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WEAPONS TEST SEISMIC INVESTIGATIONS AT YUCCA MOUNTAIN*

James S. Phillips
Sandia National Laboratories
Ground Motion and Seismic Division
P. O. Box 5800
Albuquerque, NM 87185
(505) 845-7620

Marianne C. Walck
Sandia National Laboratories
Geophysics Division
P. O. Box 5800
Albuquerque, NM 87185
(505) 846-0146

L. E. Shephard
Sandia National Laboratories
Performance Assessment Development Division
P. O. Box 5800
Albuquerque, NM 87185
(505) 844-3604

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ABSTRACT

Yucca Mountain, located on and adjacent to the Nevada Test Site, is being characterized as part of an ongoing effort to identify a potential high-level nuclear waste repository. This site will be subjected to seismic ground motions induced by underground nuclear explosions. A knowledge of expected ground motion levels from these tests will enable the designers to provide for the necessary structural support in the designs of the various components of the repository. The primary objective of the Weapons Test Seismic Investigation project is to develop a method to predict the ground motions expected at the repository site as a result of future weapons tests. This paper summarizes the data base presently assembled for the Yucca Mountain Project, characteristics of expected ground motions, and characterization of the two-dimensional seismic properties along paths between Yucca Mountain and the testing areas of the Nevada Test Site.

INTRODUCTION

The Weapons Test Seismic Investigations (WTSI) project has been gathering underground nuclear explosion (UNE)-generated ground-motion data in support of the Yucca Mountain Project (YMP) since 1977. In addition to data acquisition, this effort has included a number of analyses. These analyses involve (1) studies of ground motions to understand amplitude and frequency variation with regard to distance, source strength, and receiver depth; and (2) studies to understand geologic effects at the source, along the travel path, and at the receiver on observed ground motions. The objective of these analyses is to provide the basis for prediction of UNE-generated ground motions that will be input into the seismic design criteria for the repository facilities.

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This paper will summarize the design-basis UNE, the data acquisition effort, and the data base assembled for WTSI. In addition, results of analyses performed to date will be discussed in the context of the seismic design criteria for repository facilities.

DESIGN BASIS

Developing seismic design criteria requires characterization of the types of ground motion generated by a UNE and the definition of a design-basis event. The determination of the yield and location of this event strongly influences the data base assembled for analysis. The design-basis event is defined as a 700-kt explosion in the Buckboard Area of the Nevada Test Site (NTS). The distance between this possible future UNE and Yucca Mountain is about 22.5 km (this is the distance from Yucca Mountain to the closest point in the Buckboard Area suitable for testing). This design-basis UNE was selected on the basis of off-site damage criteria and results of real estate availability studies on the NTS without regard to any arms-control treaties.[1]

DATA ACQUISITION

The objective of the data acquisition effort is to obtain UNE-generated ground-motion data in the vicinity of Yucca Mountain. To this end, the WTSI project has deployed a total of 29 seismic stations to record UNE ground motions specifically for the YMP. These stations consist of triaxial accelerometers, amplifiers, voltage-controlled oscillators, multiplexers, and transmitters. These stations are installed at permanent locations in the vicinity of Yucca Mountain and are used to monitor selected UNEs.[a] All stations have surface accelerometers; in addition, some of the stations have companion instrumentation installed below the ground surface (generally at depths greater than 100 m). Data from the WTSI ground-motion stations are telemetered via FM signal to a central location where they are recorded on analog tape.

Stations were initially located at several points around the NTS (Figure 1). After the Yucca Mountain site became the focus of the Project at the NTS in 1980, the first WTSI seismic station at was installed at Yucca Mountain. Since that time, the WTSI project has had a total of eleven stations in the Yucca Mountain area. At the present time, five stations are active and four of these stations consist of both surface and downhole instrumentation. As shown in Figure 2, three of these active stations are located in a north-south line through the center of Yucca Mountain (W25, W28, and W30). These three stations are located in drill holes USW G-1 (W25), USW G-2 (W28) and USW GU-3 (W30) and consist of both surface and downhole instrumentation. Downhole instrumentation at these stations is between 300 and 350 m deep. At stations W30 and W25 this instrumentation is placed in the welded tuff unit described as the potential repository horizon and the downhole instrumentation at W28 is placed in the stratigraphic unit just above the proposed repository horizon. The other two stations are located near the proposed surface facilities area. Station W29 has both surface and downhole (about 80 m deep at the

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[a]Other stations are deployed by WTSI for different objectives.

alluvium/tuff interface) instrumentation, whereas W26 has only surface instrumentation.

Not all UNEs conducted at NTS are monitored by WTSI. The selection of which UNEs to monitor is based on the explosive yields. UNE yields between 80 and 150 kt are of greatest interest to the YMP. These UNEs are usually conducted in the Pahute Mesa (Areas 19 and 20) and Yucca Flat testing areas of the NTS. The distance between these testing areas and Yucca Mountain varies from about 35 km to 55 km. The lower yield limit was selected because ground motions generated by yields below 80 kt, at these distances, are of a very low amplitude (approximately 2 orders of magnitude below those expected for the design basis). While data from these lower yield UNEs would contribute to the study of seismic wave transmission at the site, they are of little value in the development of the amplitude or frequency prediction of ground motions for the design-basis event. The upper yield limit is mandated by the Threshold Test Ban Treaty of March 1976.

Figure 1 shows the location of UNEs monitored at Yucca Mountain as of the end of FY90 compared to the location of the design-basis UNE. Based on available NTS geologic data, the source geology at the Buckboard Area is thought to be similar to that at Pahute Mesa. But from Figure 1 it is apparent that the travel path azimuth of the design-basis UNE is similar to the events in Yucca Flat and therefore, path effects observed in the Yucca Flat data might be indicative of what could be expected from the design-basis UNE.

Because the UNE-generated ground-motion data recorded at Yucca Mountain are from explosions with limited variability in yield and distance, and because the yield and location of the design-basis UNE are not within the monitored ranges, it was important to assemble a data base which included ground-motion data from other UNEs that bracketed the yield and distance parameters associated with the design-basis UNE. Ground motion generated by UNEs has been of interest since the beginning of underground weapons testing. Measurements of ground motion have been made on explosions with yields up to 1400 kt, at both close-in locations (distances within a few burial depths of the explosion) and at seismic distances (tens of burial depths from the explosion). Many of these data have been used to develop prediction models for the amplitude of ground motion and to study the transmission characteristics of the NTS area. These studies were conducted before the YMP began and are not directly applicable to the Project. However, the data from some of these older UNEs exist on tape and have been analyzed in the context of the YMP.

WTSI GROUND-MOTION DATA BASE

The UNE ground-motion data base assembled by the WTSI project for the YMP consists of data from a total of 84 UNEs (57 from Pahute Mesa and 27 from Yucca Flat). Of this number, 46 have been recorded at Yucca Mountain seismic stations. The remainder of the UNEs that make up the data base are earlier events with yields ranging up to 1400 kt and recording stations located at various points on the NTS at distances of 1 km and greater. The data base brackets the yield and the distance parameters of the design-basis UNE.

The general information parameters included in this data base consist of event information such as name and location, station locations, gages used, and gage calibration dates. Ground-motion parameters of interest are maximum amplitudes of particle acceleration, velocity, and displacement and time histories of acceleration, velocity, and displacement. Other quantities, such as power density spectra (PDS) and pseudo relative velocity (PSRV) spectra, may be derived from the recorded time histories. In general, UNE yields are classified and therefore are not included in the data base.

DESCRIPTION OF ANALYSES

Ground motion observed at a particular location is a function of energy coupling at the source,[b] transmission characteristics of the geologic media along the travel path, and the properties of the geologic materials present at the recording site. Any method of predicting ground motions from UNEs must factor these elements into the procedure in some fashion. The approach taken in this effort has involved work in two general areas.

An empirical approach has been used to develop the prediction equations for surface ground motions. Yield and distance are treated as independent parameters and measured ground acceleration, velocity and displacement are treated as dependent variables. These parameters are analyzed through standard multiple linear regression techniques to develop the equation of a power curve describing the mean value of the data. The statistics of the fit are used to describe the uncertainty of the estimated mean value and to characterize UNE-to-UNE variability. This approach has been used successfully to analyze ground-motion data generated by UNEs conducted in the Pahute Mesa and Yucca Flat testing areas of the NTS and recorded at various stations on and around the NTS.[2] Separate analyses and, therefore, separate prediction equations have been developed for each of these testing areas. This approach accounts for coupling and source geology in that all events in a data set are located in the same general area with similar source parameters. By similar logic, travel path geology is also accounted for.

The analysis described above provides the prediction of amplitude and frequency characteristics in a generic sense. By obtaining ground-motion data at a particular recording site from several UNEs in a particular testing area, "station effects" may be estimated. Once these effects have been estimated, methods to account for them in a predictive situation can be derived.

A different technique to determine path effects on ground motion waveforms is to develop two-dimensional (2-D) velocity models of travel paths between Yucca Mountain and the testing areas of NTS.[3] The approach taken is to develop an initial seismic velocity profile along the travel path based on documented geologic properties. However, available properties for the NTS generally include only seismic velocity information near the source and the receiver. There is very little quantitative information available along the travel path. This preliminary model is refined using 2-D ray tracing until the travel times predicted from the model match the travel time observed in

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[b]This is a function of the source strength and the source geology.

the UNE ground-motion data. After the arrival times are matched for a variety of source locations, the observed relative amplitude patterns are modeled using zero-order asymptotic ray theory synthetic seismograms. Matches on these two quantities indicate that both integrated velocity (travel time match) and velocity gradients (relative amplitude patterns) along the modeled travel path are reasonable, non-unique representations of the actual travel path. Parametric studies using these models are helpful in separating "station effects" from "travel path effects" for the observed ground motions at Yucca Mountain.

RESULTS TO DATE

Maximum Amplitudes

Analyses performed to develop an empirical prediction procedure for maximum amplitude UNE ground motions consisted of linear regressions on the data base discussed above. Relationships have been developed for three-dimensional data vectors and also for the individual data components. These relationships were used in the specification of the seismic design basis for the exploratory shaft facility at Yucca Mountain.[4] Maximum amplitudes predicted for the design-basis UNE are summarized in Table 1. These values represent the 95% nonexceedance level. For comparison purposes the seismic design earthquake values for this same facility also are shown in Table 1. The expected earthquake ground motions generally are larger and thus expected to control the design of this facility.

TABLE 1. SUMMARY OF SEISMIC DESIGN BASES FOR UNES AND EARTHQUAKES FOR THE PLANNED EXPLORATORY SHAFT AT YUCCA MOUNTAIN

	Acceleration - g			Velocity - cm/s	
UNE Motions:					
Vert	Rad	Trans	Vert	Rad	Trans
0.2	0.1	0.1	9	12	12
Earthquake Motions:					
Vert	Rad	Trans	Vert	Rad	Trans
0.3	0.3	-	20	30	-

Vert=Vertical; Rad=Radial; Trans=Transverse

Frequency Content

To study the frequency content of ground motions, it is useful to review the nature of observed ground motion phenomena. Ground motion at the source-to-station distances included in this data set may be thought of as consisting of two general components: body waves and surface waves. Examples of "typical" body and surface waves observed at Yucca Mountain stations are illustrated in Figure 3. The time histories illustrated are the radial acceleration, velocity and displacement from a low yield (<150 kt) event as recorded at the W28 surface station. The first arrivals are the body waves. The initial body waves travel at the compressional wave speed of the material and generally produce the largest amplitude accelerations.

Also shown in this figure are the normalized PDS and PSRV spectra calculated for these components. These spectra were calculated from two segments of the acceleration time history. The body wave component was determined from the time history between 0 and 20 seconds. In general, UNE-induced body wave motions at the NTS have frequencies between 1 and 20 Hz. The surface wave component was determined from the waveform between 20 and 90 seconds. The UNE-induced surface wave motions at NTS usually have frequencies between 0.5 and 2 Hz. This comparison shows that both PDS and PSRV spectra provide the same picture of which frequencies dominate the ground motions. PSRV spectra are more practical for generating predictions for design because the PSRV represents the response of a single degree of freedom (SDOF) system. Many structural systems can be represented as either a single SDOF system or a combination of several SDOF systems. This allows engineers to estimate structural response directly. The PDS are more useful for geologic modeling applications because they are a representation of the ground motion in the frequency domain without the influence of the SDOF structure.

As part of the ground-motion analysis, PSRV prediction equations have been developed for UNEs conducted in the Pahute Mesa testing area. The prediction for the design-basis UNE compared with an estimate of design earthquake motions is shown in Figure 4. The UNE prediction consists of the prediction of the mean value plus an estimate of the uncertainty.[c] The earthquake estimates were made using probabilistic concepts.[5] This earthquake represents the design basis for repository seismic design[6] (not the ESF design basis used earlier). The earthquake ground motions in this example fall above the upper bound of the UNE prediction indicating that the earthquake ground motions would control the repository facilities design for all frequencies.

An additional concern in characterizing UNE ground motions is the behavior of these motions at depth. Knowledge of downhole ground motions is necessary for the design of underground facilities of the repository. Analyses of ground motions recorded at depth have consisted of development of ratios of measured amplitudes of surface-to-downhole ground motions for individual stations. A convenient way to study the entire ground motion is through the use of PSRV spectra and surface-to-downhole ratios of PSRV spectra. The results of these analyses (Figure 5[d]) indicate that in general, downhole ground motions are less than surface motions, with high frequency motions

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[c]The uncertainty shown on Figure 4 is twice the standard deviation calculated from the regression. This represents the 97.5% nonexceedance probability level.

[d]The ratio plotted in this figure is the surface motion to downhole motion. Therefore the larger the ratio the larger the surface motion is relative to the downhole motion.

reduced more than low frequency ground motions. There is a great deal of variability in the results at the individual stations and therefore, the results, to date, do not lend themselves to the development of a simplified, generalized model for the Yucca Mountain area. However, they do provide an indication of what might be expected from the design-basis UNE.

- Velocity Modeling

Plausible 2-D velocity structure models have been developed along three paths between the Pahute Mesa and Yucca Mountain and between Yucca Flat and Yucca Mountain (Figure 6). Two of these paths were from western and eastern Pahute Mesa to Yucca Mountain and the third was from Yucca Flat to Yucca Mountain. The velocity models derived for these paths (Figure 7) successfully modeled travel times and relative amplitudes for a total of 21 UNEs. (While care was taken to constrain these models with the available geologic information, these models are nonunique.)

The models developed show that Pahute Mesa and Yucca Flat UNEs produce distinct, repeatable patterns of travel times and relative amplitudes at Yucca Mountain stations. Analysis of these paths indicate that wave focusing effects (about a factor of 2) observed in the data and reproduced in the models change as a source of azimuth and thus probably are not associated with velocity structure directly beneath the stations. Velocity transitions between Yucca Mountain and both Timber Mountain Caldera and Shoshone Mountain appear to cause the amplitude variations observed at Yucca Mountain.

As noted earlier, the UNEs conducted at present are smaller, farther away, and at a different azimuth than the design-basis UNE. The path between the design basis and Yucca Mountain is labeled "Buck" in Figure 6. This profile is similar in azimuth to to the YF1 profile and could be expected to have similar near-receiver structure. The "Buck" profile also intersects two other profiles developed in another study.[7] Using this information, a tentative model for the "Buck" path was constructed and exercised to see if any extreme focusing of seismic energy for the design-basis UNE might be expected at Yucca Mountain. While the model is highly speculative, there is no reason at present to believe that a more severe amplitude focusing than is observed for present-day tests would be observed for a large event at the Buckboard Area.

CONCLUSIONS

The analyses performed on existing UNE ground-motion data have produced models that can be used to provide estimates of UNE-generated ground motions at Yucca Mountain. The predicted values of these ground motions indicate that UNE-generated ground motions are estimated to be less than earthquake-generated ground motions and therefore, should not control the design of repository facilities. However, this conclusion is preliminary and additional surface and subsurface data will be collected and analyzed to further evaluate the results. Additional analyses will include further study of ground-motion variations at depth and velocity modeling. These analyses will help to reduce the uncertainties present in the current models and will provide further insight into the seismic transmission characteristics at Yucca Mountain and the NTS.

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FIGURE 1. MAP OF THE NTS SHOWING THE LOCATIONS OF WTSI GROUND MOTION STATIONS, UNES INCLUDED IN THE WTSI DATA BASE, THE DESIGN-BASIS UNE, AND YUCCA MOUNTAIN

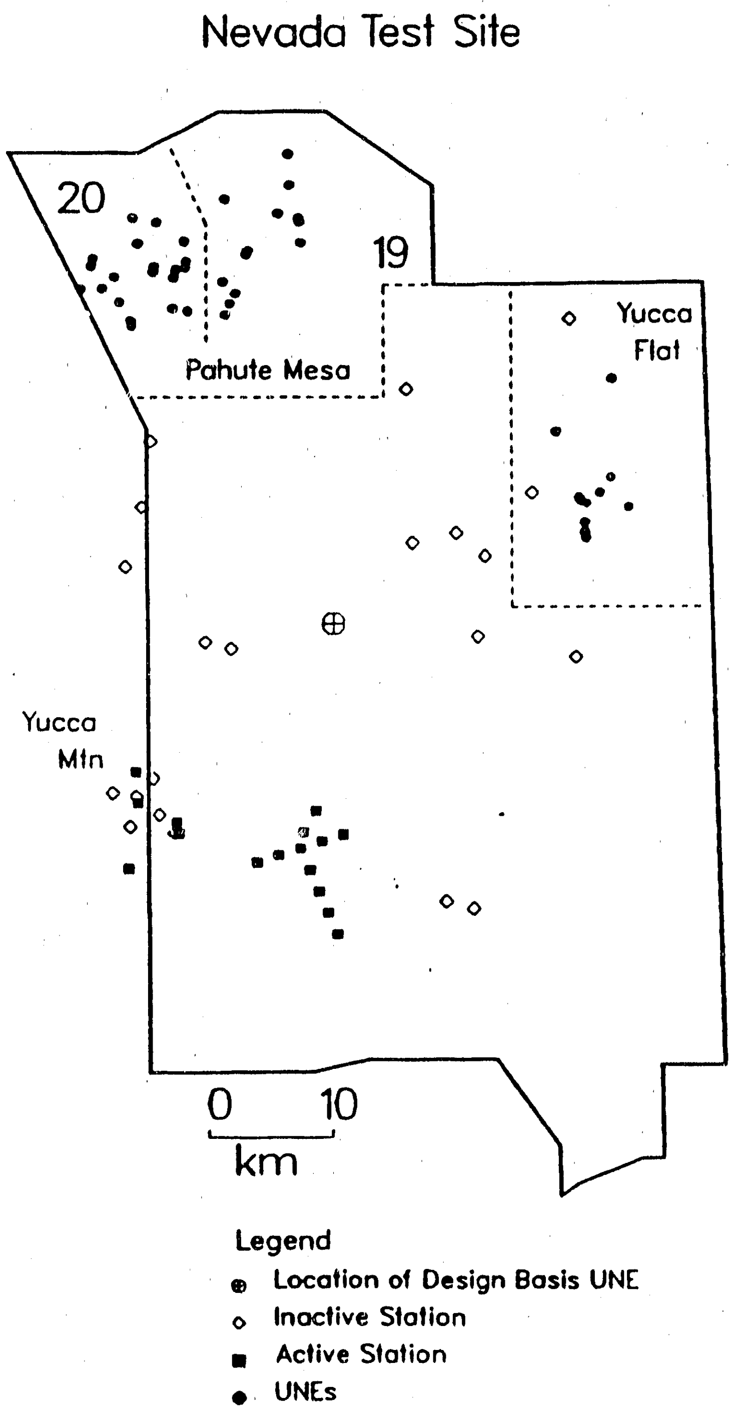


FIGURE 2. LOCATION OF THE ACTIVE YUCCA MOUNTAIN GROUND MOTION STATIONS WITH RESPECT TO FACILITIES PLANNED FOR THE REPOSITORY (NOTE: ALL VALUES SHOWN IN METERS)

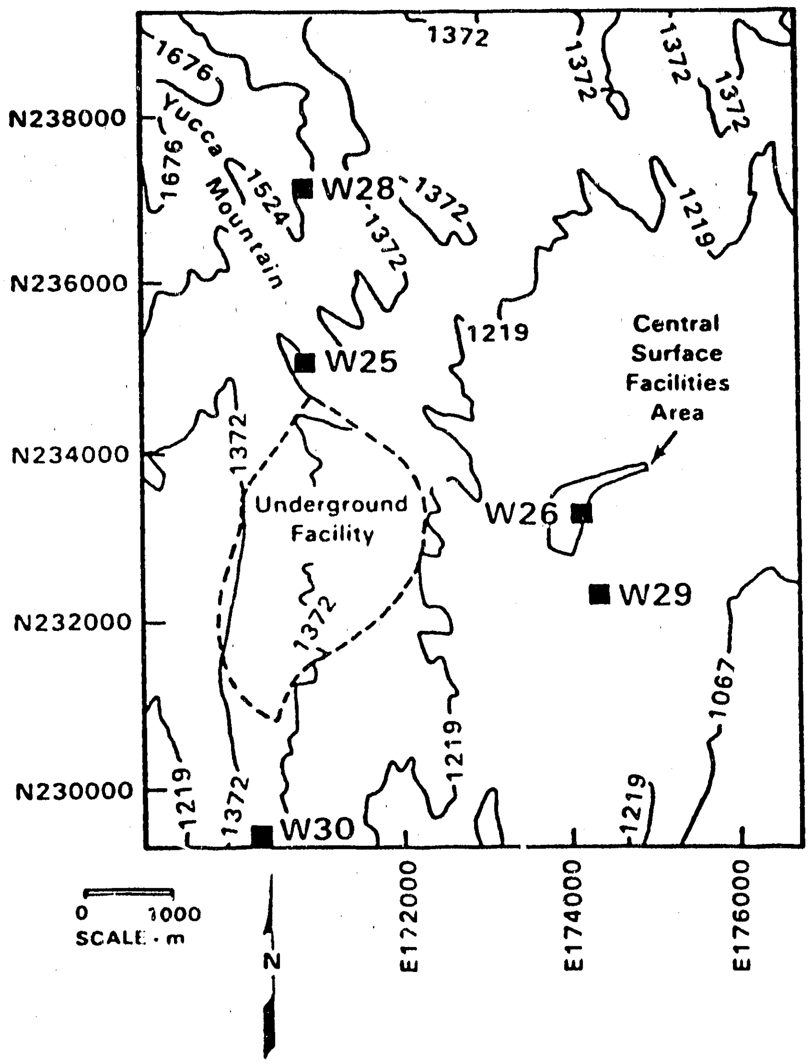


FIGURE 3. TYPICAL UNE GROUND MOTIONS AND THEIR FREQUENCY CONTENT

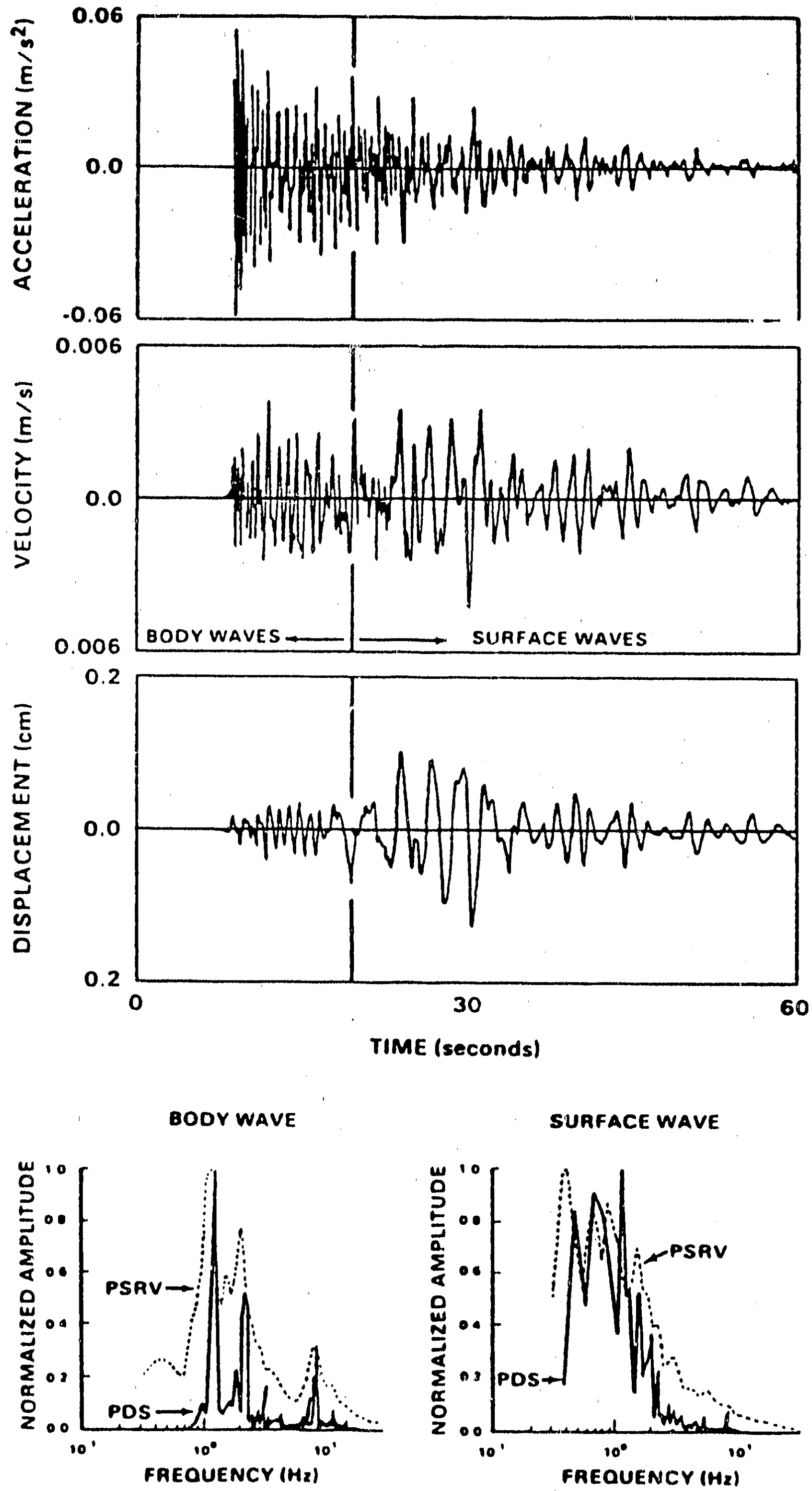


FIGURE 4. COMPARISON OF THE DESIGN-BASIS UNE AND DESIGN-BASIS EARTHQUAKE PSEUDO RELATIVE VELOCITY RESPONSE SPECTRA

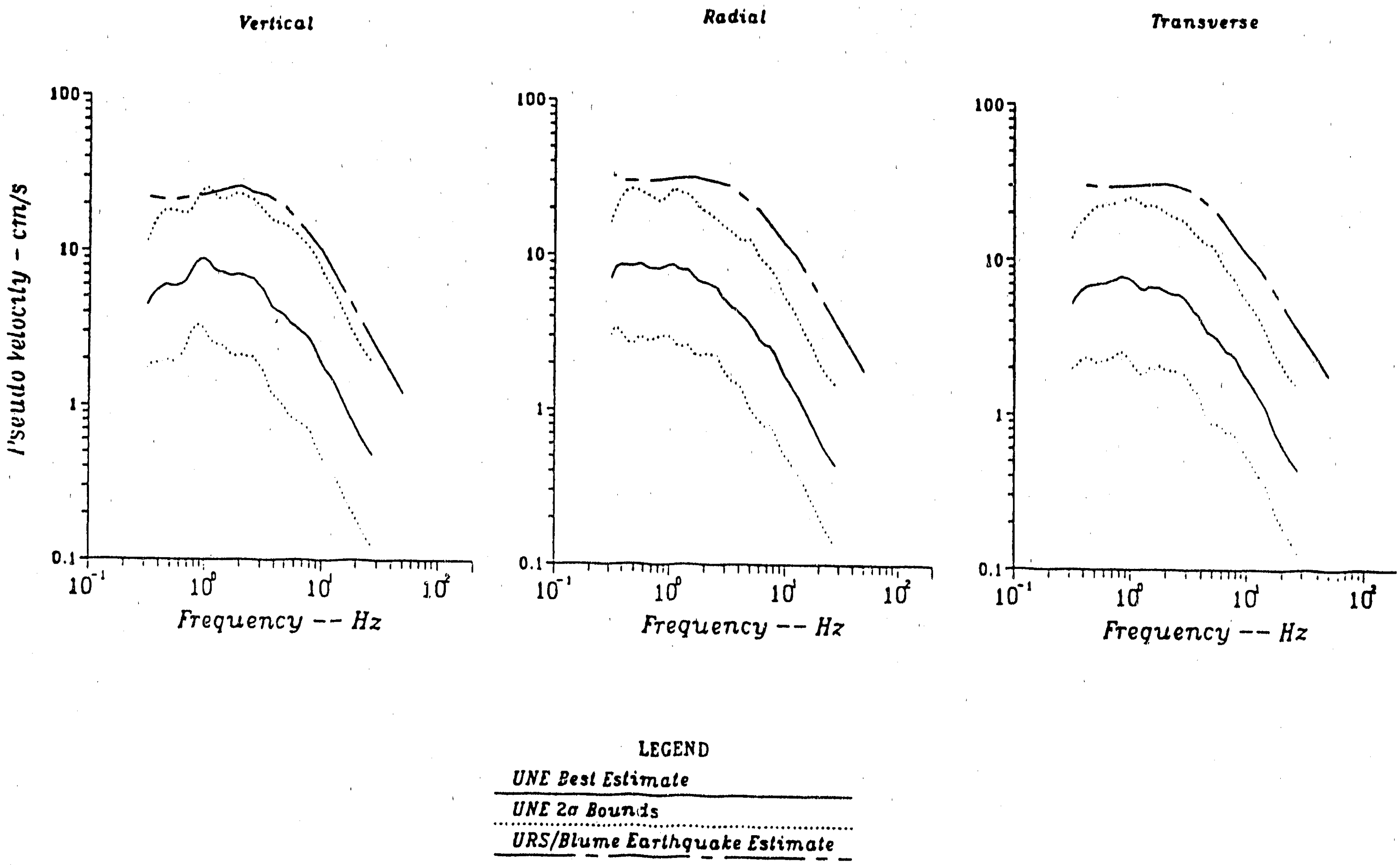


FIGURE 5. COMPARISON OF AVERAGE SURFACE TO DOWNHOLE PSRV RATIOS AT YUCCA MOUNTAIN STATIONS

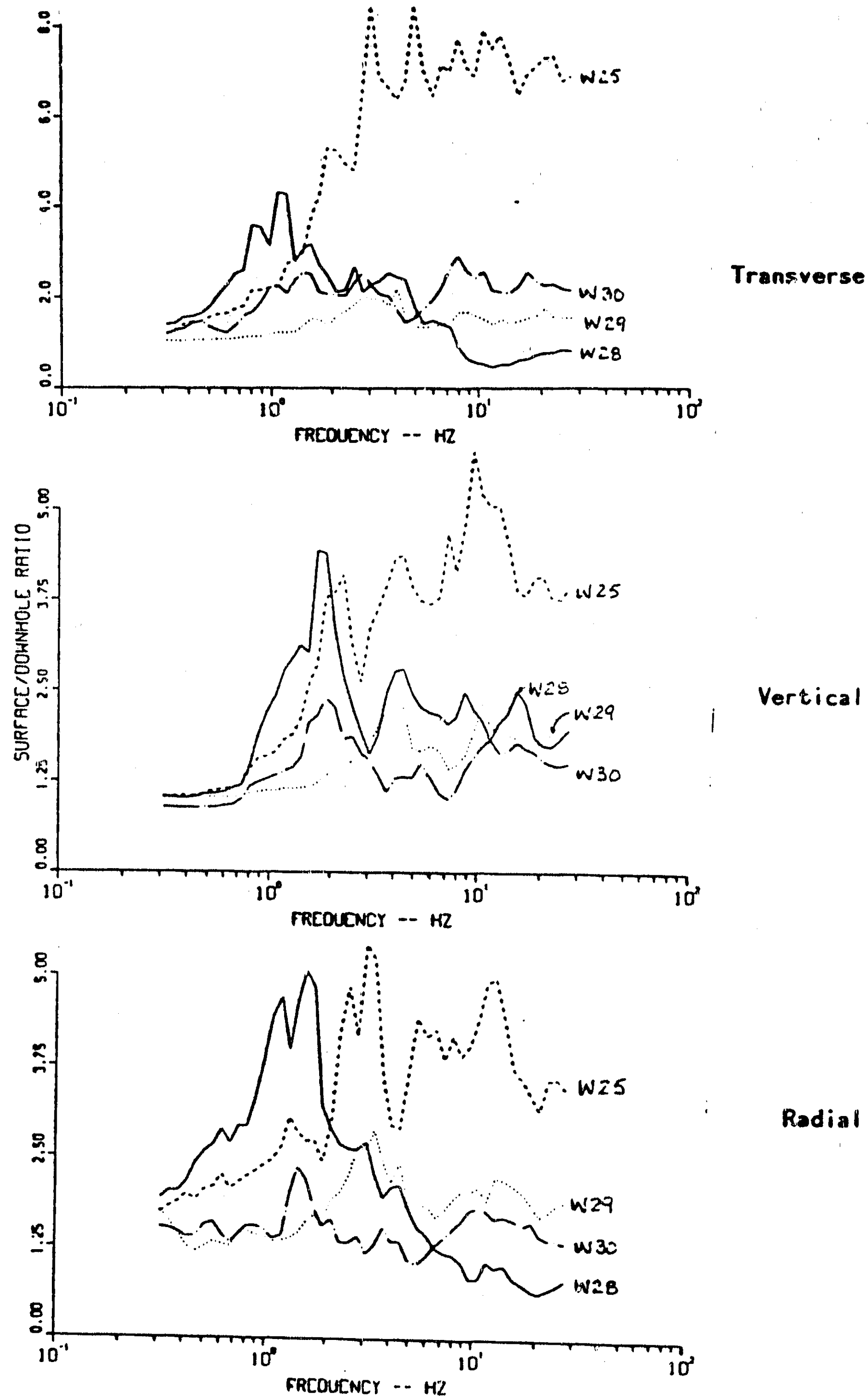


FIGURE 6. MAP OF NTS SHOWING LOCATION OF TRAVEL PATHS MODELED AND THE DESIGN-BASIS UNE

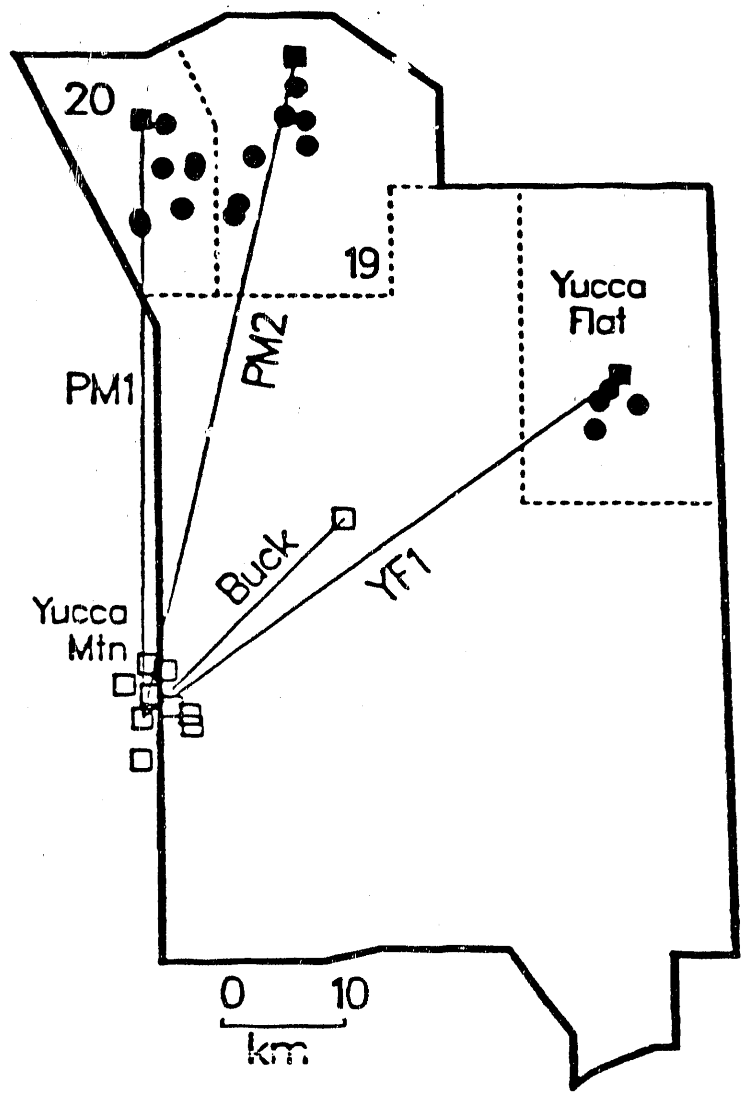
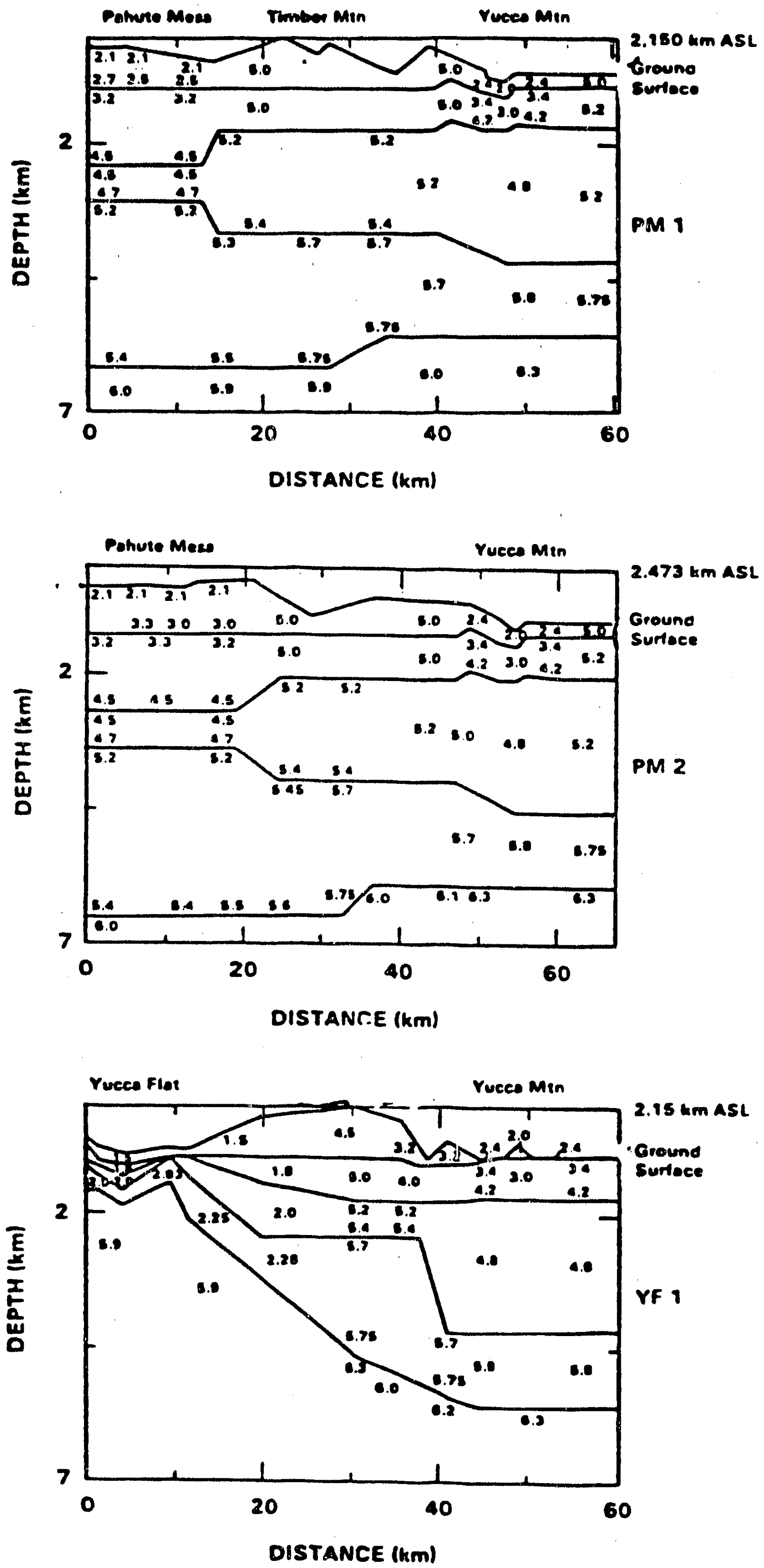


FIGURE 7. VELOCITY MODELS DERIVED FOR TRAVEL PATHS PM1, PM2, AND YF1 (SEE FIGURE 6 FOR LOCATIONS)



NOTE: ASL = Above Sea Level

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