

Historical Information  
H.6 Seismic/Ground Motion  
Activity

Book 3

Structural Effects of the Rulison  
Event

HSG16

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Structural Effects  
of the  
RULISON Event



**JOHN A. BLUME & ASSOCIATES RESEARCH DIVISION**

**SAN FRANCISCO**

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Structural Effects  
of the  
RULISON Event

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

December 1969

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for the Nevada Operations Office, USAEC

STRUCTURAL EFFECTS OF THE RULISON EVENT

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ABSTRACT

Project RULISON is a natural gas production stimulation experiment that took place in Garfield County of western Colorado on September 10, 1969. The design yield was 40 kilotons, with a maximum credible yield of 60 kilotons and a depth of burial of 8425.5 feet.

*This report includes the preliminary results of post-event structural response investigations and evaluations of ground motion effects on buildings, hydraulic structures, and earth structures.*

A summary of current damage complaint investigations is also included. Appendix A presents perceptibility observations.

## SUMMARY

This report presents the preliminary data acquired by John A. Blume & Associates Research Division concerning the structural response effects from Project RULISON, an underground nuclear event conducted on September 10, 1969, in Garfield County, Colorado. The event was a natural gas production stimulation experiment.

A limited evaluation of the currently available data indicates that the JAB pre-shot predictions of damage occurrence are generally accurate. Most of the damage reports from locations close to ground zero cited either plaster cracking or chimney damage. The ground motion perceived by observers close to GZ was felt primarily as a vertical motion, the horizontal component being felt at more distant locations.

Since complete ground motion spectra and damage data are not available at this time, only tentative analyses and conclusions can be made of the effects of the event. Future reports will contain the more complete results of the analyses and evaluations with reference to pertinent response spectra extracted from the Environmental Research Corporation report.

## INTRODUCTION

The RULISON event took place on September 10, 1969, at 1500 hours (MDT) in Garfield County, Colorado. The event location was approximately at latitude 39°24' North, 107°56'30" West. A map showing the location of ground zero in relation to neighboring communities is given in Figure 1. The event location is approximately 10 kilometers east southeast of the town of Grand Valley, 20.5 kilometers southwest of Rifle, and 18.6 kilometers north of Collbran.

A comparison of damage predictions and actual effects is given in Table 1. A summary of the damage complaints received by October 21, 1969, is presented in Table 2. The complaints are listed according to the general area from which they originated -- the areas surrounding the towns of Grand Valley, Rifle, and Collbran, as well as from areas more than 20 kilometers from GZ -- and are tabulated in 15 categories describing the types of damage.

Appendix A gives the perceptibility observations made during the event by John A. Blume & Associates Research Division (JAB) personnel stationed at specific locations surrounding GZ.

The recording instruments were installed and operated by the U.S. Coast & Geodetic Survey (USC&GS) Special Projects Party. The records obtained from these instruments were then processed by USC&GS and by the Environmental Research Corporation (ERC). Sixty-eight passive gages were installed by JAB personnel across existing cracks and at critical building features on structures surrounding GZ. Installation of gages began on July 9, 1969 in the town of Rifle and covered small towns and residences south and west to Cameo and Collbran. From the date of installation to the time of removal in mid-October, some eleven readings at uniform

intervals were taken of each gage. An analysis of these readings with correlation to damage will be presented in a subsequent report. Preliminary review of the data indicates that the passive gage program was a worthwhile part of our program.

This report was prepared for the Office of Effects Evaluation, U.S. Atomic Energy Commission, Nevada Operations Office (NV).

## RESPONSE SPECTRA

The ground motion and structural response records are currently being analyzed by ERC and by JAB personnel. The results of these analyses with pertinent response spectra plots from ERC sources will be included in a later report.

## STRUCTURAL RESPONSE

This report is essentially a data report and only limited analyses have been made from the available data. A review of peak ground motions developed by USC&GS from the L-7 recorders and extrapolation to the four-way log plot gives an indication of the acceleration levels at various locations.

### 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 as predicted.

A preliminary 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.

	<u>Z</u>	<u>T</u>	<u>R</u>
Eames Orchard (6.99 km)	1.7g	0.82g	0.50g
Lemon Ranch (6.95 km)	0.54g	0.20g	0.35g

The difference in motions is appreciable, particularly for the vertical component, and may be partly the result of the difference in elevation (400') and the variation in azimuth.

The motion perception at the Clem Ranch, 4.5 km from GZ, was similar, with the observer there reporting a sharp vertical motion but no noticeable horizontal motion -- hanging objects did not swing nor did trees sway, although power lines did jump about. Two horses grazing at this ranch showed no reaction to the ground motion or to the muffled noise associated with the explosion.

Similar motion observations were reported at the Schwab Ranch, 6.4 km northwest of GZ, and at the Smith Ranch, 8.0 km west 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 two steel truss bridges over the Colorado River at Grand Valley and at Rulison.

Observers within this range reported that the vertical motion was strongly perceptible, followed by some horizontal component. The horizontal motion is generally felt less by observers than the vertical motion probably because their standing positions tend to dampen the reaction to horizontal motion. A preliminary review of peak motion indicates that the horizontal and vertical components are very similar.

	<u>Z</u>	<u>T</u>	<u>R</u>
Grand Valley School (11.43 km)	0.60g	0.13g	0.41g
Anvil Points (13.83 km)	0.20g	0.11g	0.20g

A preliminary comparison of the observers' reports of motion direction and intensity and actual damage shows the effect of the horizontal component of motion. The amount of chimney damage and wall cracking within this 7.4 to 14 km range seems to confirm the validity of this comparison in that chimney damage and wall cracking occur at 7 to 14 kilometers where horizontal motion was strongly perceptible.

### 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 (20 km) the perceived motion was less intense but similar in direction. A preliminary review of ground motion data again confirms the motion perceptions and damage observations of the observers.

	<u>Z</u>	<u>I</u>	<u>R</u>
Union Carbide Plant (18.12 km)	0.10g	0.15g	0.08g
Collbran (18.24 km)	0.15g	0.05g	0.05g
Rifle (20.28 km)	0.08g	0.08g	0.07g
DeBeque School* (24.63 km)	0.09g	0.05g	0.06g
DeBeque Business Dist.**	0.21g	0.11g	0.09g

\* Hard rock  
\*\* Alluvium

### 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 credible 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 crack crossed a driveway which was travelled 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 crack 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.

Materials involved in the cracking as well as downslope from the crack are torrentially bedded sands, silts and gravels overlain by boulder gravels and thick beds of silts. These materials appear to be deposited in and over an old canyon scoured into beds of soft silts and hard sandstone of the Wasatch Formation.

This crack has resulted from the slumping of a portion of the valley slope along pre-existing planes of weakness. The movement is believed to have resulted from the event-related ground motion for the following reasons:

- (1) The formation of the crack is relatively fixed in time if the statement of the property owner and observer is assumed to be credible.
- (2) An examination of the crack indicates that it was extremely fresh. There was no indication that the crack had been open for any length of time. Such indications would be plant growth in the crack face, sloughing or ravelling at the crack edges, disaggregation of barely cohesive sands and silts around freshly exposed plant roots, and erosion of the crack edges by recent rainfall run-off where the crack is intersected by small scours and rills running downslope.
- (3) Ground water levels were at their lowest of the season. Seepage along the base of the slope is localized; however, alkali bloom in the soils indicates that seepage was much more extensive earlier in the season. It would be difficult theoretically to justify this type of failure in the fall because the weight of the soil mass is at its lowest and the strength is at its highest then. This type of failure would be justified in the late spring, at or following the spring thaw. The presence of older slides in identical physiographic positions flanking the cracked area implies that the soil mass was inherently unstable and also indicates that future movement of the cracked soil mass is probable from natural effects.

### Rifle Gap Dam and Reservoir

Rifle Gap Dam, approximately 28 km from RULISON GZ, is a zoned earthfill structure with a height above stream bed of 120 feet and a crest length of 1500 feet. The reservoir has a total capacity of 13,000 acre-feet. At the time of the RULISON event, the reservoir contained 6615 acre-feet or approximately 50% of its full capacity.

Seismic ground motion instrumentation at the dam was by the Corps of Engineers. Instrumentation results have not yet been received.

A non-recording float gage to measure seiche or surge was installed by JAB and manned by an observer at a point approximately 0.6 mile west of the right abutment. The instrument was originally fabricated by JAB to measure long-period waves in harbor models. The gage was installed in a stilling well connected to the reservoir by a series of holes which serve as a hydraulic filter. The observed action of the gage initiated by the RULISON event was a surface wave of translation or surge.

Computations were made of the surface wave of translation 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 3.05 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.

Cracks adjacent to road relocations on both sides of the dam were also monitored by means of two fixed bench marks on either side of the crack in firm ground. Distances between these bench marks were then measured before and after the detonation and there was no change in distance.

### Battlement Mesa Dams

The low dams on Battlement Mesa are approximately 3.1 km south of GZ at an average elevation of 10,100 feet. Several of the dams have been inoperative for a considerable number of years. Of

those which contain water, the outlet control works are inoperative. Consequently, the flow that reaches Battlement Creek is normal overflow from the reservoir surface water which is sustained by seepage through the ground from the reservoir areas in late summer.

Surveys on these earth structures consisted of visual examination of all dams and recommendations for the establishment of relative vertical and horizontal control points on four of the dams which contained water prior to the RULISON detonation date. These surveys were performed for C.E.R. Geonuclear Corp. by Western Engineers, Inc.

The vertical and horizontal surveys were performed to an accuracy of 0.01 foot. The pre-shot stations were established and initial observations performed on September 3 and 4, 1969. Post-shot observations were performed on September 12, 1969.

Within the above specified time period no measurable deformation of the dams was recorded that exceeded the normal instrumental error for this type of survey.

Observers were not stationed at the dams during shot time.

#### Harvey Gap Dam

The reservoir behind Harvey Gap Dam, at an elevation of 6379 feet, contained 1658 acre-feet of water (approximately 30% of full capacity) at shot time.

Seismic instrumentation was placed at various locations on the dam by USC&GS personnel. A portable Sprengnether was placed by JAB personnel on the crest of the dam approximately midway between the abutments. The height of the dam at the Sprengnether location is approximately 60 feet. The longitudinal axis of the Sprengnether was oriented normal to the long axis of the dam.

Additional pre- and post-shot observations consisted of vertical and horizontal surveys to detect changes in elevations and distances along the crest. These surveys were performed at the recommendation of JAB by Western Engineers, Inc. for C.E.R. Geonuclear, Inc.

Observers were present on the dam site at shot time to detect any megascopic ground motion effects on both the dam and reservoir.

From the Sprengnether a longitudinal trace was obtained which indicates measurable vibration of the dam normal to the long axis of the fill section. A comparison of the predicted and actual response of the dam as determined from the Sprengnether record follows.

<u>Parameter</u>	<u>Predicted Values</u>	<u>Observed Values</u>
Fundamental Period (seconds)	0.39	0.41
Crest Acceleration	0.11	0.15
Damping (% critical)	20	18
Shear Velocity (fsp)	400 (assumed)	380

A maximum particle velocity of 4.7 cm/sec was sustained for an incremental time period of 0.20 second.

For the survey vertical and horizontal control points were established across the crest of the dam and on each abutment. Initial observations were made on August 19, 1969. Following the initial observation, the control points were disturbed by truck traffic and the survey was repeated on September 3, 1969, to establish new positions for the control points and for comparison with post-shot observations. The post-shot observations were made on September 11, 1969.

Vertical changes were less than 0.003 foot and horizontal changes less than 0.015 foot. These slight changes are within the range

of instrumental error for the method of surveying employed. These data indicate that no measurable permanent deformations took place in the fill section of the dam as a result of the event-related ground motion.

Observers stationed on the dam reported perceptible ground motion. The seismic instrumentation over-ranged, particularly the horizontal component. These records are currently being processed; however, the values noted above appear to be reasonable approximations of the actual response of the earth structure.

## DAMAGE ANALYSIS AND COMPLAINT INVESTIGATIONS

In general, the JAB pre-shot predictions of damage occurrence were quite accurate. Damage of the type described usually occurred at the locations noted. It is also significant that the actual ground motions agreed closely with the predicted ground motions although slightly higher in the short period ranges in some cases.

Table 1 presents a comparison of damage predictions and actual effects. This table is related to the ERC-predicted PSRV at the design yield of 40 kt. By November 14, 1969, the amount paid out for damage was approximately \$50,000.

The fact that damage occurred where it was predicted and that following JAB evacuation recommendations resulted in personnel safety is of major importance.

Table 2 presents a summary of the various damage complaints by type of damage. The summary relates to the general population areas. Grand Valley includes the town of Grand Valley and structures on Battlement Mesa, Morrisania Mesa, and Holmes Mesa. Rifle includes the areas of the town of Rifle and the many farming locations on the south side of the river, including Taughenbaugh and Grass Mesas and portions of Holmes Mesa.

Collbran includes the town of Collbran, Kansas Mesa, and other nearby areas. Complaints from Grand Junction, DeBeque, Mesa, New Castle, Paonia, Palisade, Cedaredge, Somerset, Carbondale, Leadville, Delta and two locations in Utah are included under the heading of more than 20 kilometers.

The damage complaints from Grand Valley and Rifle are about equally divided between chimneys and plaster cracking. The complaints from

TABLE 1

COMPARISON OF DAMAGE PREDICTIONS AND ACTUAL EFFECTS

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

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

the areas further out are generally involved only with plaster and masonry wall cracks.

The precautions taken in having people evacuated from the area or outside of the house and two building heights away from the house were well advised. The care taken during the pre-shot activity in removing or re-building chimneys at close-in locations was also well advised. At these locations none of the remaining chimneys fell, although some loose bricks on the tops of small chimneys did fall as was predicted. 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.

Table 2 shows some 304 complaints received as of October 21, 1969. Total damage complaints as of November 13 total 361 with approximately \$50,000 paid out. Of the 304 complaints 109 complaints were for chimney damage, 151 for cracked interior plaster, 28 for broken windows, 19 for cisterns, 9 for wells, 17 for fireplace damage, 66 for foundation damage, 52 for cracked exterior masonry walls, 25 for other types of exterior walls, 9 for utility lines, 7 for roof damage, 8 for earth slides or minor rock-falls, 5 for TVsets, 8 for broken household items, and 84 were for other types of damage. Many of the complainants reported more than one type of damage.

TABLE 2: SUMMARY OF TYPES OF DAMAGE COMPLAINTS

<u>Type of Damage</u>	<u>Grand Valley</u>	<u>Rifle</u>	<u>Collbran</u>	<u>More than 20 km</u>
Chimney	77	27	4	1
Interior Plaster	65	53	13	20
Window	14	11	2	1
Cisterns	13	-	2	4
Wells	4	2	2	1
Fireplace	5	6	3	2
Foundation	17	29	12	8
Masonry Walls, Ext.	15	23	2	12
Other Ext. Walls	13	10	-	2
Utility Lines	4	3	1	1
Roof	4	3	-	1
Earth Slides	3	1	1	2
TV Sets	2	-	1	2
Household Items	4	1	2	1
Other Damage	37	22	9	16

APPENDIX A

PERCEPTIBILITY OBSERVATIONS

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PERCEPTIBILITY OBSERVATIONS  
(for observers only)

- 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 non-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.

STATION 12.5 km S. of GZ LOCATION \_\_\_\_\_ DATE 9-10-69

REMARKS: 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 the car.

OBSERVER F. R. Conwell EVENT RULISON

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

STATION 12 km WSW of GZ LOCATION \_\_\_\_\_ DATE 9-10-69

REMARKS: The motion was felt about 3 seconds after the shot from a southeast direction. The motion and noise seemed to arrive simultaneously. The motion was vertical with a duration of 12 seconds. A soft drink 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 was broken on the house. A half-full can of linseed oil fell from a shelf. Trees swayed.

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OBSERVER C. D. Kensler EVENT RULISON



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Noticed by some non-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.

STATION 6.1 km N of GZ LOCATION \_\_\_\_\_ DATE 9-10-69

REMARKS: The motion was strongly felt at approximately 1500 + 6 seconds.  
The motion was mainly vertical with a north-south orientation, with the  
magnitude of the vertical component almost obscuring the horizontal.  
This location is about 6 kilometers from ground zero. Obvious 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.

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OBSERVER W. H. Nelson EVENT RULISON



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Noticed by some non-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.

STATION 18 km NE of GZ LOCATION \_\_\_\_\_ DATE 9-10-69

REMARKS: 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. Sprengnether light traces were normal after about 20 to 30 seconds.

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OBSERVER R. E. Skjel EVENT RULISON





PERCEPTIBILITY OBSERVATIONS  
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Noticed by some non-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.

STATION 6.2 km WNW of GZ LOCATION \_\_\_\_\_ DATE 9-10-69

REMARKS: Stood facing southeast toward ground zero approximately  
30 feet northwest of the house. Felt a very distinct and sharp ver-  
tical motion, almost as if being raised off the ground. The house  
appeared to move, which may have been an illusion caused by reflec-  
tions in the windows. Heard glass and a loose storm door rattling.  
Did not feel any horizontal motion.

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OBSERVER R. F. Runge EVENT RULISON

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STATION 18 km S of GZ LOCATION \_\_\_\_\_ DATE 9-10-69

REMARKS: 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.

OBSERVER K. K. Honda EVENT RULISON



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