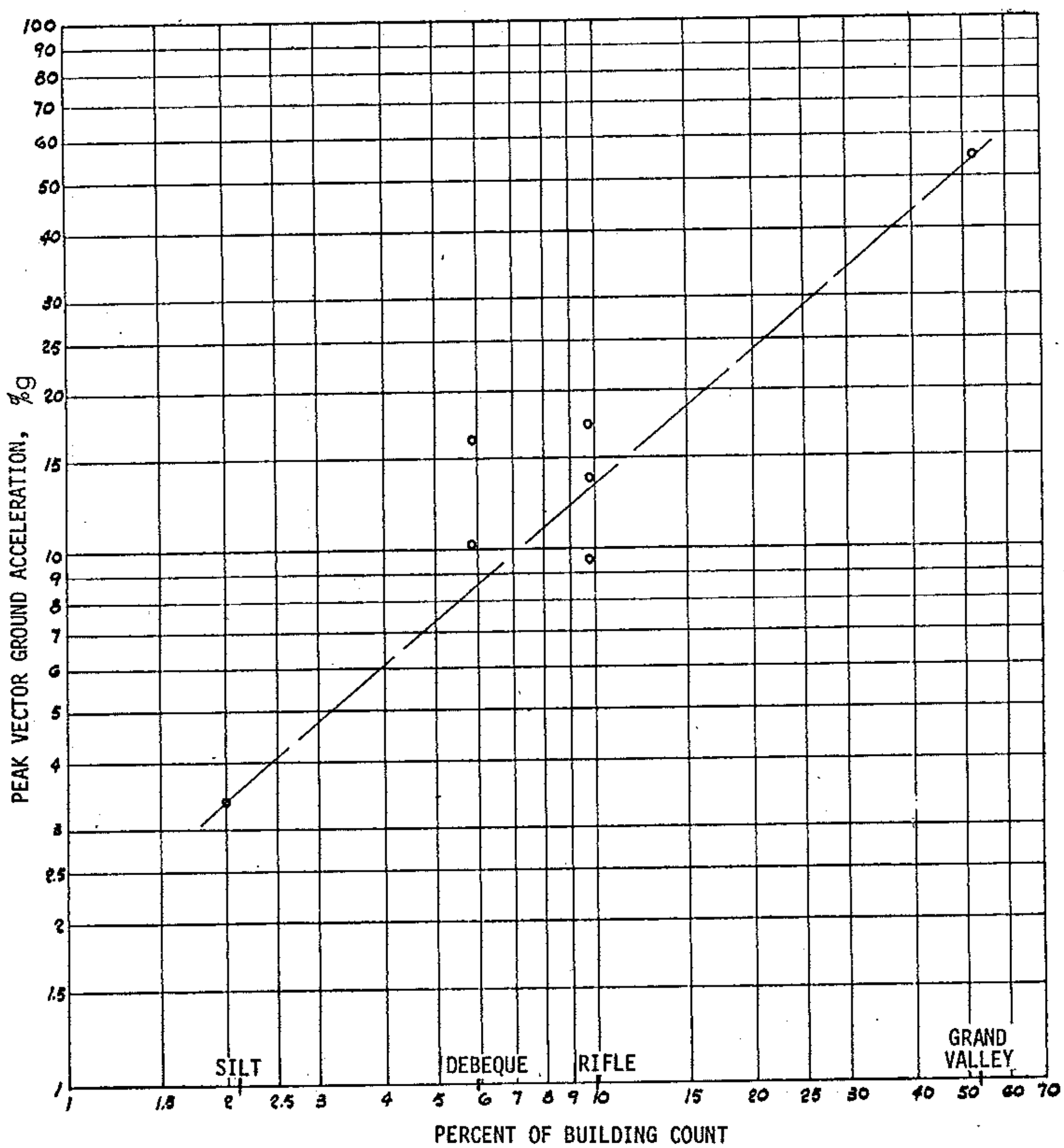


FIGURE 96. CREDIBLE DAMAGE COMPLAINTS (PERCENT OF BUILDING COUNT, TABLE 11) VS. PEAK VECTOR GROUND ACCELERATION

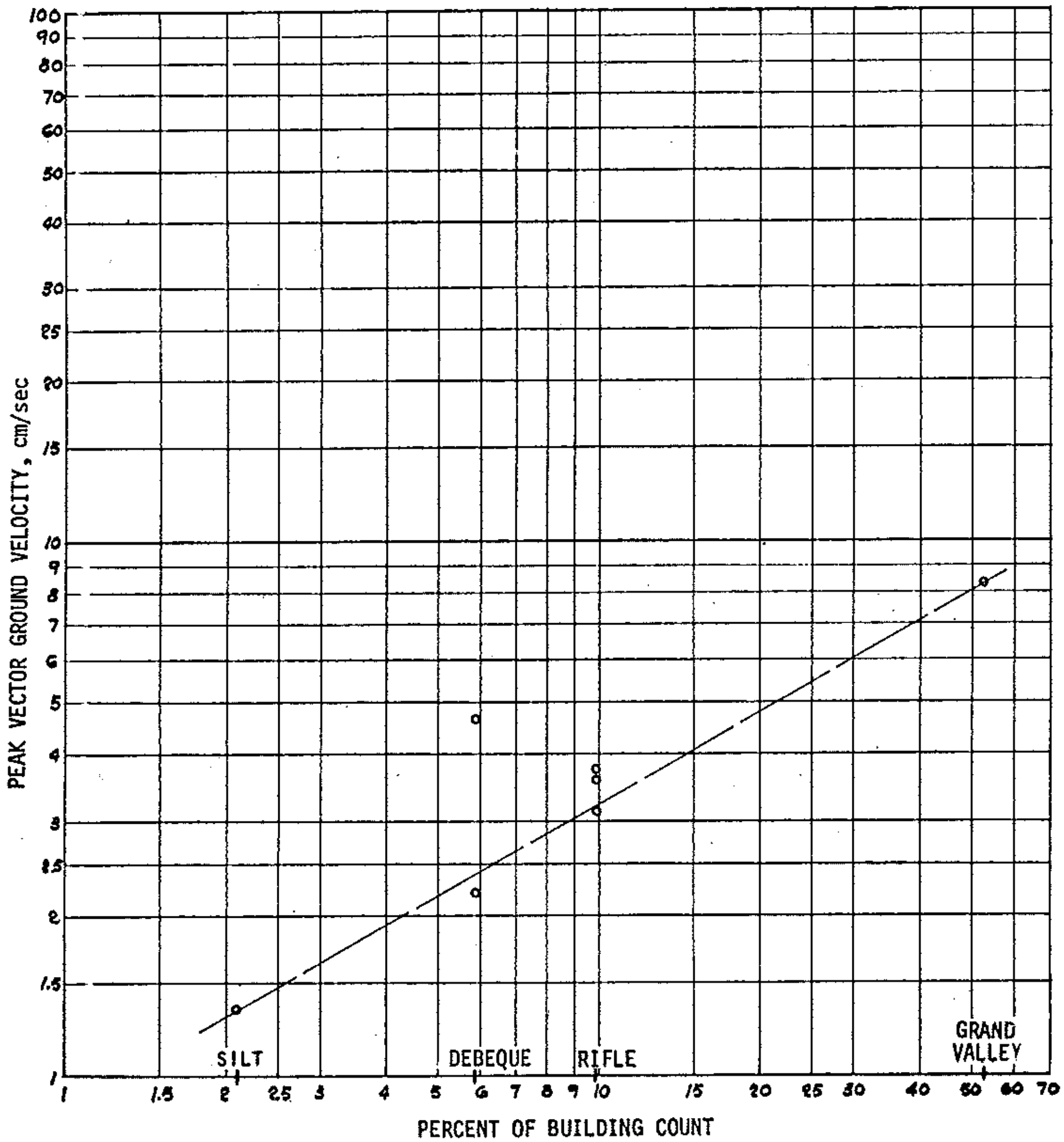


FIGURE 97. CREDIBLE DAMAGE COMPLAINTS (PERCENT OF BUILDING COUNT, TABLE 11) VS. PEAK VECTOR GROUND VELOCITY

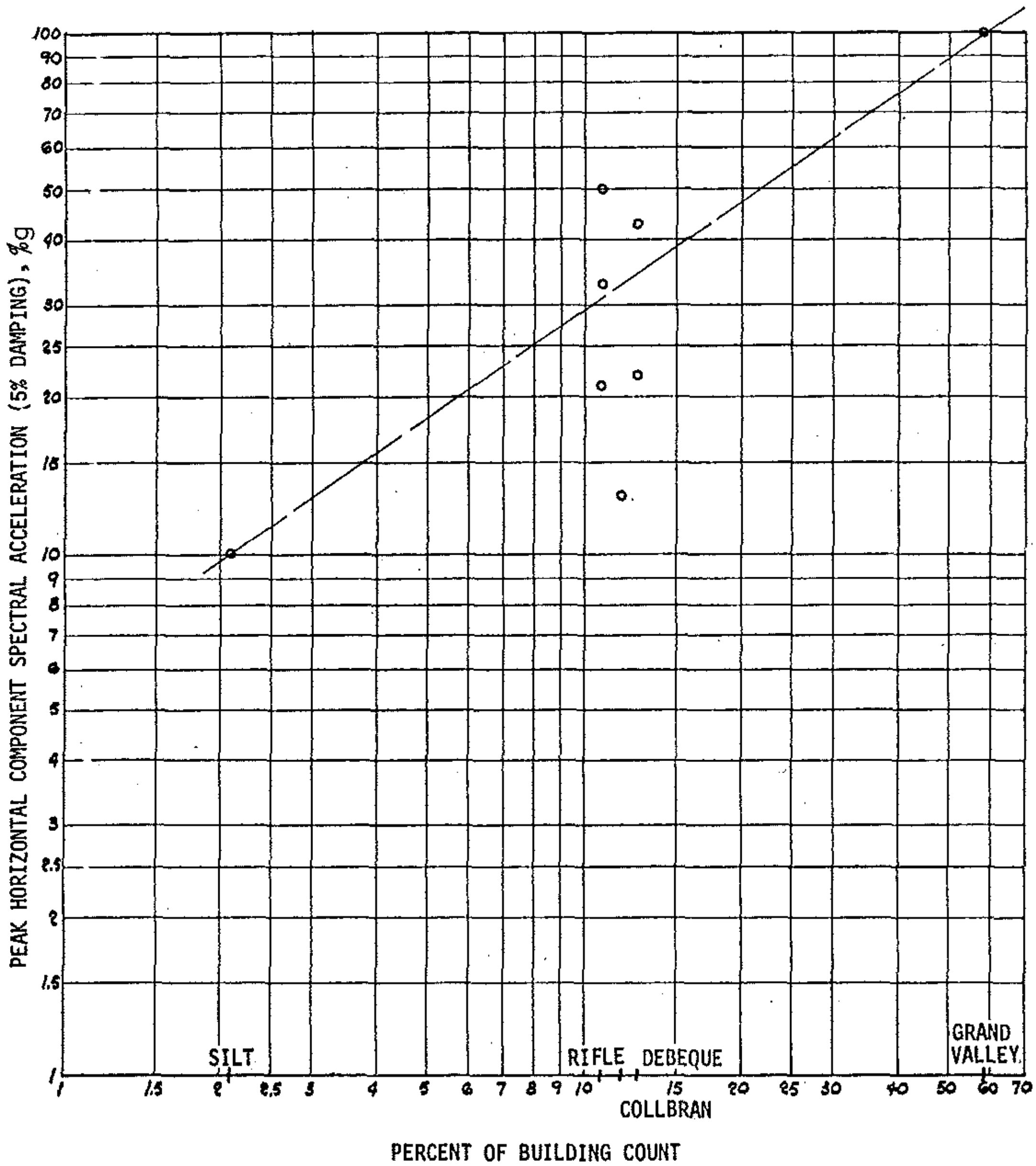


FIGURE 98. COMPLAINTS (PERCENT OF BUILDING COUNT, TABLE 11) VS. PEAK HORIZONTAL COMPONENT SPECTRAL ACCELERATION

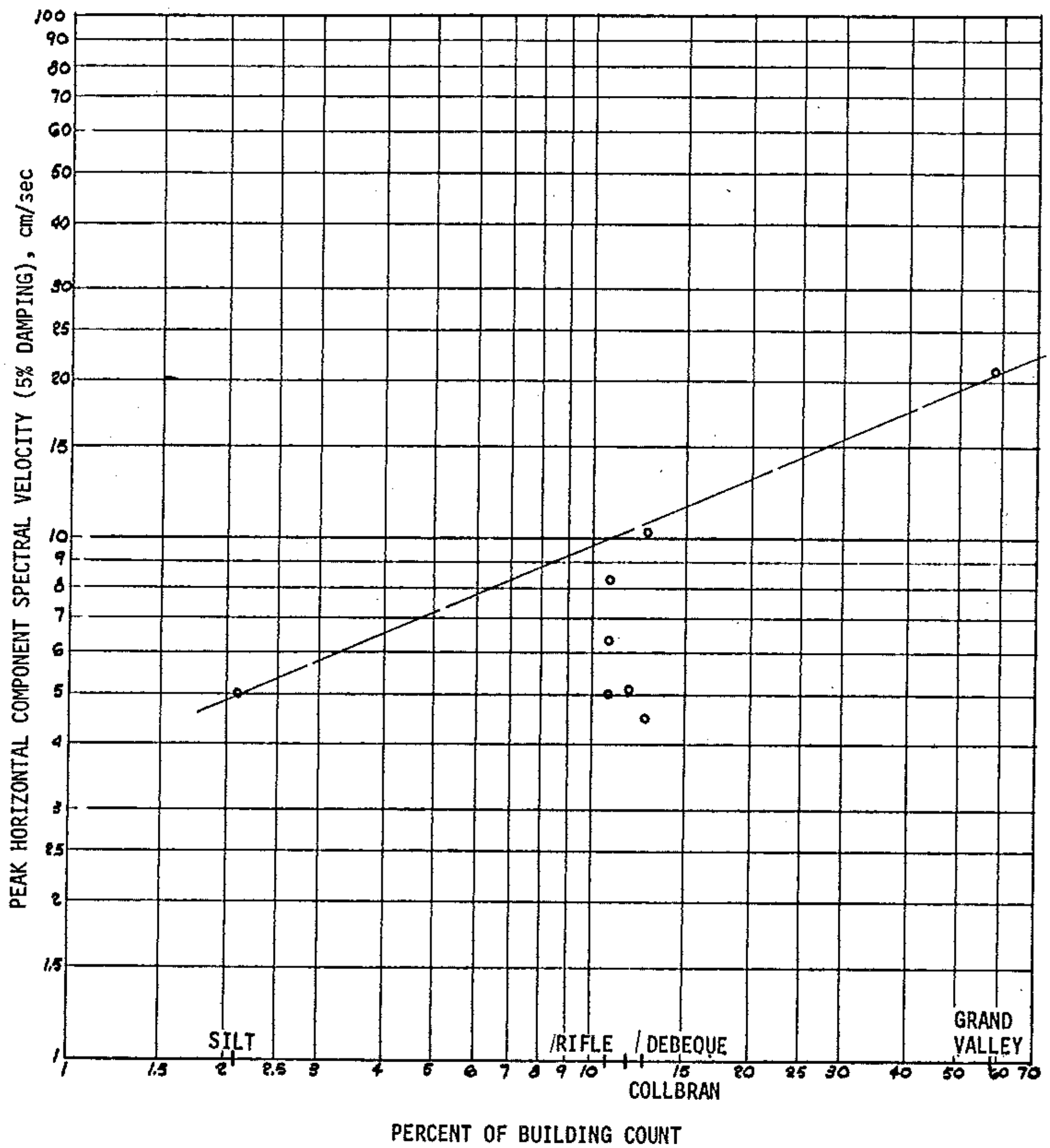


FIGURE 99. COMPLAINTS (PERCENT OF BUILDING COUNT, TABLE 11) VS. PEAK HORIZONTAL COMPONENT SPECTRAL VELOCITY

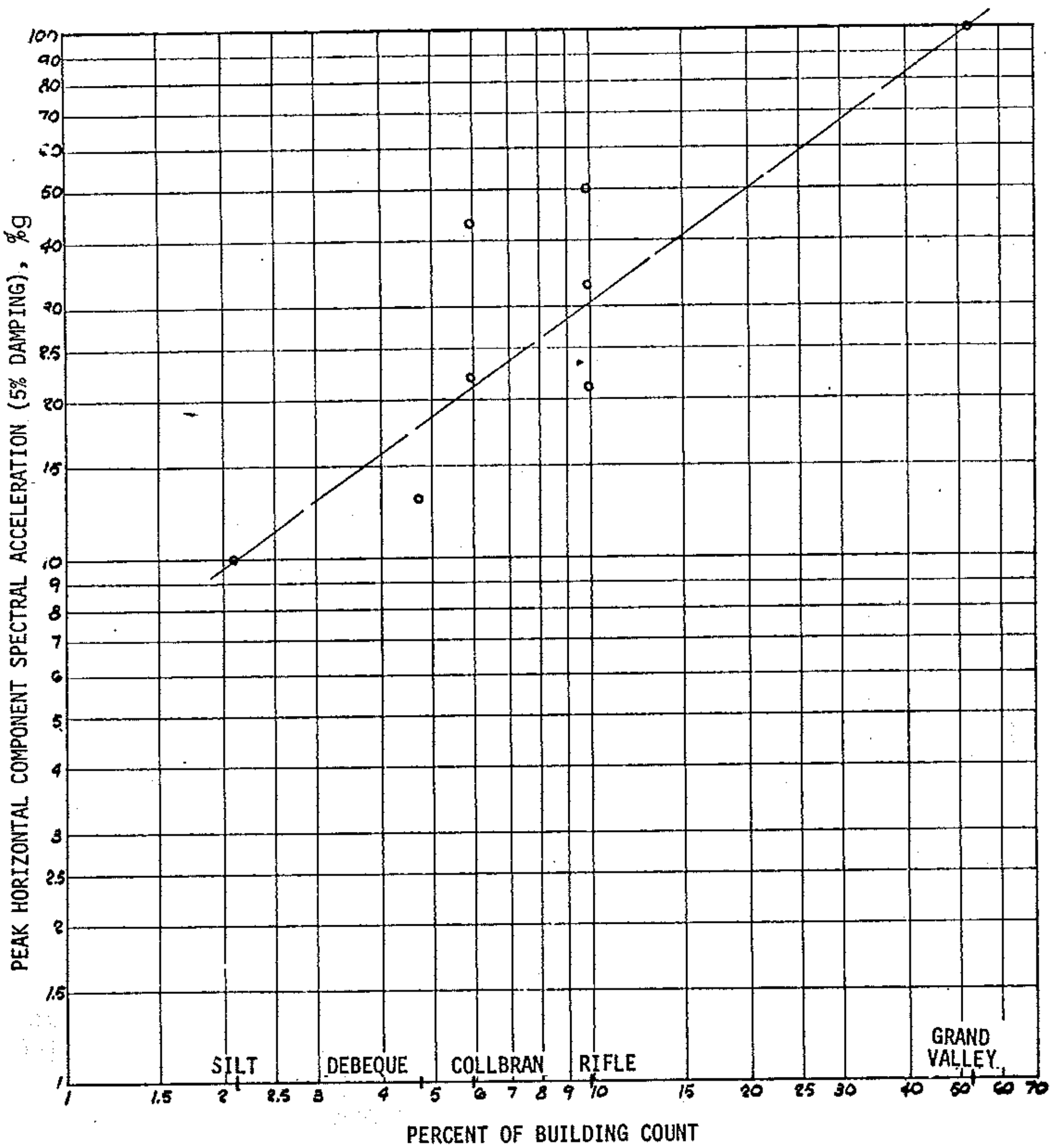


FIGURE 100. CREDIBLE DAMAGE COMPLAINTS (PERCENT OF BUILDING COUNT, TABLE 11) VS. PEAK HORIZONTAL COMPONENT SPECTRAL ACCELERATION

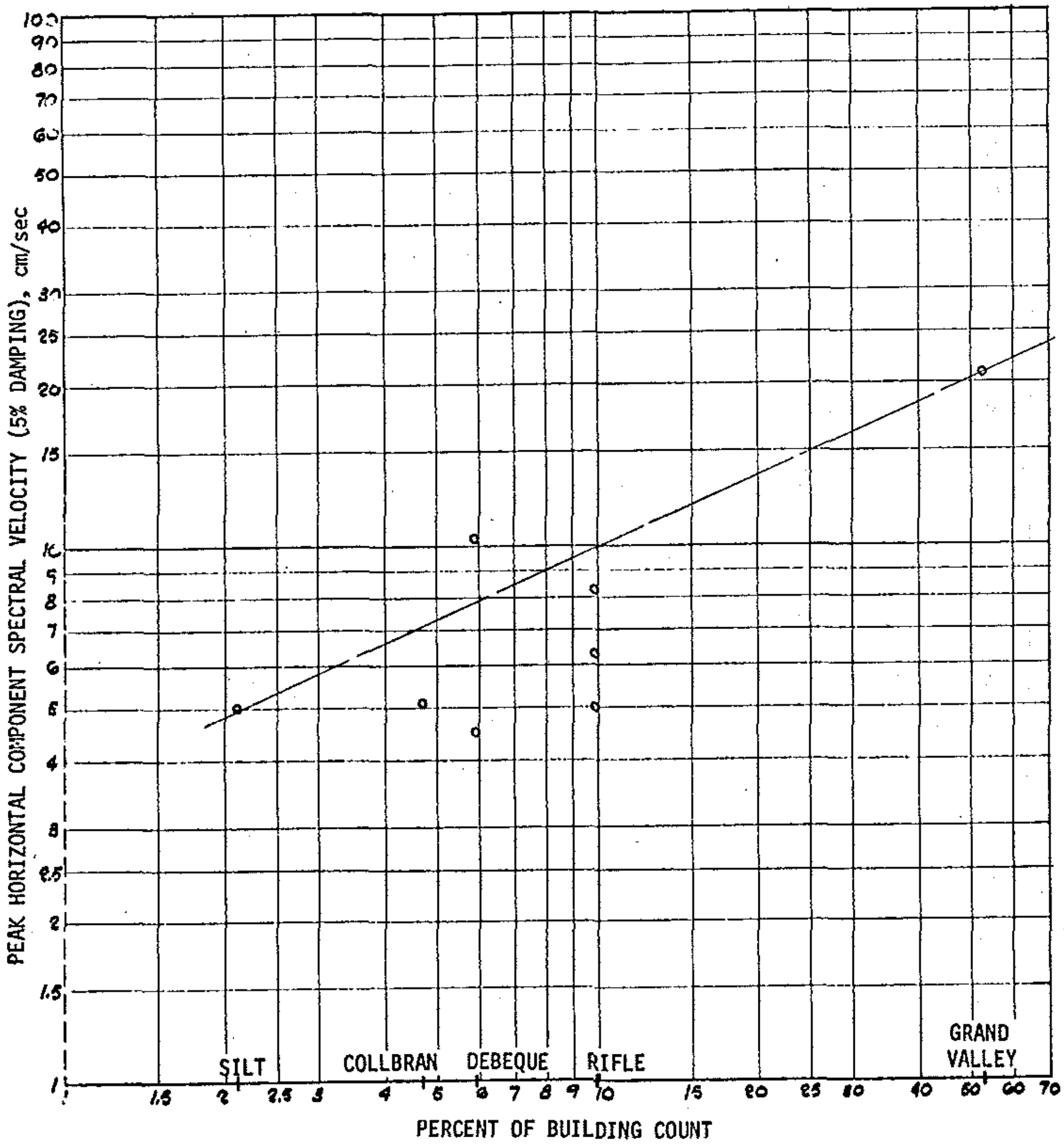


FIGURE 101. CREDIBLE DAMAGE COMPLAINTS (PERCENT OF BUILDING COUNT, TABLE 11) VS. PEAK HORIZONTAL COMPONENT SPECTRAL VELOCITY

a Collbran spectrum was available from the short ground motion record (2.4 sec.) obtained there prior to a power failure which ended the recording.

Figures 100 and 101 should be generally most meaningful, in that the spectral acceleration and velocity in the low-rise building period range constitute better parameters than ground motion for definition of the demand on the structures. Also, these plots employ the better measurement of actual structural effects; i.e., credible damage complaints expressed in terms of percent of building count.

One comparison with other complaint data is afforded by reference to Nadolski[10]. Nadolski's curve in his Figure 12 (a cumulative plot of data points from damage experience with both high explosives and underground nuclear explosions) shows the relationship between complaints expressed as a percent of building population, and peak spectral response acceleration. This should compare with Figure 98, although there are differences in the bases for the data including building count coverage, differences in damping percent for spectral values, incomplete RULISON data, etc. The comparison shows closely similar slopes for both curves. However the Figure 98 curve is displaced in the direction of higher response acceleration required to obtain the same damage percentage. For instance, at 2 percent damage, Nadolski's Figure 12 shows about 0.03g compared to about 0.10g for Figure 98 RULISON data, and at 20 percent damage Nadolski's Figure 12 shows about 0.15g compared to about 0.50g for Figure 98 RULISON data.

Little reliance should be placed on relationships observed in these plots since data on damage were not complete at the time of their preparation. It is encouraging to see indications of a direct relationship between damage and motion amplitude, and therefore justification for the more detailed analyses being carried on for subsequent reporting.

Table 12 is an interim summary of credible damage complaints as of March 31, 1970. Since each damage complaint as submitted can and usually does list more than one type of damage, the Table 12 total of complaints is larger than the total of submitted damage complaints, which was 399 on March 31, 1970.

As of October 31, 1970, a total of 455 damage complaints had been received, including one submitted after the September 10, 1970 deadline date. Distribution of types of damage complained of will be reported on in future publications.

TABLE 12

SUMMARY OF CREDIBLE DAMAGE COMPLAINTS

(as of March 31, 1970)

Type of Damage	Number of Credible Damage Complaints		
	Towns	Rural	Total
Chimney	76	67	143
Int. Plaster	93	55	148
Masonry Wall	35	13	48
Foundation	40	26	66
Windows	8	16	24
Fireplace	7	8	15
Other Ext. Wall	12	9	21
Roof	6	3	9
TV Sets	1	3	4
Household Items	9	9	18
Cisterns		23	23
Wells		4	4
Earth Slides		8	8
Utility Line	4	3	7
Other	9	10	19
TOTAL	300	257	557

COMPARISON OF PREDICTED AND ACTUAL DAMAGE COSTS

An initial damage cost prediction, based on engineering judgment estimates for the 60-kiloton maximum yield was $130,000 (as quoted in official communications from JAB to NVOO in April 1969). Response spectrum predictions were later revised upward, and a subsequent prediction for the 60-kiloton maximum yield was $234,000 and for the 40-kiloton design yield was about $123,000 (official communication from JAB to NVOO in July 1969).

As of October 31, 1970 according to NVOO data, a total of 355 formal claims had been filed and damage claim payments totalled $110,167.09. Another $7,358.95 had been offered in settlement of 5 outstanding claims, but had not yet been accepted by the claimants involved. Should acceptance at this figure take place, damage claim payments will then total $117,526.04, in comparison to the predicted $123,000 damage for the design yield.

VI. CONCLUSIONS

Detailed and reliable assessments of structural response to ground motion from underground nuclear explosions are essential for the safe conduct of such experiments in populated areas.

Structural response to ground motion is a complex phenomenon, which requires consideration of structures and their foundations as frequency-dependent oscillating mechanisms with selective response characteristics and therefore is not amenable to the application of generalized peak motion criteria for response and damage prediction.

Prediction techniques have been devised under the structural response contract with the Nevada Operations Office to enable reliable forecasting of structural response and damage. These techniques include the Engineering Intensity Scale (EIS), which provides a generalized prediction of damage occurrence related to building classes; the Spectral Matrix Method (SMM), which provides a more quantitative prediction including a forecast of the monetary value of damage; and more detailed prediction methods for forecast of the onset and nature of damage occurrence to individual important structures or types of structures.

Prediction methods for the reliable forecasting of response and damage evaluation require the collection of detailed and specific information on structural characteristics and structural population to be exposed to such ground motion. To obtain this information demands comprehensive field efforts, including reconnaissance, structural inventory and condition surveys, and earth structure slope and foundation condition evaluations.

An initial May 1969 date had been proposed for the RULISON event. As a consequence, a considerable problem was created by the expected widespread slope instability at that time of year because of spring thawing and wet weather. Field surveys therefore were directly influenced; much effort was spent in assessing potential hazards in the area. Structure studies were also hampered by unfavorable road and weather conditions. The subsequent delay to a September 1969 date permitted slopes to drain, and they were generally dry and stable -- as predicted -- with relatively little slope movement or rockfalls at shot time.

Structural response instrumentation for the event included the installation of velocity meters (operated by the USC&GS), Sprengnether blastmeters, passive mechanical gages to record movement of cracks, and a water wave gage.

High potential hazards due to ground motion were predicted to exist out to about 7.4 kilometers from Ground Zero, and it was therefore recommended that all persons be evacuated from the close-in area. However, observers within this region found less hazard to exist than was expected, and consideration should be given to revising of this requirement for future experiments.

Hazards as a consequence of structural damage were predicted to occur out to a distance of 14 kilometers. All persons were requested to be outside and away from buildings and other structures, to avoid any hazard from falling objects. This recommendation was well-advised, since observed damage was extensive enough in this region to pose a real hazard to persons, had they not been evacuated.

Hazard because of physiological or psychological response was predicted to occur out to about 100 kilometers. Such hazards were adequately safeguarded against by sufficient public notice of the shot time so that people were forewarned. No injuries occurred, although people were startled in some locations by the unexpectedly strong perception of motion.

Damage was forecast to occur primarily in the region within 35 kilometers of GZ. Almost all damage was actually observed to occur within this area, although -- as was expected -- a few very minor instances of damage did occur at greater distances.

Damage occurred generally as predicted. Although damage complaint processing is still incomplete it appears that the final total will be somewhat in excess of $100,000. The pre-shot prediction of total damage cost was $123,000 for the 40-kiloton design yield and $234,000 for the 60-kiloton maximum yield. Consequently, quite good agreement is expected between the predicted and actual damage costs.

Graphical plots of damage (expressed as a percent of building count) versus (1) peak vector ground acceleration, (2) peak vector ground velocity, (3) peak 5% damped spectral response acceleration, and (4) peak 5% damped spectral response velocity show indications of a direct relationship between motion amplitude and damage. These motion-damage studies which so far are based only on that data available as of March 31, 1970 are being continued.

In summary it may be concluded that the RULISON event necessitated pre-shot and post-shot data acquisition efforts, including thorough instrumentation, structural surveys, motion observations, and analyses. These data on response of low-rise structures in populated areas to seismic ground motion should be extremely valuable for future peaceful applications of nuclear energy. The seismic motion-damage relationship is an especially valuable field for further investigation, and maximum use should be made of these data.

Revised procedures for initial surveys and evaluations have been instituted by the Nevada Operations Office, to disclose, as early as possible, any major problem such as the expected instability of slopes in the RULISON area for the initially selected May 1969 date.

These evaluations should preclude the necessity for rescheduling events because of such problems, and are therefore highly desirable objectives.

Prediction techniques employed for RULISON damage assessment worked generally as anticipated, although some, such as the SMM, are sensitive to anomalously large uncertainties in actual ground motion. Details of these methods of prediction need further confirmation by thorough checking against actual RULISON damage occurrence. Some which were not used for the RULISON event should also be employed in hindcast predictions, to evaluate their reliability and usefulness for similar future underground nuclear events.

VII. REFERENCES

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4. Blume, J. A., and Monroe, R. E., *The Spectral Matrix Method of Predicting Damage from Ground Motion*, JAB-99-81, In preparation.

5. Blume, J. A., Newmark, N. M., and Corning, L. H., "Design of Multistory Reinforced Concrete Buildings for Earthquake Motions," Portland Cement Association, Chicago, Illinois, 1961.

6. Environmental Research Corporation, *Analysis of Ground Motions and Close-In Physical Effects*, *Rulison Event*, NVO-1163-206, April 1970.

7. Coast and Geodetic Survey, ESSA, *Rulison Seismic Effects*, CGS-746-2, February 1970.

8. John A. Blume & Associates Research Division, *Structural Condition Survey: Movement of Building Element Cracks in Six Mercury, Nevada Structures*, NVO-99-20, December 1967.

9. Seed, H. B., Sherard, J. L., and Woodward-Clyde & Associates, *Harvey Gap Dam Safety Study*, JAB-99-63, May 1969.

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APPENDIX A

INVENTORY INDEX

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INVENTORY INDEX

Location No.	Name	Lat./Long.
RB-001	Rio Blanco P.O. & Store	39-44/107-56-45
RB-002	Ranch	39-44/107-57
RB-003	Abandoned ranch	39-43-30/107-57
RB-003A	Microwave Facility	39-42/107-57-45
M-001	Ned Kennon Ranch	39-22/108-04-30
M-002	Sykes	39-22/108-04-30
M-003	Kennon Cow Camp	39-19-30/107-59
M-004	Harv Creek Place	39-21/108-02
M-005	Dept. Of Highways Maintenance Station	39-20-30/108-12
M-005A	DeBeque Bridge on Highway 6-24	39-20/108-11-30
M-005B	Colorado Overflow at DeBeque	39-20-30/108-11-30
M-006	Abandoned squaw cellar	39-21/108-11-30
M-006A	Highway 6-24 Railroad Trestle	39-20-30/108-11-30
M-007	Abandoned ranch	39-21-30/108-09-30
M-007A	Bluestone Valley Ditch	39-21/108-09
M-008	Paradise Land, Oil & Water Corp.	39-21-30/108-10
M-009	House	39-21-30/108-10
M-010	John Mitchell	39-21/108-10-30
M-011	Ranch	39-20-30/108-11
M-012	Armstrong Ranch	39-20/108-11
M-013	Thomas Etcheverry Ranch	39-17-30/108-12-30
M-014	Storage shed	39-18/108-12-30
M-015	Abandoned	39-17/108-13
M-016	Ranch	39-18/108-12-30
M-017	Abandoned ranch house	39-18/108-12-30
M-018	J. S. Novinger	39-18/108-12
M-019	Kenny Hiner Ranch	39-18/108-12
M-020	Bonita Valley Pony Stables	39-18/108-17-30
M-021	Kenny Hiner Ranch	39-18/108-12-30
M-022	Kenny Hiner Ranch	39-18-30/108-17-30
M-023	Shamrock Acres	39-18/108-12-30
M-024	Unoccupied	39-18-30/108-12-30
M-025	Abandoned ranch house	39-18-30/108-12
M-026	Del C. Rickstrew	39-19/108-12
M-027	John Etcheverry	39-19/108-12
M-028	Vernon Hotz Ranch	39-19/108-12
M-029	Abandoned ranch	39-19/108-12
M-030	Chester Rickstrew	39-19-30/108-12
M-031	M. E. Novenger	39-19/108-12
M-032	James Modrell Ranch	39-19/108-12
M-033	Abandoned ranch	39-19/108-17-30
M-034	George Kennedy	39-19-30/108-12
M-035	House	39-18-30/108-13
M-036	Kissel	39-18-30/108-13
M-037	Latham	39-18-30/108-13
M-038	Telephone Relay Station	39-18/108-13
M-039	W.R. Latham Ranch	39-17/108-14
M-040	Roberts Ranch	39-18/108-13
M-041	Abandoned log house	39-18/108-13
M-042	R. R. Inskeep	39-18-30/108-13

Location No.	Name	Lat./Long.
M-043	Mr. Parks	39-18-30/108-13
M-044	John Latham Ranch	39-19/108-13
M-045	Latham Stone Storage	39-19/108-13
M-046	Ranch Cafe & Phillips 66 Station	39-19-30/108-12
M-047	Ranch	39-20/108-12
M-048	DeBeque	
M-048A	DeBeque Bridge	39-20/108-12-30
M-048B	DeBeque Railroad Trestle	39-20/108-12-30
M-049	Bob Prather	39-17/108-13-30
M-050	Cabin and small barns	39-18-30/108-14-30

Georgia Mesa Area

515-69-06, 515-69-08, 515-69-10, 515-69-12, 515-69-14, 515-69-16, 515-69-20, 515-69-22, 515-69-24, 515-69-26, 515-69-28, 515-69-29, 515-69-31, 515-69-34, 516-69-01, 516-69-03, 516-69-37, 516-69-05, 516-69-07, 516-69-10, 516-69-11, 516-69-13, 516-69-15, 516-69-16, 516-69-19, 517-69-04, 517-69-37, 517-69-07, 517-69-09, 517-69-11, 517-69-14, 517-69-15, 517-69-16, 517-69-17, 517-69-18, 517-69-20, 517-69-38, 517-69-21, 517-69-22, 517-69-23, 517-69-25, 517-69-27, 517-69-29, 517-69-30, 517-69-33, 517-69-34, 517-69-36, 518-69-02, 518-69-04, 518-69-05, 518-69-18, 518-69-20, 518-69-21, 518-69-22, 518-69-23, 518-69-24, 518-69-26, 518-69-27.

Inventory sheets are included for the following locations:

515-69-16	Georgia Mesa Area - G. B. Currier	39-01/108-01
515-69-20	Georgia Mesa Area - L. Reed	39-11/108-10
517-69-11	Georgia Mesa Area - C. Springer	39-11/108-05
517-69-17	Georgia Mesa Area - D. Hawkins	39-08/108-03
518-69-21	Georgia Mesa Area - Webbs Indoor Arena	39-11/108-06

Silt Road Area

503-69-31, 503-69-32, 503-69-33, 503-69-36, 504-69-01, 504-69-02, 504-69-03, 504-69-05, 504-69-07, 504-69-08, 504-69-09, 504-69-11, 504-69-13, 504-69-15, 504-69-16, 504-69-17, 504-69-22, 504-69-23, 504-69-24.

An inventory sheet is included for the following location:

504-69-17	Silt Road Area - George Gipp	39-16/107-43

Collbran

An inventory sheet is included for the following location:

518-69-11	Collbran - Congregational Church	39-14/107-57

Location No.	Name	Lat./Long.

Kansas Mesa Area

501-69-18, 501-69-19, 501-69-20, 501-69-21, 501-69-22, 501-69-23, 501-69-24, 501-69-25, 501-69-26, 501-69-27, 501-69-28, 505-69-27, 505-69-28, 505-69-32, 505-69-33, 506-69-03, 506-69-04, 506-69-07, 506-69-10, 506-69-11, 506-69-12, 506-69-13, 506-69-14, 506-69-16, 506-69-17, 506-69-19, 506-69-21, 506-69-22, 506-69-23, 506-69-25, 506-69-26, 506-69-27, 506-69-29, 506-69-31, 506-69-33, 506-69-35, 507-69-02, 507-69-05, 507-69-09, 507-69-10, 507-69-12, 507-69-14, 507-69-15, 507-69-16, 507-69-18, 507-69-19, 507-69-21, 507-69-23, 507-69-24, 506-69-37, 508-69-01, 508-69-04, 508-69-06, 508-69-10, 508-69-15, 508-69-17, 508-69-18, 508-69-20, 508-69-22, 508-69-25, 508-69-28, 508-69-30, 508-69-32, 508-69-35, 509-69-01, 509-69-02, 509-69-05, 509-69-06, 509-69-08, 509-69-10, 509-69-12, 509-69-13, 509-69-14, 509-69-17, 509-69-19, 509-69-20, 509-69-22, 509-69-24, 509-69-25, 509-69-28, 509-69-30, 509-69-32, 509-69-33, 509-69-34, 509-69-36, 510-69-02, 510-69-04, 512-69-01.

Inventory sheets are included for the following locations:

501-69-26	Kansas Mesa Area - Brasher Ranch	39-12/107-56
508-69-01	Kansas Mesa Area - Ranch	39-14/107-57
508-69-22	Kansas Mesa Area - Ray Look	39-12/107-57
509-69-06	Kansas Mesa Area - W/J Ranch #2	39-12/107-58
509-69-20	Kansas Mesa Area - Kelley Ranch	39-13/107-59
510-69-02	Kansas Mesa Area - Melendy Ranch	39-13/107-58

Kimball Creek Area

502-69-25, 502-69026, 502-69-27, 502-69-28, 502-69-29, 502-69-30, 502-69-31, 502-69-32, 504-69-31, 504-69-32, 504-69-34, 504-69-36.

An inventory sheet is included for the following location:

502-69-31	Kimball Creek Area - Wallace Ranch	39-15/107-57

Salt Creek Area

501-69-29, 501-69-30, 501-69-31, 501-69-32, 501-69-33, 501-69-34, 501-69-35, 501-69-36, 502-69-00, 502-69-01, 502-69-02.

An inventory sheet is included for the following location:

502-69-02	Salt Creek Area - Ed Gunderson	39-15/107-55

Peninsula Road Area

502-69-03, 502-69-04, 502-69-05, 502-69-06, 502-69-07, 502-69-08, 502-69-09, 502-69-10, 502-69-11, 502-69-13, 502-69-14, 502-69-15, 502-69-17, 502-69-18, 502-69-19, 502-69-21, 502-69-22, 502-69-23, 502-69-24, 502-69-37, 503-69-23.

Location No.	Name	Lat./Long.

Inventory sheets are included for the following locations:

502-69-08	Peninsula Road Area - Blair Ranch	39-16/107-53
502-69-11	Peninsula Road Area - Bruce A. Berner	39-16/107-54
503-69-23	Peninsula Road Area - Bar 70 Ranch	39-15/107-53

Buzzard Creek Area

503-69-19, 503-69-20, 505-69-06, 505-69-08, 505-69-10, 505-69-13, 505-69-15, 505-69-21, 505-69-23.

Inventory sheets are included for the following locations:

503-69-20	Buzzard Creek Area - Griffiths Ranch	39-17/107-51
505-69-15	Buzzard Creek Area - Donner Ranch	39-16/107-56

Molina City Area

Inventory sheets are included for the following locations:

518-69-06	Molina Post Office and Groceries	39-11/108-03
513-69-28	Upper Molina Power Plant	39-09/108-00
513-69-17	Lower Molina Power Plant	39-12/108-03

Mormon Mesa Area

513-69-01, 513-69-04, 513-69-08, 513-69-10, 513-69-13, 513-69-14, 513-69-17, 513-69-18, 513-69-19, 513-69-21, 513-69-22, 513-69-23, 513-69-27, 514-69-01, 514-69-03, 514-69-05, 514-69-07, 514-69-12, 514-69-13, 514-69-15, 514-69-16, 514-69-18, 514-69-20, 514-69-21, 514-69-23, 514-69-25.

Inventory sheets are included for the following locations:

513-69-04	Mormon Mesa Area - Ben Nichols	39-13/108-00
513-69-23	Mormon Mesa Area - C.J. Charlesworth	39-12/108-01
514-69-07	Mormon Mesa Area - Wissel	39-11/108-01

Vega Dam Recreation Area

An inventory sheet is included for the following location:

503-69-18	Ranch	39-15/107-51

Plateau City

No inventory sheets are included for Plateau City

Location No.	Name	Lat./Long.

Mesa City - 523-69-14

Inventory sheets are included for the following locations:

523-69-07	Mesa City - Lee Shriver	39-10/108-08
523-69-17	Mesa City - Mesa Community Club	39-09/108-08

Mesa Creek Area - 520-69-37

519-69-01, 519-69-03, 519-69-05, 519-69-07, 519-69-08, 519-69-09, 519-69-12, 519-69-14, 519-69-16, 519-69-18, 519-69-19, 519-69-21, 519-69-22, 519-69-25, 519-69-28, 519-69-30, 519-69-32, 519-69-34, 520-69-01, 520-69-04, 520-69-06, 520-69-07, 520-69-09, 520-69-12, 520-69-14, 520-69-15, 520-69-17, 520-69-20, 520-69-23, 520-69-25, 520-69-27, 520-69-29, 520-69-31, 520-69-33, 520-69-35, 521-69-01, 521-69-02, 521-69-04, 521-69-06, 521-69-07, 521-69-10, 521-69-11, 521-69-12, 521-69-14, 521-69-17, 521-69-18, 521-69-20, 521-69-22, 521-69-24, 521-69-25, 521-69-27, 521-69-29, 521-69-31, 521-69-33, 521-69-35, 522-69-01, 522-69-04, 522-69-05, 522-69-06, 522-69-08, 522-69-10, 522-69-12, 522-69-14, 522-69-16, 522-69-17, 522-69-18, 522-69-21, 522-69-23, 522-69-24, 522-69-26, 522-69-27, 522-69-29, 522-69-31, 522-69-32, 522-69-33.

Inventory sheets are included for the following locations:

519-69-09	Mesa Creek Area - Clarance Fetters	39-08/108-07
519-69-25	Mesa Creek Area - Allen Delling	39-09/108-07
520-69-17	Mesa Creek Area - J. Wiscomb	39-10/108-08
521-69-12	Mesa Creek Area - W. D. Meador	39-09/108-11
501-69-01	Colorado National Monument - east entrance	39-02/108-38
501-69-07	Colorado National Monument - Visitor Center	39-06/108-44
501-69-01A	Black Ridge - Radio Antenna	39-04/108-46
501-69-01B	Black Ridge - Airway Beacon and Radio Tower	39-04/108-44
515-69-01	Bonham Reservoir	39-06/107-53

G-001	Ranch	39-41/107-55-30
G-002	E. E. Dewitt Ranch	39-40-30/107-54-30
G-003	Ranch	39-40/107-53-30
G-004	Willard N. Beane	39-39-30/107-53
G-005	Wilcox Ranch & Grain Tank	39-39/107-53
G-006	Lyle Pickard	39-38-30/107-52
G-007	Rufo Eisaguirre Residence	39-38-30/107-52
G-008	House and sheds	39-38/107-52
G-009	Two abandoned cabins	39-38/107-51
G-010	Harvey Gap Reservoir	39-36-30/107-38-30
G-011	Southern Union Production Co. Federal No. 14-95	39-26-30/107-57-45
G-011A	Television Relay Station	39-27/107-57-30
G-012	Summer cabin	39-24-30/107-57

Location No.	Name	Lat./Long.
G-013	Claude Hayward Summer House	39-25/107-57-30
G-014	Ron Reese Ranch	39-27/107-58
G-015	Bush Ranch	39-27/107-58
G-016	Ed Sifer Ranch	39-27/107-58-30
G-017	Hayward Ranch	39-27/107-58
G-018	Ranch	39-27/107-58
G-019	St. Johns	39-27/107-58
G-020	Burtard Ranch	39-27/107-58
G-021	James St. Johns Ranch	39-27/107-58-30
G-022	Ranch	39-27/107-58-30
G-023	Ranch & Tank	39-27/107-58-30
G-024	Barrick Ranch	39-27-30/107-58-30
G-025	Morrisania Community Center	39-27-30/107-58-30
G-026	Ranch (Ben Bair, occupant)	39-27/107-58-30
G-027	Glenn Nelson Ranch	39-27-30/107-59
G-028	G.C. Barrick	39-27-30/107-59-30
G-029	Mr. Pfost	39-27-30/107-58-30
G-030	Eames Ranch	39-27-30/107-59-30
G-031	Aitt Bronson	39-28/107-58-30
G-032	Everett Baldwin	39-27/107-58-30
G-033	E.R. Schwab	39-27/107-58-30
G-034	Barr Residence	39-27/107-58-30
G-035	Wallace Myers	39-37-30/107-58
G-036	Hugh Bond	39-37-30/107-58
G-037	I. and E. Moore	39-27-30/107-58-30
G-038	Oliver Wood	39-28/107-58-30
G-039	Abandoned Watson Ranch	39-28/107-58-30
G-040	F. E. Cooley Ranch	39-28/107-58
G-041	Baum Ranch	39-28/107-58
G-042	Eames Orchard Inc.	39-27/107-58-30
G-043	Lee Hayward	39-27/107-59
G-044	Ranch	39-27/107-59
G-045	Ranch	39-27-107-59
G-046	John Clem	39-26-30/107-59
G-047	Unoccupied ranch	39-27-30/107-59-30
G-048	Power Plant & Tanks	39-30/107-54-30
G-049	John Savage Ranch	39-27-30/108-0-30
G-050	Arthur L. McLane	39-26-30/108-0-30
G-051	Don D. Duplice (Owner)	39-26-30/108-1-30
G-052	Mr. and Mrs. Smith	39-26/108-0-30
G-053	Abandoned ranch	39-26-30/108-0-30
G-054	Unoccupied ranch	39-26/108-01
G-055	Abandoned ranch	39-26/108-01-30
G-056	M. Martin	39-26/108-01-30
G-057	M. C. Wehr	39-26/108-1-30
G-058	Albert Gardner (Owner)	39-26/108-02
G-059	Tosco Oil	39-25-30/108-02
G-060	Arnet	39-26-30/108-01-30
G-061	Battlement School (Abandoned)	39-26-30/108-01-30
G-062	Nordstrom	39-26/108-02
G-063	(Abandoned)	39-26/108-02
G-064	(Abandoned)	39-26-30/108-02-30

Location No.	Name	Lat./Long.
G-065	Cecil Gardner	39-26-30/108-03
G-066	Bob Latham	39-26-30/108-03
G-067	(Abandoned)	39-26-30/107-02
G-068	(Unoccupied)	39-27-30/108-02
G-069	G. A. Knight	39-28-30/108-00-00
G-070	Edward Forshee	39-28-30/107-58-30
G-071	Ed Hoaglunds	39-28-30/107-57-30
G-072	R. A. Hoaglund	39-28-30/107-57-30
G-073	Charles W. Clark	39-28-30/107-57
G-074	Williard Taylor	39-28-30/107-57
G-075	George Scarrow	39-29/107-57
G-076	Unoccupied ranch	39-28-30/107-57
G-077	Group of structures near Rulison	39-30/107-56-30
G-078	Abandoned ranch	39-28-30/107-58
G-079	Unoccupied ranch	39-28-30/107-58-30
G-080	Ranch	39-28-30/107-57-30
G-081	Dale L. Trahern	39-28-30/107-53-30
G-082	Old School (abandoned)	39-28-30/107-53
G-083	Carl H. Bernklau	39-28-30/107-53-30
G-084	(Abandoned)	39-29/107-53-30
G-085	J. A. Schneider	39-29/107-54
G-086	(Abandoned)	39-29/107-55
G-087	(Not occupied)	39-27/108-02
G-088	(Abandoned) Tosco Oil	39-25-30/108-03
G-089	Tosco Oil	39-25-30/108-03
G-090	Tosco Oil	39-25-30/108-03-30
G-091	Abandoned (very old)	39-24/108-05
G-092	Woody Booth	39-24-30/108-04-30
G-093	Weldon Deering Ranch	39-24/108-04-30
G-094	Knox Ranch	39-23-30/108-05-30
G-095	D. M. Knox	39-23-30/108-05-30
G-095A	Wallace Creek Area Bridge	39-24/108-06
G-096	Kenneth Aumiller	39-23-30/108-4-30
G-097	D. M. Knox	39-28/108-05
G-098	Lee Knox	39-22/108-05
G-099	N. Dutton	39-22/108-03
G-100	Otis Murry	39-22-30/108-03-30
G-101	Claude Hayward	39-23-30/108-06
G-102	Van Pelt	39-23-30/108-06
G-103	Bud and Ruth Ellis	39-24/108-06
G-104	Leonard Ranch	39-24/108-06
G-105	B. L. Smith	39-27-30/107-57
G-106	B. L. Smith	39-28/107-57
G-107	Shelter and corral	39-22/108-10
G-108	Sheep-herders shelter	39-23-30/108-08
G-109	B. L. Smith Ranch	39-27-30/107-56
G-110	Lemon Ranch	39-27-30/107-55-30
G-111	Lemon Ranch	39-27-30/107-55-30
G-112	B. L. Smith (Abandoned)	39-28/107-56
G-113	Lemon Ranch	39-28-30/107-56
G-114	F. S. Sefcovic Ranch & Tank	39-27-30/107-55-30
G-115	Russell Bingham	39-28/107-55-30
G-116	R. L. Dick Johnson	39-28/107-54-30
G-117	Trahern Cabin	39-27/107-54-30

Location No.	Name	Lat./Long.
G-118	Wm. C. Moore	39-28-30/107-54-30
G-119	William C. Moore Cabin	39-24-30/107-54
G-120	Dennis Trueblood Ranch	39-28/107-54-30
G-121	Howard Dean	39-28-30/107-54-30
G-122	Trahern Cabin	39-27/107-53
G-123	Bernklau, Carl H.	39-26/107-55
G-124	D. Winch	39-29/107-53-30
G-125	Cache Creek Corp.	39-29/107-53
G-126	Ole-O- Ranch	39-20-30/107-53
G-127	Bernklau Homestead	39-28/107-53-30
G-128	Bernklau Ranch (abandoned)	39-28-30/107-53-30
G-129	Grand Valley	
G-129A	Grand Valley	
G-129B	Water Tank	39-27-30/108-3
G-129C	Grand Valley Bridge	39-27/108-02
G-130	Unoccupied	39-27/108-2-30
G-131	Under Reconstruction	39-26/108-3-30
G-132	Abandoned house	39-25-30/108-4-30
G-133	Morris Pontius	39-25/108-4-30
G-134	Microwave Tower (Grand Valley)	39-26/108-06-30
G-135	Union Oil Co.(Refinery Complex) & Tank	39-35/108-06
G-136	Ranch	39-35/108-06
G-137	Granlee School (Abandoned)	39-33-30/108-07
G-138	Abandoned	39-33/108-06-30
G-139	Abandoned ranch	39-32-30/108-06-30
G-140	Charles I. Lewis Ranch	39-32/108-06-30
G-141	Cabin	39-30-30/108-07-0
G-142	R. A. & Paul Bumgardner	39-30/108-07
G-143	Abandoned ranch	39-30/108-07
G-144	O. Lindauer	39-29-30/108-07-30
G-145	D. Freeland	39-29-30/108-07
G-146	Ranch	39-29/108-07
G-147	Cattle feeding station	39-29/108-06-30
G-148	Floyd & Maude Brucker Ranch	39-29/108-06
G-149	Parachute Ranch	39-29/108-06
G-150	F. Spangler Ranch	39-28-30/108-06
G-151	Ranch	39-28-30/108-06
G-152	Union Oil Co. Ranch	39-28-30/108-05-30
G-153	Union Oil Co. Ranch	39-28/108-05-30
G-154	Union Oil Co. Ranch	39-28/108-05
G-155	Abandoned	39-28/108-04-30
G-156	Mahaffey Ranch	39-29/108-00
G-157	B.Hamrick Ranch (unoccupied)	39-23-30/108-06-30
G-158	Malcolm Jolly	39-23-30/108-07
G-159	Jack Smith Ranch	39-29/107-52
G-160	Abandoned ranch	39-29-30/107-52
G-161	Leslie Dotson Ranch	39-29-30/107-52
G-162	Old Langstaff Ranch	39-38-30/107-51-30
G-163	Norman Mead	39-29-30/107-51-30
G-164	Abandoned School	39-30/107-51-30
G-165	C. H. Harris	39-30/107-51-30
G-166	Herbert Boor	39-30/107-51
G-167	G. M. Saulbury Ranch	39-30-30/107-53
G-168	Loren Mead	39-30-30/107-51

Location No.	Name	Lat./Long.
G-169	Donald Dorrell Ranch	39-30-30/107-50-30
G-170	Jesse Estes	39-31/107-49-30
G-171	Abandoned	39-31/107-49-30
G-172	The Squires Ranch	39-31/107-49
G-173	The Thompson Ranch	39-31/107-49
G-174	Shed	39-31/107-49
G-175	C. C. Selle	39-31/107-48
G-176	David Kehr	39-31/107-48
G-177 G-177A, G-077B, G-177C	Helmer Gulch Water Treatment Plant	39-31/107-48
G-178	Relay Station (TV?)	39-31/107-47
G-179	Ethie E. Hall	39-30-30/107-48-30
G-180	Reuben F. Gardner	39-30-30/107-48-30
G-181	Squires Ranch	39-30-30/107-49
G-182	Shreve Ranch	39-30-30/107-49
G-183	The Broughton Ranch	39-30-30/107-49
G-184	Glen McCormick	39-30-30/107-49-30
G-185	Trailer (expando)	39-30/107-49-30
G-186	Tom Von Dette	39-30/107-50
G-187	The Hunt Ranch	39-29/107-49-30
G-188	Von Dette Summer Ranch	39-26-30/107-50
G-189	Von Dette Saw Mill	39-26/107-50
G-190	Dorrell Summer Cabin	39-26/107-50-30
G-191	Tepee Park Cabin	39-23-30/107-50
G-192	Von Dette Cabin on West Mamm Creek	39-25/107-47-30
G-193	Rickhart Cabin	39-26-30/107-49
G-194	Rifle	--
G-195	Rifle	--
G-195A	Texaco	39-31-30/107-47
G-195A	Standard	39-31-30/107-47
G-195B	Rifle Sewer Lagoons	39-31-30/107-47-30
G-195C	Rifle Bridge	39-32/107-47
G-195D	Rifle Plant	41-21/107-49
G-196	Two buildings & granary	39-30-30/107-52-30
G-197	Loren Jewell Ranch	39-31-30/107-43
G-198	Loren Jewell (Grass Mesa)	39-29/107-46
G-199	Loren Jewell (Grass Mesa)	39-29-30/107-45-30
G-200	Rifle	
G-200A	Rifle, Storage Tank	39-32-30/107-46-30
G-200B	Rifle, Purification Plant	39-32-30/107-46
G-200C	Rifle, Purification Plant	39-32-30/107-46
G-200D	Microwave Tower (Inaccessible)	39-32-30/107-45-30
G-200E	Radio Transmission Tower	39-33/107-46
G-201	Municipal Airport	39-31-30/107-43-30
G-202	Vaughn Cameron Ranch	39-26/107-45
G-203	Ron Pittman	39-26-30/107-45
G-204	Joseph Ellis Ranch	39-26/107-46-30
G-205	Frank Franks	39-26/107-44-30
G-206	Abandoned house; sheds & granaries	39-27/107-44
G-207	Public Service Transformer Station	39-31-30/107-44-30
G-208	Unoccupied ranch	39-31-30/107-44/30
G-209	Unoccupied	39-31-30/107-44-30

Location No.	Name	Lat./Long.
G-210	Jack Jewell Ranch	39-32/107-43-30
G-211	Guy Snyder Ranch	39-32/107-43
G-212	Unoccupied	39-32/107-42-30
G-213	Haas Ranch	39-37/107-42-30
G-214	B. C. Shideler Ranch	39-25/107-42-30
G-215	Four abandoned structures	39-25-30/107-42
G-216	Deardorff Ranch	39-25-30/107-42
G-217	Harry R. Cogburn	39-27/107-40-30
G-218	Abandoned School	39-27/107-41
G-219	Covey Ranch	39-27/107-41
G-220	Covey Place (abandoned)	39-28/107-41
G-221	Animal shelters, granary	39-31-30/107-42-30
G-222	Abandoned	39-29-30/107-41-30
G-223	Abandoned	39-29-30/107-41-30
G-224	Earl Hollenbeck Ranch	39-29/107-41
G-225	Unoccupied	39-29/107-42
G-226	Leonard Ivie	39-28-30/107-40-30
G-227	Ranch	39-27/107-40
G-228	Ranch	39-27/107-38-30
G-229	Bar-M-S-Ranch	39-24-30/107-39-30
G-230	T. P. O'Connel Ranch	39-24/107-39-30
G-231	Glenn Gaasch Ranch	39-25/107-40
G-232	Summer cabin	39-25-30/107-39-30
G-233	B. R. Shideler	39-26/107-40-30
G-234	S. Lambson Ranch	39-26/107-40-30
G-235	Shorty Hall Ranch	39-25-30/107-40-30
G-236	Ron Crandall Ranch	39-26/107-40
G-237	Charles O'Connell	39-26/107-39
G-238	Rufus Raley Ranch	39-27/107-39-30
G-239	Ralph Terrell Ranch	39-27/107-39-30
G-240	T. J. Flynn Ranch	39-27/107-39-30
G-241	Preston Ranch	39-28/107-39-30
G-242	J. E. Flynn	39-28/107-38-30
G-243	Bill Joe Adkins	39-28/107-38-30
G-243A	Terrell Silo	39-28/107-38-30
G-244	John R. Boolton	39-28-30/107-38-30
G-245	Jack Schultz Ranch	39-28-30/107-39-30
G-246	R. E. Lyons	39-29/107-39
G-247	Abandoned School	39-29/107-39
G-248	Errol R. Raley	39-29/107-39
G-249	Ranch	39-29-30/107-39
G-250	Rulison	
G-250A	Rulison Bridge	39-29/107-56
G-251	F. Alsbury Ranch	39-30/107-38
G-252	D. R. Henrie Ranch	39-32/107-42
G-253	Cabin	39-32/107-42
G-254	Barn	39-32/107-41-30
G-255	T. Sweeny	39-32/107-41-30
G-256	Limbach	39-32/107-40-30
G-257	John Everett	39-32-30/107-43
G-258	Silt	
G-259	Rifle	
G-260	Jesse and Edith Langstaff	39-31-30/107
G-261	The Oil Shale Corporation	
G-300	Silt	
G-300A	Silt Bridge	39-32-30/107-38-30

Location No.	Name	Lat./Long.
G-305	Snow White	39-33/107-40
G-306	Ranch	39-33/107-39-45
G-307	John A. Canto Ranch	39-33-30/107-40
G-308	Abandoned	39-33-30/107-40
G-309	W. H. Brinkman Ranch	39-34/107-40
G-310	Ranch	39-33-30/107-40
G-311	John Nelson Ranch	39-33-30/107-40
G-312	Ranch	39-33-30/107-40
G-313	Claude and Esma Lewis Ranch	39-33-30/107-40
G-314	Johnny Spruell Ranch	39-33-30/107-40
G-315	Ranch	39-33-30/107-40-45
G-316	J. Gillmore Ranch	39-33-30/107-41
G-317	Ranch	39-33-30/107-41
G-318	Ranch	39-33/107-41
G-319	Ranch	39-33/107-40-30
G-320	Hugo R. Kruger Ranch	39-34-30/107-40
G-321	Abandoned	39-35/107-40
G-322	Chet L. Bradley Ranch	39-35/107-40-30
G-323	Haywood, Lopez, and Hang Ranches	39-35-30/107-40
G-324	Joseph Brethauer Ranch	39-35/107-39-30
G-325	Zang Ranch	39-35/107-39-30
G-326	House	39-35/107-39-30
G-327	Barn-sheds	39-34-30/107-39-30
G-328	Carl D. Walker Ranch	39-34-30/107-39
G-329	Unoccupied Ranch	39-34-30/107-39
G-330	Ranch	39-34/107-38
G-331	B. L. Weber Ranch	39-34/107-39
G-332	Ranch	39-32-45/107-40-30

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