Amplification Of Earthquake Motions in the Great Salt Lake Valley Due to Deep Basin Shape and Shallow Soil Stratigraphy

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ABSTRACT

A number of recent earthquakes (1985 Mexico City, 1989 Loma Prieta, 1994 Northridge) have demonstrated that local site conditions can significantly alter measured ground motions and the potential for earthquake damage. The Salt Lake Valley has many of these local characteristics which have caused problems in other areas. The valley is underlain with a bedrock / stiff alluvium interface which forms an energy focusing basin. In addition, the valley floor contains soft lacustrine clays which can slow and amplify seismic energy. The USGS conducted a study to investigate the potential for seismic amplification in the Salt Lake Valley. This study measured the accelerations caused by a nuclear explosion at the Nevada Test Site in southern Nevada at over 30 different sites in the valley. Spectral accelerations at sites in the valley center were from 1 to 11 times larger than spectral accelerations on rock sites at the valley edges. Previous attempts to apply computer analyses to this phenomenon have not been completely successful. This paper describes an uncoupled modeling effort of combining a 2D basin program with a 1D surface program in an attempt to better model the measured results from the nuclear blast study.

INTRODUCTION

A number of recent earthquakes (1985 Mexico City, 1989 Loma Prieta, 1994 Northridge) have demonstrated that local site conditions can significantly alter measured ground motions and the potential for earthquake damage. The Salt Lake Valley has many of the same local site conditions that have caused problems in other locations. The underlying bedrock/stiff alluvium forms a basin shape with relatively steep sides along the eastern mountain front. Also, the shallow surface soils contain moderately dense alluvial sands and gravel's near the mountain fronts but softer lacustrine silts, sands and clays near the center of the valley.

To evaluate the influence of basin shape and local soil conditions on amplification in the Salt Lake Valley, a group of researchers from the United States Geologic Survey (USGS) placed 30 seismographs throughout the Salt Lake Valley. Ground surface accelerations were measured from a number of nuclear detonations at the Nevada Test Site in southern Nevada (Hays and King, 1982; Hays, 1987). Their results indicate that in the period range from 0.2 to 0.7 sec., spectral accelerations in the valley center were typically 5 to 11 times greater than spectral accelerations recorded on bedrock at sites on the east bench of the Salt Lake Valley.

Several studies (Benz and Smith, 1988; Hill, 1988; Martin, 1989; Olsen et al. 1994) have attempted to match the measured USGS amplification using either one, two or three dimensional numerical methods. Geophysicists have concentrated on the effect of the deep basin shape, while geotechnical engineers have concentrated on the effect of the shallow surface soils. However, none of these studies have adequately accounted for the amplification observed in the USGS study.

The purpose of this research was to more accurately quantify the expected amplification in the Salt Lake Basin by evaluating the influence of both the shallow surface soils and deep basin shape. Numerical models were created using the available data from previous research. A unique method was implemented to analyze the response of the models using a low-strain, far-field (nuclear blast) event. The computed amplification was then compared with measured low-strain amplification. Finally, the same models and methods were used to compute the expected ground motion amplification from a high-strain near-field (earthquake) event.

BASIN AND SHALLOW SOIL CHARACTERISTICS OF THE SALT LAKE VALLEY

Basin Characteristics

Seismic reflection data recorded at the north end of Salt Lake Basin indicate that the basin contains three main material interfaces. These interfaces, or reflectors, represent the boundaries between four soil zones with distinct material properties. Reflector 1 (R1), separates unconsolidated Quaternary deposits and semi-consolidated Tertiary deposits. Reflector 2 (R2), separates semi-consolidated Tertiary deposits and consolidated rocks of several ages. Reflector 3 (R3), separates the consolidated rock and the underlying basement rock (Arnow and Mattick, 1968; Mattick, 1970; Hill, 1988; Radkins et al, 1989). Shear wave velocity and density data for each soil zone are shown in Table 1.

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Table 1 *Summary of shear wave velocity and density for soil/rock layers within the Salt Lake Basin (Radkins et. Al. 1989).*

Layer	Shear Wave Velocity	Density
Unconsolidated Quaternary Deposits	V_s = 0.98 km/s (3200 ft/s)	γ = 2.15 gm/cm^3 (134 pcf)
Semi-consolidated Tertiary Deposits	V_s = 1.42 km/s (4660 ft/s)	γ = 2.45 gm/cm^3 (137 pcf)
Consolidated Rock	V_s = 2.89 km/s (9500 ft/s)	γ = 2.65 gm/cm^3 (165 pcf)
Basement Rock	V_s = 3.46 km/s (11,350 ft/s)	γ = 2.75 gm/cm^3 (172 pcf)

Researchers at the University of Utah (Olsen et al., 1994) recently created a 3D model of the R2 interface using 3D gravity inversion techniques. Seismic data and well logs were used for control. This 3D model improves the model developed by Fox (1983). For use in this study, data for four 2D cross sections of the R1 and R2 interfaces were obtained from this model. These cross sections correspond to latitudes 40.80 , 40.78 , 40.75 and 40.69 and are shown in Figure 1.

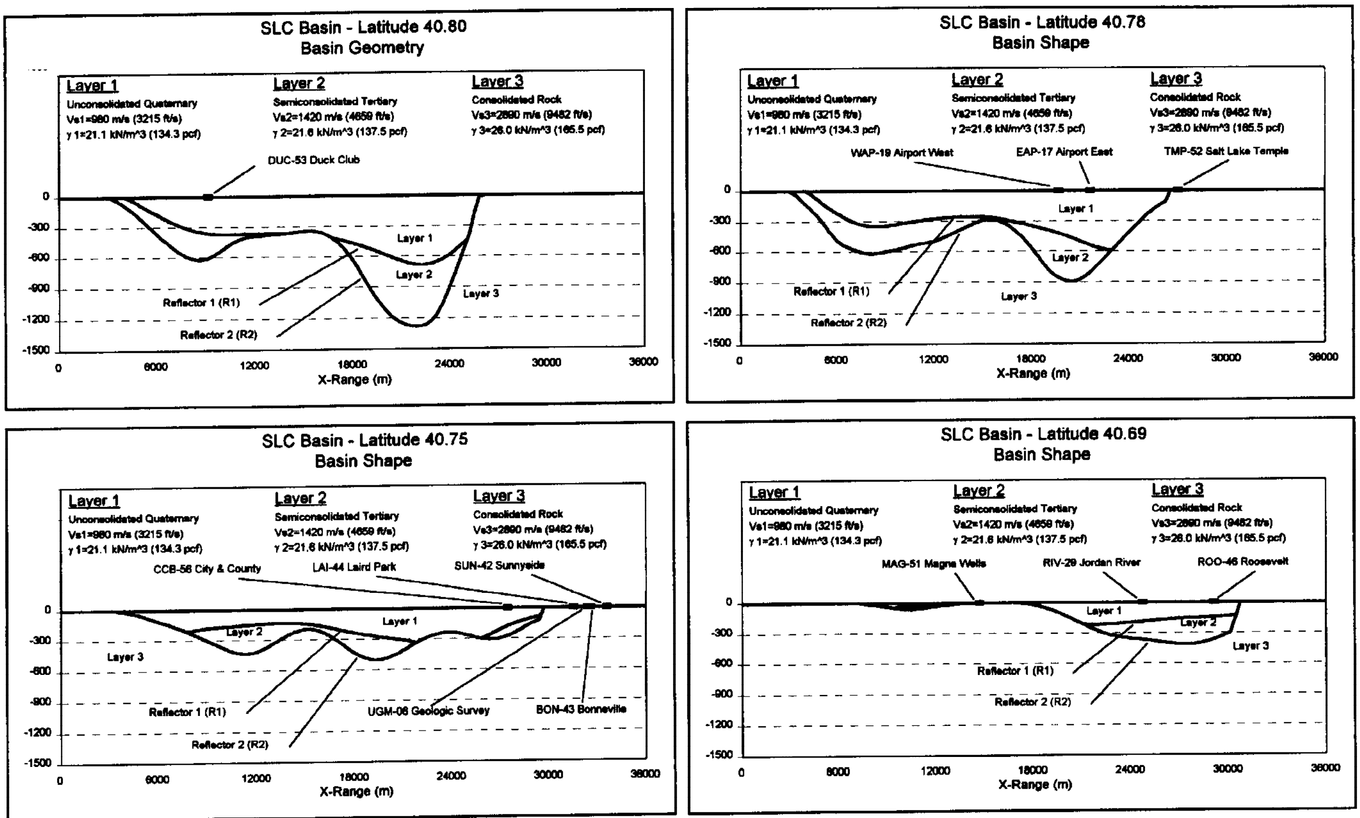

Figure 1 *Cross sections of the Great Salt Lake Basin showing R1 and R2 interfaces and basin characteristics. The USGS sites associated with each cross section are also shown.*

Shallow Soil Characteristics

Source of Data

As part of the study by Hays and King (1982), boreholes were drilled at each USGS seismograph location and a limited number of soil samples were taken. The boreholes generally extended to a depth of 60 m (200 ft) or until a layer of underlying rock was encountered. Well logs were compiled and limited soil testing was performed.

Amplification Zones and Representative Sites

Based upon the amplification ratio from the nuclear blast data, the valley can be divided into four amplification zones. The four zones had average spectral ratios of 1-3, 3-5, 5-8, and 8-11. Three representative USGS boring sites were chosen for analysis in each amplification zone for this study. The longitude and latitude as well as the name for each of these 12 sites are shown in Table 2. The measured spectral ratios at each location for two period bands are also shown in Table 2. A summary of characteristics for the soils found in each zone is given in Table 3.

Table 2 *Summary of USGS Seismograph Station Locations and Spectral Ratios.*

Station		Latitude	Longitude	Spectral Ratio 0.2<T<0.7	Spectral Ratio 0.7<T<1.0	Amplification Zone
UGM-06	Utah Geol. & Min.	40.7564°	111.8278°	2.5	2.8	1-3
SUN-42	Sunnyside Trng. Ctn.	40.7469°	111.8135°	2.3	1.9	1-3
LAI-44	Laird Park	40.7436°	111.8378°	1.3	1.1	1-3
BON-43	Bonneville Golf Course	40.7467°	111.8253°	4.5	2.0	3-5
ROO-46	Roosevelt School	40.7012°	111.8669°	4.6	5.5	3-5
TMP-52	Temple Square	40.7699°	111.8900°	4.1	4.5	3-5
MAG-51	Magna Wells	40.7102°	111.0352°	5.5	6.2	5-8
CCB-56	City and County Bldg.	40.7594°	111.8856°	6.0	6.0	5-8
EAP-17	SLC Airport - East	40.7850°	111.9550°	8.0	6.1	8-11
WAP-19	SLC Airport - West	40.7817°	111.9767°	11.0	8.0	8-11
RIV-29	Jordan River	40.6830°	111.9280°	11.6	6.2	8-11
DUC-53	SLC Duck Club	40.7980°	111.1008°	15.0	13.0	8-11

Table 3 *Summary of Profile Characteristics in each USGS Amplification Zone.*

Amplification Zone	1-3	3-5	5-8	8-11
Average Depth to Rock-like Material	28 m (shallow) (93 ft)	43 m (moderate) (140 ft)	> 60 m (deep) (200 ft)	> 60 m (deep) (200 ft)
Shear Wave Velocity Range	180-900 m/s (600-3000 ft/s)	200-800 m/s (700-2600 ft/s)	150-480 m/s (500-1600 ft/s)	135-425 m/s (450-1400 ft/s)
Soil Consistency	Stiff	Medium Stiff	Medium Soft	Soft
Test Sites Within Each Zone	UGM-06 SUN-42 LAI-44	BON-43 ROO-46 TMP-52	MAG-51 CCB-56	EAP-17 WAP-19 RIV-29 DUC-53

PREVIOUS MODELING EFFORTS

Several studies have been done to model the influence of the basin on site amplification in the Great Salt Lake Valley (Benz and Smith, 1988; Hill, 1988; Martin, 1989; Olsen et al. 1994). Below are conclusions based on a review of these previous efforts.

1. Response is generally dominated by the R2 interface. The R1 interface is also important but the R3 interface can be neglected without significant error.
2. Response is greater for cross sections with steeper boundaries. This effect is less pronounced for dip angles above 45 degrees.
3. Response is typically 2 times higher for waves coming from the west than for vertically incident waves. Spectral ratios computed for the center of the valley are typically between 2 and 4 for vertically incident waves and between 4 and 8 for waves moving from the west.
4. The response to vertically incident plane waves is generally similar to that from a line source representing an earthquake rupture on the Wasatch Fault.
5. Basin shape is more important than basin depth in determining basin response.

COMBINED DEEP BASIN AND SHALLOW SOIL RESPONSE ANALYSIS

The objective of this study was to evaluate response due to both deep basin structure and shallow soil conditions in Salt Lake Valley. The method described in this section was used to compute (1) the spectral ratios from a distant nuclear blast (very low strain) event and (2) the expected response due to an earthquake on the Wasatch Fault. These computations were made by combining a 2D analysis of the deep basin structure with a 1D analysis of the shallow surface soils. The 2D finite element program QUAD4M (Idriss and Hudson, 1994) was chosen to analyze the basin response. To analyze the 1D response, the program SHAKE, written by Schnabel and others (1972) and modified by J.I. Sun (1990) to allow for 100 sublayers within a profile, was used.

Method of Analysis

The method used for analyzing both the nuclear blast (low strain) event and the Wasatch Fault earthquake (high strain) event was similar and involved the following steps. This process is shown schematically in Figure 2.

1. The chosen input motion was introduced at the top of a 1D "rock" column. The motion was then deconvolved inelastically to the bottom of the 1D "rock" column using SHAKE. The 1D "rock" column consisted of 100 15 m (50 ft) layers, with material properties identical to those of the underlying rock in the 2D model. The resulting motion was then a sublayer motion and could be applied to the base of the 2D cross sections.

2. The deconvolved input motion was applied to the base of each 2D cross section using QUAD4M.
3. The acceleration time histories computed at the appropriate locations on the surface of the 2D cross sections were then used as rock outcrop input motions for each USGS 1D soil profile. The response spectra computed at the top of each 1D soil profile then represents the combined influence of basin shape and soil effect. The analyses of each 1D profile for the nuclear blast motion were computed without shear modulus reduction. The analyses of each 1D profile for the earthquake motion were computed with modulus reduction and increased damping to account for soil non-linearity.
4. The combined amplification effect is defined as the spectral acceleration at the top of the 1D soil model divided by the spectral acceleration at the surface of the east side of the 2D cross section

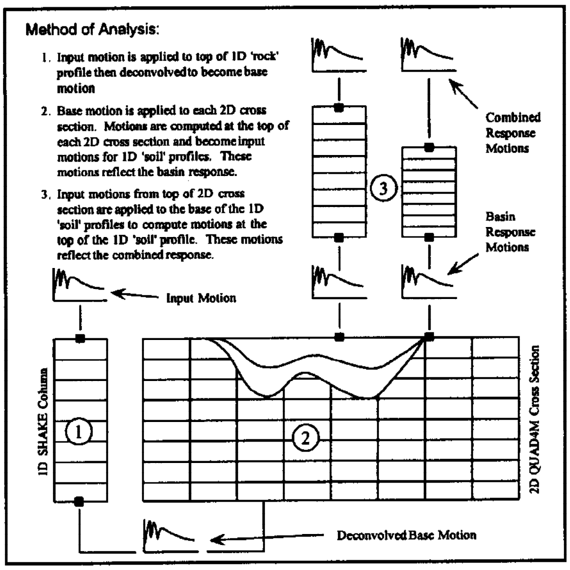

Figure 2 *Method of combining 1D and 2D analyses.*

Ideally, it would be desirable to combine the analysis of surface soil and the deep basin response into one computer model. However, data on soil properties is not well defined throughout the valley and limitations on computer memory and speed make this difficult. Element thickness was selected so that it was 1/5th of the wavelength for the highest frequency wave to be transmitted through the mesh, which in this case was 10 Hz. In the softer soil layers near the ground surface this thickness was only 1 to 2 m, therefore a 2D model would have required an extremely fine mesh and would have overwhelmed the capacity of the computer.

ANALYSIS OF NUCLEAR BLAST SIMULATION

Input Motion Used For Nuclear Blast Simulation

Between 1978 and 1983, USGS researchers recorded ground motions on five rock sites at the base of the Wasatch Mountains due to several nuclear blasts at the Nevada test site (King et al, 1983). An attempt was made to locate and use a time history from a nuclear blast recorded in the original 1983 study, however this did not prove fruitful. Therefore, a representative nuclear blast time history of acceleration was created by modifying an existing far-field motion in the frequency domain until the spectrum matched the recorded spectra. The peak ground acceleration for this synthetic motion was then scaled to 5.3×10^{-5} g. In contrast with earthquake response spectra on rock which typically have peaks at periods less than 0.5 sec., the spectrum for the nuclear blast had large peaks at periods of 1.0 and 2.25 sec.

Basin Response

Finite element meshes created for each of the cross-sections shown in Figure 1 typically extended to a depth of 1500 m and 2000 to 5000 m beyond the margins of the basins. The vertical grid spacing was typically 30 m and each mesh consisted of over 12,000 elements. The peak ground surface acceleration was computed at each node across the surface of each 2D cross section. Typically, computed peak ground acceleration was greatest where the basin depth was greatest. This coincides with recorded observations by King et al (1983). A typical plot of computed peak acceleration across the basin is shown in Figure 3. The ratio of the maximum computed peak ground surface acceleration to the peak acceleration of the input motion (5.3×10^{-5} g) is shown in Table 4 for each cross section. Amplification ratios for peak acceleration were typically about 1.5 to 2 due to the basin shape alone.

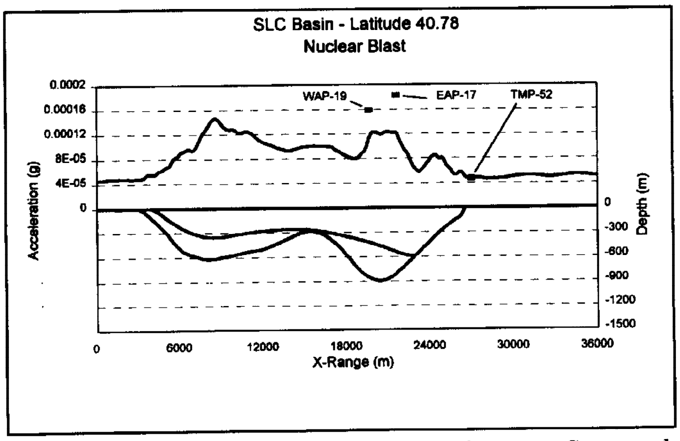

Figure 3 2D *Peak Ground Surface Accelerations Computed at latitude 40.78°. 1D Peak Ground Surface Accelerations computed at three USGS seismograph locations are also plotted.*

Table 4 *Largest Amplification of Peak Ground Surface Accelerations.*

Maximum peak ground surface acceleration amplifications				
Cross Section	40.69°	40.75°	40.78°	40.80°
Amplification	1.9	2.4	2.7	2.5

Combined Response

The response of the shallow soil profiles at each of the 12 seismograph stations was evaluated using the 1D computer program SHAKE (Schnabel et al., 1972). SHAKE computes the motions in a horizontally layered soil profile using wave propagation techniques. The equations are solved in the frequency domain and ground motions are assumed to be vertically propagating shear (SH) waves.

Based on the soil and shear wave velocity profiles at each of the 12 USGS seismograph sites, input files were created for SHAKE. Because of the very low acceleration levels involved with nuclear blasts, the soil was assumed to behave elastically for these analyses. The ground motions computed at the surface of the appropriate 2D cross section were treated as "rock outcrop" motions and were used as input motions for each soil profile following deconvolution to the base of the soil column. While some of the materials used as base rock in the 2D cross sections were unconsolidated deposits (soils), they all had shear wave velocities greater than 750 m/s (2500 ft/s). Soils with shear wave velocities above 750 m/s (2500 ft/s) are often treated as "soft rock" and are taken as the base of a SHAKE model.

For stiff shallow soil sites located at the edge of the basin, the peak accelerations at the top of the soil column are not significantly different from the peak accelerations at the top of the rock. However, for sites located over the deeper parts of the basin, the peak accelerations are amplified by a factor between 1.2 and 2.0 in comparison with motions at the top of the 2D model. Peak accelerations computed at the USGS recording sites are also shown in Figure 3.

Computed mean response spectra for each amplification zone are shown in Figure 4. There is a general trend for spectral acceleration to increase in accordance with the amplification zone. The peak spectral acceleration also occurs at progressively longer periods for the higher amplification zones. The computed and recorded average spectral ratios for each USGS site are shown in Table 5. The spectral ratios are split into short period and long period ranges for easy comparison with the recorded ratios. For the sites in the 8-11 zone, the computed ratios are generally in line with the recorded ratios. However, for the sites in the 1-3, 3-5, and 5-8 zone, the computed ratios are 40 to 60% of the recorded ratios. This discrepancy is likely a result of using vertically incident waves rather than inclined waves. Previous investigations have shown that spectral ratios are generally 2 times higher for waves moving from the west side of the valley than for vertically incident waves. Additional analyses using computer programs capable of applying inclined waves would be desirable for a verification of this hypothesis.

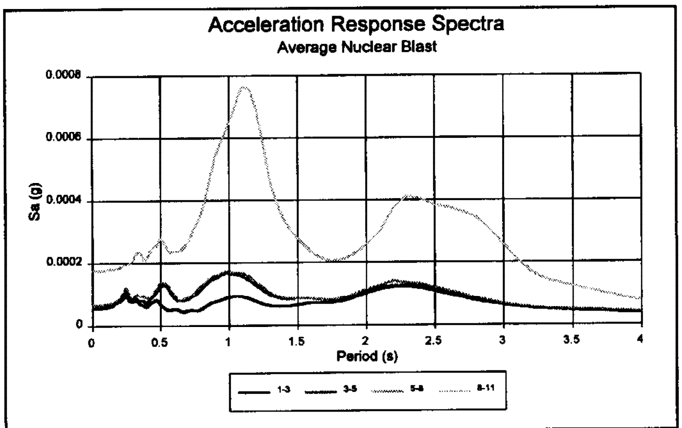

Figure 4 *Computed Mean Response Spectra for each amplification zone.*

Table 5 *Computed and Measured spectral ratios for each USGS site. Computed results are from the nuclear blast analysis.*

Station	Spectral Ratio 0.2<T<0.7 (Measured)	Spectral Ratio 0.7<T<1.0 (Measured)	Spectral Ratio 0.2<T<0.7 (Nuclear)	Spectral Ratio 0.7<T<1.0 (Nuclear)	Spectral Ratio 1.0<T<2.0 (Nuclear)	Spectral Ratio 2.0<T<3.3 (Nuclear)
UGM-06	2.5	2.8	1.1	1.0	1.0	1.0
SUN-42	2.3	1.9	1.4	1.1	1.0	1.0
LAI-44	1.3	1.1	1.2	1.0	1.0	1.0
BON-43	4.5	2.0	1.3	1.1	1.0	1.0
ROO-46	4.6	5.5	2.9	4.4	2.3	1.3
TMP-52	4.1	4.5	0.9	0.8	0.9	0.8
MAG-51	5.5	6.2	2.0	1.7	1.2	1.1
CCB-56	6.0	6.0	1.8	2.7	1.7	1.1
EAP-17	8.0	6.1	3.8	5.7	5.8	4.7
WAP-19	11.0	8.0	3.3	6.4	5.8	3.7
RIV-29	11.6	6.2	4.2	9.5	4.2	1.5
DUC-53	15.0	13.0	4.8	5.9	5.5	4.1

Observations and Results for Nuclear Blast Analysis

1. The results for the 1-3, 3-5 and 5-8 zones are lower than the measured values. This may be the result of not analyzing 3D effects and only using a vertical plane wave as input.
2. In the basin analysis, the highest amplifications typically occurred at the sites with the greatest basin depth, although variations in basin geometry sometimes caused changes amplification patterns.
3. The largest spectral ratios appeared at a period of approximately 0.25 seconds for the sites located in the 1-3 zone, 0.5 seconds for the sites located in the 3-5 zone, 0.8 seconds for the sites located in the 5-8 zone and 0.9 seconds for the sites located in the 8-11 range. This demonstrates a gradual increase in the natural period in progressively higher amplification zones.
4. The spectral ratios for each site in the 8-11 zone exhibit a secondary peak from between 2-3 seconds. This indicates an increase in long period energy for sites where the basin was the deepest.
5. Results at each site can vary from the averages indicating a site sensitivity to the analysis method.
6. The duration of the ground motion was significantly longer where the basin was the deepest.

EARTHQUAKE INDUCED GROUND MOTIONS

The second goal of this investigation was to analyze the response of the Salt Lake basin to a potential earthquake by combining a 2D basin analysis with 1D shallow analyses at each USGS seismograph station.

Input Motion For Wasatch Fault Earthquake

A number of investigators (Idriss, 1985; Joyner and Boore, 1988; Sadigh et al., 1986) have proposed an average response spectrum shape for a magnitude 7.5 earthquake recorded on rock. Because no strong motion events have been recorded from an earthquake on the Wasatch fault, a rock motion with a spectrum similar to this typical rock spectra was selected. The rock input motion was an earthquake record which was modified by Seed and Sun (1989) to better match the typical rock spectrum shape. The time history has a peak acceleration of 0.29 g and a duration of 34 seconds. This corresponds to a peak acceleration having a 10% chance of being exceeded in 50 yr. and is commonly used in design. The response spectrum for this motion has a peak at a period of 0.25 seconds and the peak spectral acceleration is 2.8 times higher than the peak ground acceleration. In contrast with the nuclear blast event, the earthquake motions have significantly larger accelerations as well as a smaller predominant period. As a result, much more energy will be transmitted in the short period range.

The same general procedure was followed in running the analysis for this event as with the low strain event. The input motion was first deconvolved though a rock stratigraphy. Second, this motion was applied to the base of the 2D cross section and allowed to propagate to the surface where acceleration time histories were computed. These acceleration time histories were then applied to the 1D soil profiles. The same 1D and 2D models were used to analyze the high strain earthquake event.

Basin Response

The computed peak accelerations on the eastern edges of the model are typically about 0.3 g while the peak accelerations above the basins are between 0.3 g and 0.6 g. In Figure 5, a significant difference between the earthquake analyses and the nuclear blast analyses becomes evident. The largest peak accelerations often occur near the edges of the basins rather than over the center of the basin. This is most evident at the latitude 40.78° cross sections. In these cross sections there are sections where the peak ground surface accelerations over the deep basin are only slightly larger than those on rock east of the basin. This same phenomenon was observed by Olsen in a study of 3D amplification effects in the Salt Lake Basin (Olsen et al., 1994) and by Fäh et. al. (1993) in a 2D study on amplification in the city of Rome, Italy. The variation in the location of the peak acceleration for the earthquake event is likely a response to the difference in frequency content of the input motions. The earthquake motions tend to

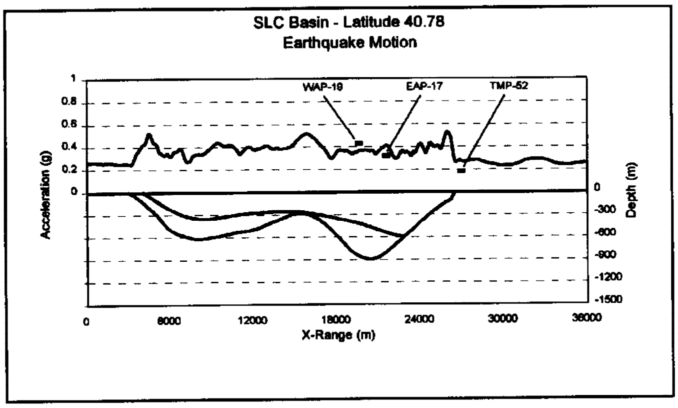

Figure 5 2D *Peak Ground Surface Accelerations Computed at latitude 40.78°. 1D Peak Ground Surface Accelerations computed at three USGS seismograph locations are also plotted.*

resonate in the shallow deposits near the edges of the basin while the long period nuclear blast motions resonate in the deep deposits in the center of the basin. The ratio of the maximum peak ground surface acceleration to the peak acceleration of the input motion (0.29 g) is shown in Table 6 for each cross section.

Table 6 *Largest Amplification of Peak Ground Surface Accelerations*

Maximum peak ground surface acceleration amplifications				
Cross Section	40.69°	40.75°	40.78°	40.80°
Amplification	2.2	2.2	1.8	1.8

Combined Response

Because the motions at the top of the 2D cross sections are between 0.3g and 0.6g, the effect of non-linear soil behavior in the near surface soils must be considered. In the 1D analyses with SHAKE, computations were performed using the equivalent linear method where strain compatible shear modulus and damping values are determined in an iterative manner. Relationships defining shear modulus and damping vs. shear strain proposed by Dobry and Vucetic (1991) were used in the analyses.

The computed peak accelerations were amplified by the stiff-shallow soil deposits at the basin margins, however the soft soils in the valley center actually attenuated the peak accelerations somewhat as shown in Figure 5. Computed mean response spectra for each amplification zone are shown in Figure 6. Notice that for the sites in the 1-3, 3-5 and 5-8 zones, the predominant period is at about 0.25 seconds whereas for the sites in the 8-11 zone the predominant period has shifted to 1.0 second. The average spectral ratios computed at each site are shown in Table 7. The measured spectral ratios from the nuclear blast analysis are also shown for comparison. The spectral ratios computed for the earthquake event are lower than ratios computed for the nuclear blast event.. This is due primarily to the non-linear soil response at the higher acceleration levels.

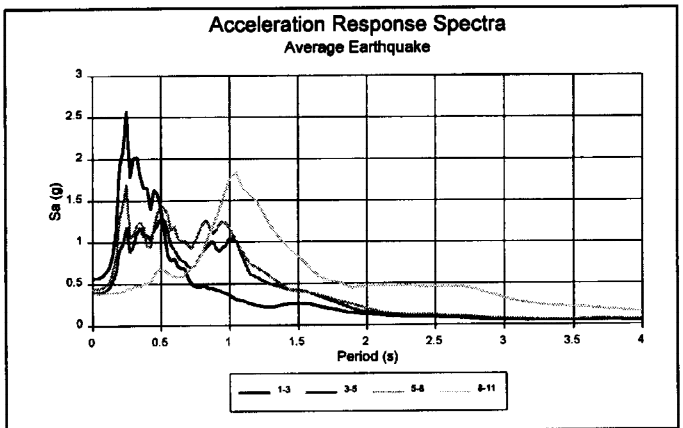

Figure 6 *Computed Mean Response Spectra for each amplification zone.*

Table 7 *Computed and Measured spectral ratios for each USGS site. Computed results are from the nuclear blast analysis.*

Station	Spectral Ratio 0.2<T<0.7 (Measured)	Spectral Ratio 0.7<T<1.0 (Measured)	Spectral Ratio 0.2<T<0.7 (Earthquake)	Spectral Ratio 0.7<T<1.0 (Earthquake)	Spectral Ratio 1.0<T<2.0 (Earthquake)	Spectral Ratio 2.0<T<3.3 (Earthquake)
UGM-06	2.5	2.8	1.6	1.2	1.1	1.1
SUN-42	2.3	1.9	2.6	1.9	1.4	1.1
LAI-44	1.3	1.1	2.0	1.2	1.1	1.1
BON-43	4.5	2.0	1.9	1.6	1.3	1.1
ROO-46	4.6	5.5	1.9	6.2	4.7	2.3
TMP-52	4.1	4.5	0.8	0.8	1.1	0.8
MAG-51	5.5	6.2	1.3	2.8	2.5	1.5
CCB-56	6.0	6.0	2.4	4.5	2.7	1.4
EAP-17	8.0	6.1	0.7	2.2	4.1	7.6
WAP-19	11.0	8.0	1.1	3.9	5.4	4.5
RIV-29	11.6	6.2	1.0	5.8	5.3	2.8
DUC-53	15.0	13.0	0.8	2.6	4.7	5.0

Summary of Results for Earthquake Event

1. In the basin analysis, the highest peak accelerations occur near the edges of the basins and do not appear to be directly related to basin depth.
2. Amplification is a factor of both basin shape and shallow soil effects. The amount of basin vs. soil effect is site specific.
3. The largest spectral ratios appeared at a period of approximately 0.3 seconds for the sites located in the 1-3 zone, 1.0 seconds for the sites located in the 3-5 zone, 0.9 seconds for the sites located in the 5-8 zone and 1.1 seconds for the site located in the 8-11 range. This demonstrates a gradual shift in the natural

period at each particular site.

4. The spectral ratios for the each site in the 8-11 zone exhibit a secondary peak at 2.8 seconds. This indicates an increase in long wave energy for sites where the basin was the deepest.
5. Results at each site can vary from the averages indicating a site sensitivity to the analysis method.
6. The duration of the ground motion was doubled where the basin was the deepest.

Overall Conclusions

The following list is a summary of the findings from this study:

1. The potential for amplification of ground motions in the Salt Lake valley is dependent on both deep basin geometry and the characteristics of the shallow soil profile. The amount of amplification each effect has on ground response is site specific. The ability to determine if basin shape effect or shallow soil effect was the predominant influence at a particular site is one of the main benefits of this method.
2. The peak ground accelerations caused by basin shape tends to mirror the bedrock geometry for the nuclear blast simulation. However, for the earthquake analysis, the highest peak accelerations occur near the edges of the basins and do not appear to be directly related to basin depth. In both cases, the amplification due to basin shape is typically between 1.5 and 2.5.
3. On average for each site, the nuclear blast analysis accounted for 44% of the measured motion for the period range from 0.2 seconds to 0.7 seconds, 65% of the measured motion for the period range from 0.7 seconds to 1.0 seconds. Previous studies suggest that the computed ratios would likely be about twice as high if a point source on the western side of the valley had been used rather than a vertical plane wave. This would make the computed ratios very close to the measured ratios. In addition, three dimensional effects were not considered in the analysis.
4. This analysis approach was time consuming and should be reserved for analyzing critical structures only. With additional research and measurements it might be possible to develop general amplification factors which could account for basin effects.
5. The spectral amplification zones based on the USGS research is a reasonable grouping of sites having similar amplification characteristics.

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