GROUND RESPONSE IN THE SALT LAKE CITY-OGDEN-PROVO, UTAH, URBAN CORRIDOR

by

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SUMMARY

An evaluation of the ground-shaking hazard, based on the spectral characteristics of ground motion, has been unavailable in the Salt Lake City-Ogden-Provo, Utah, urban corridor until now. This region, which had a population of approximately 900,000 in 1975, is on or adjacent to the Wasatch fault zone, a fault system that may have the potential for producing a large (M=7.5) earthquake. Because only one accelerogram exists for Utah earthquakes of the past, nuclear-explosion ground-motion data were recorded at sites in each city to estimate the characteristics of ground response. These data show that the ground-shaking hazard is significant and a function of the local geology.

INTRODUCTION

This paper presents results of research to define the ground-shaking hazard in the important Salt Lake City-Ogden-Provo urban corridor. These three cities (Fig. 1) are built on unconsolidated deposits of the Pleistocene-age Lake Bonneville and are on or adjacent to the Wasatch fault zone, a 370-km-long north-trending zone of young, active, normal faulting. Although the Wasatch fault zone has not produced an earthquake as large as magnitude 6 since 1850 (Arabasz and others, 1979), the geologic and geomorphic records clearly show that faults in this zone have been active for millions of years (Hamblin, 1976) and may have the potential for generating an earthquake of magnitude 7.5. Such earthquakes could potentially produce severe ground shaking as well as surface faulting, landslides, and ground failure due to liquefaction.

THE RESEARCH PROBLEM

At present, only one strong ground-motion record exists in Utah. This accelerogram was recorded at Logan during the 1962 Cache Valley earthquake. Because of the lack of ground-motion data from past earthquakes in the Wasatch fault zone, nuclear-explosion ground-motion data were recorded at selected sites in each city to provide a basis for estimating the spectral characteristics of ground response. Ground-motion measurements were made using broadband velocity seismographs at 27 locations in Salt Lake City (Fig. 2), 18 in Ogden, and 11 in Provo. Some of the recording sites in each city are underlain by rock (for example, limestone, shale, sandstone, and quartz monzonite), but others are underlain by unconsolidated material (Table 1). Each site was selected so

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as to encompass the widest possible variety of physical properties and to define the ground response in the vicinity of the Wasatch fault zone.

The unconsolidated material related to Lake Bonneville in the Salt Lake City area has fairly well defined physical properties. The deposits range in thickness from about 100 to 900 m, have shear-wave velocities that average about 200 m/s, and have a natural moisture content by weight of about 43 percent. Some variance exists for each value.

Although considerably less information is available in both Ogden and Provo to define the physical properties of the unconsolidated material, the best available data suggest that the physical properties of the material underlying these two cities are similar to that underlying Salt Lake City. A borehole in the Provo area indicates a shear-wave velocity of about 155 m/s. This value and the value of 200 m/s obtained in a borehole in Salt Lake City can be compared with values ranging from 55 to 310 m/s for soil types in the San Francisco Bay region (Gibbs and others, 1976).

Several research questions were addressed in the evaluation of the ground-shaking hazard for each city. They include:

1. Do the various types of consolidated and unconsolidated material in an area respond to ground motion in a distinct manner?
2. Are ground-motion data from nuclear explosions adequate for defining the relative response of geologic units to earthquake ground shaking?
3. Over what range of ground-motion levels and strain does relative ground response behave linearly?
4. What physical properties control the horizontal spatial variation of ground response in each geographic area?

GROUND RESPONSE

The transfer-function technique was used to define the frequency-dependent ground response in each city. The transfer function (which is defined as the average ratio of the 5-percent damped, horizontal, velocity response spectra for a pair of sites) has been shown to be a function of the shear-wave velocity, thickness, water content, and geometry of the unconsolidated material and rock underlying the two sites (Borcherdt, 1975; Hays and others, 1978; Rogers and Hays, 1978; and Hays and others, 1979). Rogers and Hays (1978) suggested on the basis of the best available data that the transfer function can be determined reasonably well from either earthquake or nuclear-explosion ground-motion data, even though there may be significant differences in the level of peak ground acceleration and strain (defined as the ratio of the peak particle velocity and the shear-wave velocity of the material underlying the site) represented by the ground-motion data. Consideration of the signal-to-noise ratio is also important when deriving transfer functions, especially for the short periods where the noise level often is high.

Salt Lake City area

In the Salt Lake City area, the horizontal ground response varies considerably. The range of ground response for sites underlain by unconsolidated materials is shown in Figs. 3 and 4, relative to a rock site on the Wasatch front. The ground response for sites underlain by thin, semisaturated gravel and clay is approximately greater by a factor of 2 across the period band 0.2-2 s than that for sites underlain by rock. The ground response for sites underlain by thick, water-saturated, fine-grained unconsolidated material is approximately greater by a factor of 10 in the same period band.

Provo area

The horizontal ground response, relative to a rock station on the Wasatch front also varies markedly in the Provo area. As in the Salt Lake City area ground response seems to correlate primarily with the lateral variation in thickness, lithology, and high moisture content by weight of the unconsolidated material in the Utah Valley. High moisture content in the fine-grained, thick silts and clays produces low shear-wave velocity and causes a high contrast in acoustic impedance between the unconsolidated material and rock which, consequently, causes a large relative ground response. The unconsolidated material tends to be thinner and to consist of semisaturated, coarse gravel sand and to be near the Wasatch front. This material has a higher shear-wave velocity and, consequently, lower relative ground response.

Ogden area

The horizontal ground response of the unconsolidated materials in the Ogden area, relative to a rock station on the Wasatch front, is similar to that noted in Salt Lake City and Provo. The sites underlain by thick, water-saturated, fine-grained unconsolidated material show a much greater response across the period band than do sites underlain by thin, semisaturated, coarse material.

Ground-response maps

Ground response in the Salt Lake City area is depicted in the format of a contour map in Fig. 5 to show the spatial variation of ground response for a particular period band, 0.2-0.7 s. This period band corresponds to the fundamental mode of response of 3 to 7-story structures. The contours give best estimates of the ground response at sites underlain by unconsolidated material, relative to a rock site on the Wasatch front. The map illustrates the effect noted above; namely, the general correlation of low relative ground response with thin, semisaturated, coarse gravel and sand near the Wasatch front and higher relative ground response with thick, saturated, fine-grained silts and clays underlying sites some distance from the front. Although not illustrated here, similar maps would be obtained for the Provo and Ogden areas.

EARTHQUAKE GROUND-SHAKING HAZARD

Determination of the earthquake ground-shaking hazard for the Salt Lake City-Ogden-Provo region is a complex research problem (Hays, 1980). However, a reasonable approach to the problem is provided by using the probabilistic ground-shaking hazard map for Utah prepared by Algermissen and Perkins (1976) in conjunction with the ground response data for each city. The probabilistic map for Utah, which was based on the structural geology and historical seismicity, depicts the 90-percent probable peak horizontal acceleration that would be expected to occur at sites underlain by rock in a 50-year exposure time. For the Salt Lake City-Ogden-Provo region, this value of acceleration is 20 percent g.

Design response spectrum

The value of 20 percent g can be used to define the short-period asymptote of a smooth design response spectrum. If we use Salt Lake City as a representative example, the spectrum for sites underlain by rock (such as station 7) on the Wasatch front is shown in Fig. 6. Its shape is based on guidelines published by the U.S. Nuclear Regulatory Commission (U.S. Atomic Energy Commission, 1973) and its level on actual response spectra derived from the accelerograms recorded at 3737 Lankershime (a rock site) during the 1971 San Fernando earthquake. Superposed on Fig. 6 for comparison are the damage and hazard threshold spectra (Blume and Skjei, 1970); the boundary of the hazard spectrum represents a postulated level of response below which serious injury or death due to structural damage is unlikely.

An estimate of the ground-shaking hazard at sites in the Salt Lake City area underlain by unconsolidated material is shown in terms of response spectra in Fig. 6. This estimate was obtained by multiplying discrete values of the smooth rock spectrum (Fig. 6) by values at corresponding periods of the transfer function for each site in the area. (For example, the contour values in Fig. 5 for the period band 0.2-0.7 s are multiplied by the appropriate part of the rock spectrum in Fig. 6.) The range of values is shown in terms of the upper and lower spectral envelopes and denotes the large variation in ground response in the region.

High-strain ground motion

The spectral values shown in Fig. 6 incorporate a reduction to account for possible high-strain effects in an earthquake that produces a peak ground acceleration of 20 percent g. The question of the dependence of a transfer function on the shear-strain level is controversial, primarily because of limited ground-motion data. However, recent empirical data (Hays and others, 1979) suggest that ground response for some unconsolidated material is essentially independent of shear strain in the range of 10^{-5} to 10^{-3} percent. Above 10^{-3} percent, the response at sites underlain by unconsolidated material may be reduced by about a factor of 2 relative to that for sites underlain by rock, as compared with the reverse effect for lower strain levels. The epicentral distance to the 10^{-3} strain level produced by an earthquake in the Wasatch fault zone is about 19 km; the distance to the $5x10^{-3}$ strain level is about 2 km.

Potential damage

An earthquake on the Wasatch front producing a peak ground acceleration of 20 percent g at sites underlain by rock and unconsolidated material and spectral velocities ranging from 20 to 100 cm/s in the period band 0.05 to 4 s would have a significant effect on all types of structures, whether located on rock or soil. Although a detailed investigation of loss from ground shaking is beyond the scope of this paper, considerable damage, which varies as a function of the ground condition, is clearly likely in such an earthquake.

CONCLUSIONS

The research on ground response in the Salt Lake City-Ogden-Provo urban corridor has provided some important results. These results, although based on limited site-dependent data, suggest the following conclusions:

1. The consolidated and unconsolidated material in the Salt Lake City-Ogden-Provo area have distinctive characteristics of ground response.
2. The horizontal spatial variation of ground response in the area is complex and varies by as much as a factor of 10 in some period bands. The physical properties controlling ground response appear to be the laterally varying thickness and contrast in acoustic impedance. High moisture content by weight in the unconsolidated material is very important in causing a high relative ground response.
3. The ground-response data coupled with low shear resistance and high moisture content of the unconsolidated material suggest that portions of the urban corridor may be susceptible to failure from ground shaking.

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FIGURES

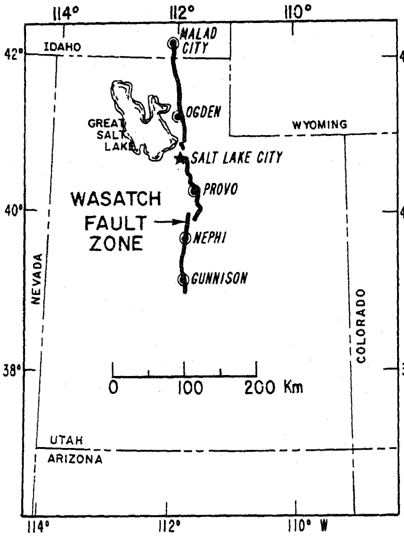

Fig. 1.--Map showing Salt Lake City, Ogden, and Provo, and the Wasatch fault zone.

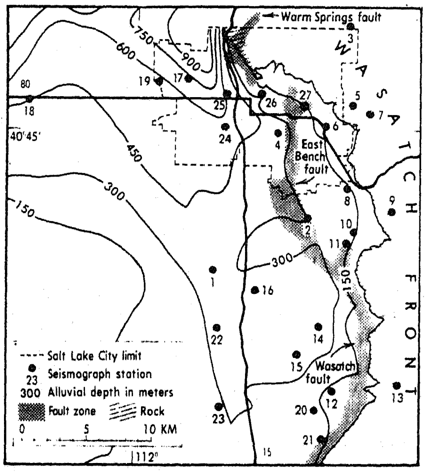

Fig. 2.--Map showing locations of seismograph stations, thickness of unconsolidated material, and Wasatch fault zone; Salt Lake City area (see Table 1).

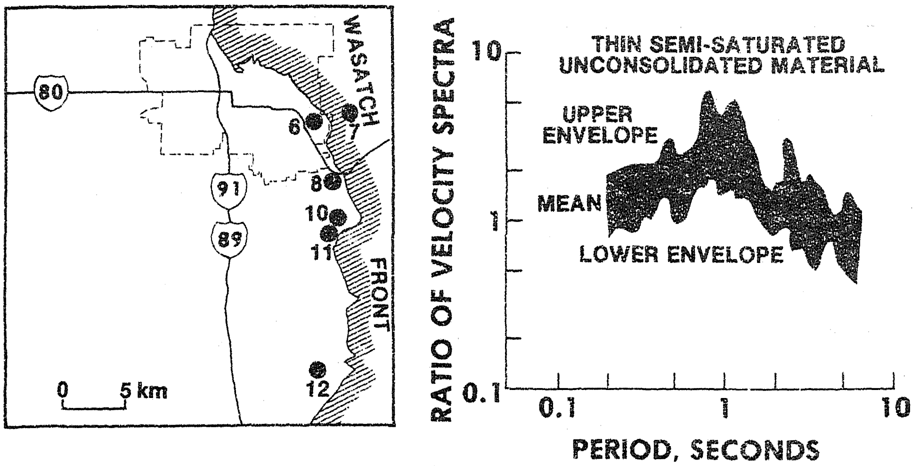

Fig. 3.--Range of transfer functions showing horizontal ground response of thin semisaturated unconsolidated material (stations 6, 8, 10, 11, 12) relative to a rock site (station 7) on the Wasatch front, Salt Lake City area (see Table 1).

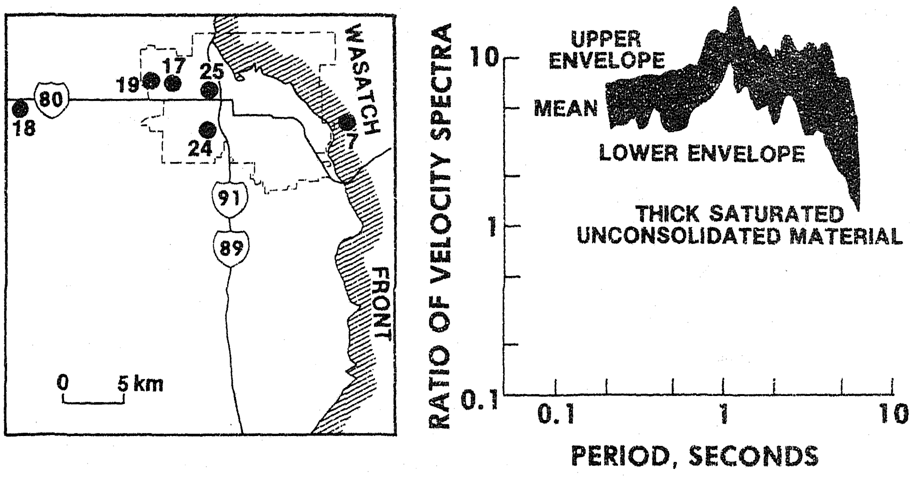

Fig. 4.--Range of transfer functions showing horizontal ground response of thick saturated unconsolidated material (stations 17, 18, 19, 24, 25) relative to a rock site (station 7) on the Wasatch front, Salt Lake City area (see Table 1).

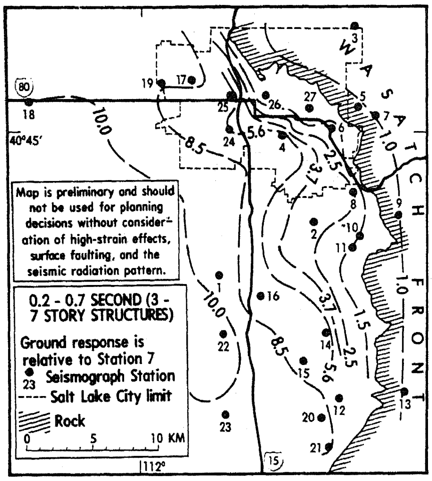

Fig. 5.--Map of estimated horizontal ground response for the period band 0.2-0.7 s, Salt Lake City area. Values on contours indicate the ratio of velocity response spectra relative to station 7 on the Wasatch front.

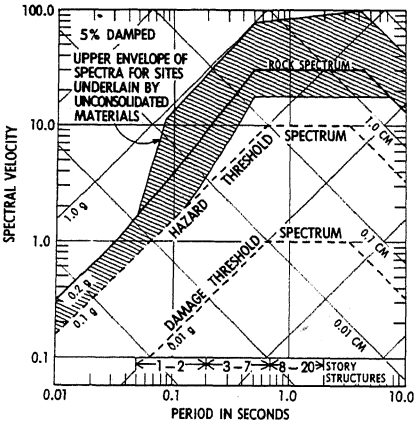

Fig. 6,--Estimated range of values of horizontal spectral velocity for sites underlain by rock and unconsolidated material in the Salt Lake City area.

Table 1.--Brief description of the site geology for recording stations in the Ogden, Salt Lake City, and Provo areas. Numbers in parenthesis (e.g., (1)) are station designations.

OGDEN AREA	SITE DESCRIPTION
Barrets Dairy Farm (1)	Alternating clay and sand, possibly old liquefaction slide
293 10th Street (2)	- do -
Plain City Grade School (3)	- do -
Ogden Canyon (4)	*Rock*; quartzite
Washington St. Library (5)	Alluvium/sand/gravel
Weber Main Library (6)	Sand/gravel/clay
4581 Taylor Street (7)	*Rock*; quartzite
Syracuse Grade School (8)	Fine grained clay and silt
Municipal Airport (9)	Sand and gravel
Southeast of Washington Terrace near Highway 89 (10)	Alternating sand and clay
Washington Heights Cemetary (11)	*Sand/alternating sand and clay*
Farmhouse, Taylor (12)	Silty clay
Post office, Hooper (13)	*Sand/clay/alternating sand and clay*
Weber State College (14)	Sand and gravel/clay/sand and gravel
Federal Building (15)	Alluvium/sand and gravel/clay
West Warren (16)	Silty clay/sand/alternating sand and clay
South of Garner Canyon (17)	*Rock*; quartzite
Radio Tower on Little Mountain (18)	*Rock*; tillite
SALT LAKE CITY AREA	
West bank of Jordan River (1)	Sand/silt, clay/alternating gravel and clay
Near East Bench fault (2)	Clay/alternating clay and gravel
Rotary Park in City Creek (3)	*Rock*; Fitchville limestone
Liberty Park (4)	Clay alternating with sand
Georges Hollow, Fort Douglas (5)	*Rock* ; Nugget sandstone
Utah Geological and Mineralogical Survey (6)	Silt and clay/gravel/sandy silt
Emigration Canyon (7)	*Rock*; Twin Creek limestone
South side of Parleys Creek (8)	Gravel/alternating silt and clay
Mill Creek Canyon (9)	*Rock*; Weber quartzite
4500 South Street near Wasatch Blvd.(10)	Sand
Castro Springs (11)	Silt and clay
North bank of Dry Creek (12)	Windblown sand/gravel/sand and silt
Little Cottonwood Canyon (13)	*Rock*; quartz monzonite
1932 Parkridge (14)	Windblown sand/sand and gravel
Sand Creek Fire Station (15)	Sand and gravel
Murray City (16)	- do -
Salt Lake International Airport (17)	Silty clay/alternating clay, silt and sand
Morton Salt Plant, Saltair (18)	- do -
Salt Lake International Airport (fire station (19)	*- do -*
South bank of Dry Creek (20)	Sand/sand and gravel
Draper (21)	Sand/sand and gravel/gravel
West side of Jordan River, Midvale (22)	Sandy silt/clayey silt/gravel and clay
South Jordan Cemetary (23)	Silty sand/silt
North of Jordan Park (24)	Silt/sand/silt
Northeast corner, state fairgrounds (25)	Silt/sand
South of State capitol (26)	Gravel and sand
University of Utah campus (27)	- do -
PROVO AREA	
Provo Canyon (1)	*Rock*; limestone and shale
Provo Canyon (gravel pit) (2)	*Rock*; shale
Fire station, Orem (3)	Thick gravel/clay/alternating gravel and clay
Post office, Orem (4)	- do -
Lakeview, along highway (5)	Thin sand/thick silt and clay/alternating gravel and clay
Provo Airport (6)	Clay and fine sand/gravel
Boat harbor, Utah Lake (7)	Sand and clay
Fire station, Provo (8)	Thin silt/coarse gravel and alternating clay
Southeast Interstate 15 (9)	Thin silt/gravel/thick clay
Youd Farm (near lakeshore) (10)	Alternating sand and clay
Fire station, Springville (11)	Gravel/thick clay