10-7-2003

Final report on Task 12: Southern Great Basin seismic network operations

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Final Report on Task 12:

Southern Great Basin Seismic Network Operations

10/07/2003

Prepared by the Nevada Seismological Laboratory (Reno, Nevada) for the U.S. DOE/UCCSN Cooperative Agreement Number DE-FC28-98NV12081

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Introduction

The Nevada Seismological Laboratory began seismic monitoring operations under the DOE-UCCSN Cooperative Agreement on 11/01/1999. This final report summarizes our activities and studies made in the four years up to 09/30/2003. Previously, NSL operated under the M&O for the Yucca Mountain Project from October 1995 through September 1999 and under the U. S. Geological Survey from October 1992 through September 1995. For purposes of this report, earthquakes occurring in the years FY1998 and FY1999 were analyzed in the first two years of the NSL’s involvement with the Cooperative Agreement, and they will be treated here, along with the data in the years FY2000, FY2001, and FY2002. During the four years of funding under the Cooperative Agreement, FY2000-FY2003, NSL has maintained a seismic network in the vicinity of Yucca Mountain; installed a strong-motion capability at 10 sites; installed a borehole array of strong-motion instruments near the ESF north portal; and has conducted various studies on seismic-wave attenuation, earthquake interactions, the character of the stress field, and seismotectonics, all within the southern Great Basin and mostly focused on the immediate vicinity of Yucca Mountain. This report will summarize these operational efforts and associated investigative studies. This report references many of the previous reports submitted under the Cooperative Agreement and does not present any new data itself.

The Networks Operated Under the Cooperative Agreement

Figure 1 shows the configuration of the seismic networks around Yucca Mountain operated by the NSL. Station locations for the permanent monitoring network and the strong-motion sites
were submitted as a dataset in DTN # UN0006SPA012DV.001. Location data for the analog stations are contained in another dataset – DTN # MO0210UCC023DV.001.

The basic monitoring network consists of 32 three-component seismic stations using Geotech S-13 velocity sensors (GS-13 in two cases); RefTek digital acquisition units sample the data with 24-bit resolution. This network of permanent monitoring stations is called the Southern Great Basin Digital Seismic Network (SGBDSN). These stations were mostly installed prior to the Cooperative Agreement, but five (HEL, LEC, PIT, SGR, and STH) were added during the Cooperative Agreement time period. Of the 32 stations, two stations using GS-13 (ECO and YFT) were actually installed by Sandia Laboratories; but data is collected at the NSL in the same manner as for the 30 other stations. During the Cooperative Agreement, original Guralp CMG-40 instruments at six sites were replaced by Geotech S-13 instruments for QA reasons. All the permanent stations transmit their data in real-time to the NSL for archival and for event location purposes. Implementing procedure UNR-001 ("Operation of the Yucca Mountain Digital Seismic Network") covers the operation of the permanent seismic monitoring network.

At 10 of the permanent monitoring stations, 3-component strong-motion accelerometers have been collocated. These accelerometers are recorded by the same DAS units which record the S-13 channels; but they are only recorded at 16-bit resolution. These accelerometers were installed in late 1999 and early 2000 under the Cooperative Agreement. Data from these instruments is also transmitted to the NSL in real-time. Implementing procedure UNR-001 also covers the operation of these strong-motion instruments.
In addition to real-time strong-motion sensing, there are 9 sites at which independent TerraTech 3-component accelerometers provide data, but only by downloading the data during a site visit. These also record at 16-bit resolution. They had been installed prior to the Cooperative Agreement. One of these stations has been recently removed (BYMS) due to the fact that another accelerometer installation (STO) exists very nearby. Implementing procedure IPR-004 (“Operation of the Yucca Mountain Strong Motion Network”) covers the operation of the independent strong-motion network.

In early 2003, the NSL installed an array of nine 3-component strong-motion sensors at three boreholes on the pad adjacent to the north portal of the ESF. At each borehole, one 3-component sensor was placed at the surface, one at shallow depth in the borehole (10-15 m), and one at the bottom of the borehole (100-150 m). The output of these sensors are digitized by Kinemetrics Q330 recorders and transmitted to a recording computer on the ESF pad.

Lastly, NSL still operates eleven analog stations, mostly within the boundaries of Death Valley National Park. These sensors enable NSL to monitor seismicity along the important Furnace Creek-Death Valley Fault Zone and also throughout the park. These stations all have a vertical seismometer, and three of them have one horizontal seismometer in addition. The data is digitized in Reno at the NSL after analog transmission. The resolution of this data is roughly 12 bits, and therefore it is used primarily for timing and polarity of earthquake arrivals.
Figure 1: Stations Used for Monitoring Seismic Activity and Recording Strong Ground Motion in the Vicinity of Yucca Mountain

Legend
- analog stations
- digital strong-motion stations
- digital weak-motion stations
- digital weak/strong-motion stations
- Death Valley National Park
- Nevada Test Site boundary

Kilometers
In all, NSL now routinely collects 191 channels of seismic data under the Cooperative Agreement, with all but 24 of them in real-time. Of the 191, 113 existed before the Cooperative Agreement and 78 have been installed during it; this translates into an increase of 69% in seismic sensing capacity.

**Basic Monitoring Results – FY1998 to FY2002**

**FY1998-FY2002 Seismicity**

Under the Cooperative Agreement, annual reports on the seismicity near Yucca Mountain were submitted (see references), and results are only summarized here. During the 5-year period of seismicity covered in those reports (FY98-FY02), 15173 earthquakes were located within 65 km of Yucca Mountain. (The station RPY at 36.8515, -116.4563 is actually used as the reference point; it lies directly over the ESF.) Figure 2 shows these earthquakes; the data was taken from the following datasets:

- FY02    UCCSN DID #012DV.014
- FY01    MO0205UCC012DV.008
- FY00    UN0106SPA012JB.001
- FY98-99 UN0007SPA012DV.002

There are two principle zones of activity within this plot. One is roughly 20 km southeast of the ESF and is the aftershock zone of the 06/29/1992, M 5.6 Little Skull Mountain earthquake. The other is roughly 45 km east of the ESF and is the aftershock zone of the M 4.7 Frenchman Flat earthquake of 01/27/1999. In order to more clearly present the larger events, Figure 3 shows those earthquakes with M > 3 during this same 5-year time period. Within this plot are three earthquakes with M > 4: 1) the 1999 Frenchman Flat earthquake, 2) a M 4.0 foreshock of that
event on 01/25/1999, and 3) the 06/14/2002 M 4.4 earthquake in the aftershock zone of the Little Skull Mountain earthquake. Monitoring results for the vicinity of Yucca Mountain for the years 1992-2002 are treated in a recently submitted paper (Smith et al., 2003); those results include data for the five years under the Cooperative Agreement.

**Strong-Motion Observations**

As indicated on Figure 1, strong-motion recordings are obtainable from as many as 19 sites in the vicinity of Yucca Mountain. Several earthquakes during the 5-year reporting period covered here have resulted in usable strong-motion recording, notably the 1999 M 4.7 Frenchman Flat earthquake and the 2002 M 4.4 Little Skull Mountain earthquake. The latter occurred when the strong-motion capability was fully installed. Figure 4 shows the peak accelerations that were measured for this event in map view. These data was measured from Q datasets submitted as MOL 20020912.0548 and MOL 20020920.0275; program SAC (STN # 10085) was used to display the waveforms for measurement. A discussion of these results in relation to the PSHA (Probabilistic Seismic Hazard Assessment) predictions of ground motion at Yucca Mountain is contained in von Seggern and Smith (2003).
Figure 2. Seismicity in the vicinity of Yucca Mountain for the period 10/01/1997 to 09/30/2002.
Figure 3. Earthquakes with $M > 3$ in the vicinity of Yucca Mountain for the period 10/01/1997 to 09/30/2002.
Focal Mechanisms

For the 5-year catalog of earthquakes shown in Figure 1, 204 events were large enough to determine reliable focal mechanisms. The positions of the pressure (P) and tension (T) axes on the focal spheres for these events are shown in Figure 5. This data was merged from the following datasets of focal mechanism solutions:

<table>
<thead>
<tr>
<th>Year</th>
<th>Dataset</th>
</tr>
</thead>
<tbody>
<tr>
<td>FY02</td>
<td>UCCSN DID # 012DV.015</td>
</tr>
<tr>
<td>FY01</td>
<td>MO0205UCC012DV.009</td>
</tr>
<tr>
<td>FY00</td>
<td>UN0108SPA012DV.006</td>
</tr>
<tr>
<td>FY98-99</td>
<td>UN0009SPA012DV.005</td>
</tr>
</tbody>
</table>

Note that the tension axes mostly lie at shallow dips and mostly align along a WNW to ESE direction. The azimuths of the compressional axes are orthogonal to the tensional ones, but the dips of the compressional axes are more evenly distributed, reflecting the presence of both strike-slip and dip-slip behavior. This data is corroborated by many previously determined focal mechanisms for the southern Great Basin (von Seggern and Brune, 2000). The mean direction of the tensional stress is in good agreement with other stress and strain indicators in the vicinity of Yucca Mountain.
Figure 4. Peak accelerations (cm/s^2) measured at the strong-motion sites in the vicinity of Yucca Mountain.
Figure 5. Azimuths and dips for the compressional and tensional axes of the focal mechanisms determined for earthquakes in the vicinity of Yucca Mountain for the period 10/01/1997 to 09/30/2002.
Little Skull Mountain Earthquake, 1992

Although it occurred before the time period of the Cooperative Agreement, the M 5.6 Little Skull Mountain earthquake of 29 June 1992 was still a focus of investigation. The aftershock rate in the zone of this earthquake remained high, with roughly an average of 5 earthquakes detected per day even into year 2003. In the five years covered under the Cooperative Agreement, over half the earthquake catalog consists of aftershocks of this event. A seismotectonic study of this event was published under the Cooperative Agreement (Smith et al., 2001). The focal mechanism of this earthquake is dip-slip to the southeast, with a small strike-slip component, on a steeply dipping (~70°) fault that trends at approximately 60° east of north. The nearest strong-motion instrument at 11 km recorded a peak acceleration of 0.21 g.

Events Near Yucca Mountain

During the 5-year monitoring period covered here, only fifteen earthquakes were located within 10 km of station RPY directly over the ESF. Figure 2 indicates this lack of seismic activity close to Yucca Mountain. The largest magnitude among these 15 events was an M 0.55. In von Seggern et al. (2001), it was determined that the seismicity rate within this 10-km circle around Yucca Mountain, as determined by the SGBDSN, was at least 20 times less than for the southern Great Basin as a whole. Thus the SGBDSN has confirmed, and strengthened, the inference made in a study of historical seismicity by von Seggern and Brune (1999) that the area immediately around Yucca Mountain is relatively aseismic.
Investigative Studies

Attenuation and kappa

Ground-motion attenuation parameter kappa was studied in several reports during the Cooperative Agreement. In Biasi and Smith (2001) kappa was estimated from small earthquakes using the slope of displacement spectra under the assumption that the corner frequency contributed minimally to the slope. The average kappa at permanent network stations by this method was 36 msec. This average was substantially higher than a previous study using more conventional methods and portable station recordings of moderate earthquakes (ML > 2.8) recorded in 1992 after the Little Skull Mountain M 5.6 earthquake (Su et al., 1996). The difference in results evoked a second study (Anderson and Su, 2001) that reanalyzed the portable station data and also evaluated the effect on kappa of an assumed velocity and Q structure. Average kappa at the portable sites depended on the choice of assumptions, but the new results generally confirmed the earlier estimates.

The combined catalog of magnitude 3 and larger earthquakes recorded since the installation of new, high dynamic range recorders in 1995 made possible another study of kappa using moderate earthquakes recorded by permanent network stations. Included among these stations were several digital accelerographs that recorded some strong-motion data. The data cover a wider range of source areas and source-station distances, and include more stations on tuff than did the 1992 data set. The first year of a two-year report has been written to present the preliminary results of analyzing this data. This analysis included a strong emphasis on accounting for errors and tradeoffs between parameters. As seen in earlier studies, the
displacement slope kappas were larger than those found when fitting for corner frequency and moment along with kappa, and by an amount consistent with previous studies. The new data set included a better basis to estimate the distance dependence of kappa. If distance dependence is modeled as increasing linearly with distance, the average kappa of four stations on Yucca Mountain was 20 ms. Systematics of the misfit of this model suggested an alternative, bilinear distance dependence function in which no increase with distance is accrued before a distance of about 35 km, with a linear increase after that. Physically this corresponds to a high Q in the brittle crust, where rays travel for distances less than about 35 km, and a linear increase corresponding to ray paths in the ductile lower crust, where lower Q is thought to prevail. Average kappa for four stations on Yucca Mountain using the bilinear model is 31 ms, a significant increase. It was also found that an event term significantly improves the quality of fit of kappa versus distance. This and the scatter of kappa estimates from common source areas indicate that the earthquake source spectra are often not simply following the omega-squared model. This report presents the first-year results of what is programmed as a two-year study.

**Small earthquake b-value**

The ability to see small earthquakes in the aftershock zone of the Little Skull Mountain earthquake made it possible to construct a cumulative distribution curve for earthquakes down to roughly M ~2 in von Seggern et al. (2003). This curve appears to be linear down to approximately M ~1.3, thus indicating that, at least for this seismic zone, there is a self-similar behavior for seismic energy release to very small source sizes, on the order of a few meters.
Software and Hardware Improvements

Antelope Recording System

On 01/01/2000 NSL began to operate the *Antelope* (BRTT, Inc.) software system for collecting real-time data. This system collects data from the SGBDSN, its associated real-time strong-motion sensors, and the few analog stations depicted in Figure 1. It also collects data from numerous non-YMP sources that the NSL maintains as part of its statewide seismic hazard mission. The Antelope system was a major improvement for NSL, as it supplanted two inadequate data collection systems, one for digital data and the other for analog data, into a comprehensive data recording and preprocessing system (von Seggern et al., 2000). The Antelope system includes a database, seismic processing programs, and tools for monitoring the real-time data flow. Figure 6 shows a typical display of real-time data from Antelope. Antelope is run to collect YMP seismic data at the NSL and also at the ESF north portal pad to collect data from the nine-instrument borehole accelerometer array.
Computing and Communications Network Monitoring

Recently, NSL has installed a program to monitor the computing and communications network. This program, called Nagios, is a powerful UNIX freeware tool. It is capable of monitoring all specified IP devices on the Internet and report their state-of-health, downtime periods, and other requested information. Alarms can be set for specific conditions and sent to cell phones or pagers for operator notification. Over 200 IP devices are now being monitored with Nagios now for the NSL. As an example, Figure 7 shows the borehole accelerometer portion of our network, a small part of the entire Nagios coverage. This program substantially improves our network hardware monitoring and alerts us to problems before they develop to the point of causing data loss.
Hardware Upgrades

During this Cooperative Agreement period, the NSL has been able to use DOE funds to significantly improve our computing resources. Fourteen Sun computers have been purchased with these funds, assuring that all personnel are capable of running the latest software versions at acceptable speeds and that we have redundancy in ability to perform critical computing functions. A color printer was purchased to enable us to make better presentation materials. A large RAID (Redundant Array of Individual Disks) was purchased to reliably store online all the waveforms for local earthquakes resulting from NSL event analysis. We have acquired several network routers and hubs to improve data flow. A DVD-ROM writer was acquired in order to archive YMP data on reliable, long-life media.
Figure 7. Network status map for the borehole array devices at the north portal of the ESF.
References


