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Precarious Rock Methodology for Seismic Hazard: Physical Testing, Numerical Modeling, and Coherence Studies

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Scientific Investigation Plan (SIP)

Task Title: Precarious Rock Methodology for Seismic Hazard:
Physical Testing, Numerical Modeling, and Coherence
Studies

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26 Sep 2006

Date

REVISION HISTORY

| <u>Revision Number</u> | <u>Effective Date</u> | <u>Description and Reason for Change</u> |
|-------------------------------|------------------------------|---|
| 0 | 12/17/2004 | Initial Issue. |
| 1 | 9/26/06 | Reduction in scope—age dating work will not be conducted; and subtask 3.2 change in status from Q to Non-Q (paras. 2.3, 3.1 & 3.2). Incorporated DCN 1. |

Table of Contents

| | | |
|------|--|----|
| 1 | Introduction | 4 |
| 2 | Work Scope, Objectives, and Subtasks | 4 |
| 2.1 | Scope | 4 |
| 2.2 | Objectives | 4 |
| 2.3 | Subtasks | 5 |
| 2.4 | Schedule of Work | 6 |
| 3 | Methods and Approach | 6 |
| 3.1 | Precarious Rock Methodology | 6 |
| 3.2 | Sensitivity Studies of PSHA | 7 |
| 3.3 | Coherence of Earthquake Motion (non-Q sub-task) | 7 |
| 4 | Applicable Standards and Criteria | 7 |
| 5 | Implementing Procedures and Documents | 7 |
| 5.1 | Field Experiments | 8 |
| 5.2 | Numerical Modeling | 8 |
| 6 | Equipment | 8 |
| 7 | Q-Affecting Procurements | 8 |
| 8 | Hold Points and Decision Points | 8 |
| 9 | Accuracy, Precision, Error, and Uncertainty | 9 |
| 10 | Records, Reports, and Submittals | 9 |
| 11 | Verifications and Reviews | 10 |
| 12 | Computer Software | 10 |
| 13 | Interfaces Among BSC, HRC, DOE, and UNR Components | 10 |
| 13.1 | Internal Interfaces | 10 |
| 13.2 | External Interfaces | 10 |
| 14 | References | 11 |

1 Introduction

QAP-3.0 (*Scientific Investigation Control*) of the University and Community College System of Nevada (UCCSN) Quality Assurance (QA) program requires that, prior to initiating work, a Scientific Investigation Plan (SIP) must be prepared and approved. This SIP is the planning document for "Precarious Rock Methodology for Seismic Hazards: Physical Testing, Numerical Modeling and Coherence Studies" funded as Task ORD-FY04-020 by the UCCSN/DOE cooperative agreement DE-FC28-04RW12232. This SIP is intended to cover the precarious rock methodology, and coherence of earthquake motion performed by the UNR Seismological Laboratory. This SIP represents an independent confirmatory study supporting previously gathered information. This SIP is a stand-alone document, and one or more subtasks will utilize scientific notebooks as appropriate, but all planning of the task is described in the SIP and subsequent revisions as needed. The first few pages of the scientific notebooks will reference or summarize this SIP. The work described in this SIP is subject to UCCSN QA program requirements.

2 Work Scope, Objectives, and Subtasks

2.1 Scope

The precarious rock methodology used for seismic hazard assessment includes location, age dating, field measurements of the quasi-static toppling acceleration of balanced rocks, and study of their dynamic response to realistic strong motion seismograms using numerical modeling. The work scope is contained in the task description issued by the DOE to the Seismology Laboratory of the University of Nevada, Reno and is itemized in section 2.3 below. In addition, measurement of the coherence of seismic energy at high frequencies, critical to the understanding of the variability of high frequency ground motions at the repository level, will be estimated based on data collected in limited scope portable instrument deployments. Existing high-frequency geophones that remain in place from earlier geophysical experiments will be used.

2.2 Objectives

The objectives of the work are:

- Further quantification of precarious rock constraints on ground motion
- Comparison of results with predictions of the existing PSHA
- Sensitivity studies of PSHA to: (1) the "ergodic" assumption, and (2) to truncating attenuation relations at various multiples of one standard deviation.
- Installation of portable recorders at existing geophone locations to estimate the coherence of seismic energy from local earthquakes.
- Write final report on age dates.

2.3 Subtasks

Subtasks for this project are:

1. Carry out field work at precarious rock sites in the Yucca Mountain area to determine the quasi-static toppling acceleration. The field work involves (a) recording the GPS location of the rocks, (b) determining the direction that each rock is likely to topple, (c) measuring the quasi-static toppling force by applying a horizontal force through the center of mass of the rock, and (d) estimating the mass of the rock. The ratio of the force that just tips the rock to the mass of the rock is defined as the quasi-static toppling acceleration. This parameter is then used in numerical analysis to estimate the dynamic toppling accelerations during earthquakes.
2. Survey new areas in the vicinity of Yucca Mountain for possible precarious rock sites. The survey begins with visual inspection from car and on foot using binoculars when needed. Once the potential precarious rocks are sighted, we hike to the sites to investigate whether or not they are good candidates for field test.
3. Use numerical modeling techniques to study the response of precarious rocks to variously shaped seismograms to determine the precarious rock constraints on response spectra. There will be no models produced requiring compliance with QAP-3.3. Compare numerical results with shake table testing results.
- 4.
5. Compare precarious rock results statistically with specific Probabilistic Seismic Hazard Analysis (PSHA) models.
6. Perform sensitivity studies of PSHA to: (1) the “ergodic” assumption, and (2) to truncating attenuations relations at various multiples of one standard deviation.
7. Visit ESF to assess the state of existing geophones that will be used in the coherence evaluation.
8. Install short-term portable data acquisition systems at selected locations along the ESF west wall that can efficiently retrieve earthquake data from a set of existing high frequency geophones in order to evaluate coherence of ground motion.
9. Report results, analyses and interpretations, and implications for seismic hazard estimates.

2.4 Schedule of Work

Schedules for submittals and reports are entered in the UCCSN/YMP Cooperative Agreement Milestone Schedule (http://hrcweb.nevada.edu/data/co-op/milestones_rev09-24-2004.pdf).

Below are the major milestones for this project:

| | |
|--------------------|--|
| November 30, 2004 | Install instruments in the ESF |
| November 30, 2004 | Begin field testing of precarious rocks |
| January 4, 2005 | Begin numerical testing |
| May 16, 2005 | Begin PSHA sensitivity studies |
| June 30, 2005 | Complete field testing |
| July 29, 2005 | Complete numerical modeling |
| August 15, 2005 | Complete PSHA sensitivity studies |
| September 29, 2005 | Complete data reduction/analysis |
| October 3, 2005 | Submit scientific notebook for QA/Technical review |
| October 14, 2005 | Submit data to TDA |
| November 1, 2005 | Submit final report for QA/Technical review |
| November 25, 2005 | Submit final report to DOE |
| November 30, 2005 | Submit final records |

3 Methods and Approach

3.1 Precarious Rock Methodology

Estimates of the dynamic toppling accelerations obtained from rocking response of precarious rocks can provide constraints on ground motion. Analysis of the rocking response of a rock during earthquakes requires knowledge of a few parameters specific to that rock. The most important parameter is the angle α between the vertical and the line through the rocking points and the center of mass of the rock. The majority of the precariously balanced rocks tend to oscillate about two rotation axes when subjected to ground motion. Obviously, since there are two rocking points, two angles need to be determined. In general, there can be more than one rocking direction, which might require measurements of more than two angles. Although these angles can be estimated by direct measurements in the field, the most reliable method is by determining the quasi-static toppling acceleration ($\cong \alpha g$). Precarious Rock Methodology is described in details in Anooshehpour et al. (2002, 2004).

Other parameters measured in the field are the dimensions of the rock including the distance between the center of mass and the rocking points and the direction that a rock is more likely to topple during earthquakes. These parameters are then used to estimate the dynamic toppling acceleration. The dynamic toppling acceleration will be estimated by numerical simulations (non-Q because qualifying the software is beyond the present scope of this task).

3.2 Sensitivity Studies of PSHA (non-Q sub-task)

A complete analysis of this is beyond the scope of the study, as it would require rerunning the complete PSHA with various modifications to the input. This is the reason this subtask is non-Q. We would execute simplified PSHA calculations where the input is the same as some individual models – i.e. a specific fault model, a specific background seismicity model, and one of the same ground motion prediction equations as the complete PSHA. With this model, we can test the ergodic assumption and the effect of truncating the attenuation curves at two or three standard deviations above the mean. Since this kind of input is aggregated over thousands of specific input models in the complete PSHA, the results will give some indication of the type of effect these decisions may have had on the complete analysis.

3.3 Coherence of Earthquake Motion (non-Q sub-task)

A portable seismic recorder will be deployed at one location in the ESF to record local earthquakes to evaluate the coherence of seismic energy at the ESF level generated from local earthquakes. Events will be selected from the SGBDSN catalog and extracted using standard tools. Details will be documented in the Scientific Notebook. This is a non-Q sub-task and will be conducted to assess the coherence of seismic energy over a broad a band as possible under the limitations of the existing high-frequency, 10 Hz, geophones that are installed along the ESF backwall. The coherence and correlation coefficients between various sensor records, over this as yet unknown band width, will be evaluated using SAC routines. Using a single seismic recorder, 6 geophones will be recorded. Data will be collected at 200 sps, and since only one digitizer will be applied, timing precision is therefore controlled within instrument. Only relative timing control will be used and will be sufficient; absolute time control is not required. We have not been able to evaluate the state of the in place sensors. Before deploying the recorder, we will induce a pulse with known current, into each sensor and measure the output through the digital data acquisition system and with a QA multi-meter; only ‘consistent’ relative amplitude information between adjacent sensors is required. Assessment of coherence of seismic energy within the scoping study will be documented in scientific notebooks and be provided in a report. Earthquake waveform data will be submitted. The results of this study will not be used as “quality affecting” work.

4 Applicable Standards and Criteria

There are no special standards and criteria for this task. All work will be conducted or supervised by professional seismologists, but there are no specific job skills required beyond those stated in the position descriptions filed with the HRC.

5 Implementing Procedures and Documents

UCCSN Quality Assurance Procedures (QAP) apply to the subtasks listed below, as appropriate.

Implementing procedures (IP) and scientific notebooks (SN) that are applicable to specific subtasks for Task 20 are listed below.

5.1 Field Experiments.

IPR-007: Methodology to Determine the Quasi-Static Toppling Acceleration in the Field

5.2 Numerical Modeling

IPR-008: Methodology of Inferring the Dynamic Toppling Acceleration from the Quasi-Static Toppling Acceleration

6 Equipment

Field equipment consists of:

- GPS (Global Positioning System) units. GPS unit does not require calibration.
- Digital forcemeter manufactured by Chatilan, which consists of a digital force gauge, and two load cells with capacities of 2000 and 10,000 lb. The load cell will be calibrated by a qualified supplier before usage.
- Portable digital seismic instruments and data collection mechanisms. Digital acquisition units are manufactured by Refraction Technology and will be calibrated in house before deployment. The calibration process will be documented in the scientific notebook. For sensors, the existing high-frequency geophones in the ESF (installed during prior geophysical investigations by non-UNR organizations) will be utilized.

Equipment used for this project will be kept in locked storage. Desk and portable computers used in this study will be password-protected and kept in a locked office.

7 Q-Affecting Procurements

All quality-affecting equipment procurements and subcontracts are through UNR purchasing, with the approval of the UCCSN Quality Assurance Manager and in accordance with the QAP-7.0 and cooperative agreement. All work planned or performed and all 'Q' procurements and subcontracts are subject to review and/or verification by the DOE Office of Quality Assurance.

8 Hold Points and Decision Points

None

9 Accuracy, Precision, Error, and Uncertainty

Measurements on a precarious rock in the field would include GPS location, quasi-static toppling force, toppling direction, dimensions, location of the rock's center of mass, and density. The accuracy of GPS location is 10 meters horizontal and 20 meters vertical. The error in measuring toppling force with the load cell is less than 5%. Uncertainty in density measurement is less than 5%. Depending on rock shapes, the error in locating the center of mass, and the mass of the rock could be around 10 to 15%. Estimates of errors in the field will be recorded in the scientific notebook and incorporated in data analyses.

Error in numerical calculation of the dynamic toppling acceleration will depend on errors in input parameters measured in the field.

10 Records, Reports, and Submittals

QA records produced as a result of the UCCSN QAPs and this task's IPs will be controlled in accordance with QAP-17.0. Data collected in the field, results of the numerical modeling and reduced data will be used and controlled electronically. Electronic data will be protected in accordance with QAP-3.1, "Control of Electronic Data". All the reduced data will be submitted to the UCCSN Technical Data Archive (TDA) in accordance with QAP-3.6, "submittal of data". All the data will be quality affecting, however, if unqualified data were to be used for corroborative purposes, they will be labeled "unqualified" and traceability to their origin will be maintained. All the data will be protected on computers with "password" in limited access rooms. Back-ups of data will be kept in a safe in LMR building on the UNR campus, as well as a locked office.

Quarterly report submittals are submitted in accordance with the Cooperative Agreement. At the end of the project a report (submittal) will present results, analyses and interpretations, and implications for seismic hazard elements. This report will be reviewed according to QAP-3.4 (Technical Reports). Submittals are submitted in accordance to the Cooperative Agreement to the administrative task PI to DOE. Results will also be reviewed and submitted to a peer-reviewed journal. UCCSN QAP-3.0, "*Scientific Investigation Control*" governs scientific notebooks used in this work plan. Submittal of the notebooks and report constitutes evidence of the work performed.

A report summarizing field work at precarious rock sites, numerical modeling analyses, comparison of precarious rock results with specific PSHA models, and results of sensitivity studies to the ergodic assumption and truncation of attenuation relations will be submitted to DOE.

11 Verifications and Reviews

Scientific notebooks started under this task will be reviewed at the end of the subtask, or earlier as needed. Study data and/or results will be reviewed in accordance with QAP-3.0.

12 Computer Software

The following computer programs are used in this task and controlled according to QAP-3.2: *Software Management*.

| <u>Program Name</u> | <u>STN</u> | <u>Purpose</u> | <u>Computer</u> |
|---------------------|-------------|---|-----------------|
| SAC | 10085-00.46 | process and analyze seismograms | Sun O/S 2.8 |
| ROCKING | 10453-1.0 | The two-dimensional toppling program will need to be qualified as a software routine. | Sun O/S 2.8 |

13 Interfaces Among BSC, HRC, DOE, and UNR Components

13.1 Internal Interfaces

The UCCSN provides indoctrination and training, as specified by the PI, and works with the PI or designee to track the status of personnel training. All quality-affecting procurements of calibration items and services will be made through UCCSN North purchasing, with approval of the UCCSN and in accordance with QAP-7.0 and the Cooperative Agreement.

The following UNR personnel are involved with the subtasks described in Section 2.3 and may make entries in the appropriate scientific notebooks:

| <u>Title</u> | <u>Name</u> |
|------------------------|----------------------|
| Principal Investigator | James Brune |
| Research professor | Rasool Anoooshehpoor |
| Professor | John Anderson |
| Research professor | Ken Smith |

13.2 External Interfaces

Study results will contribute to seismic design input, through the Probabilistic Seismic Hazard Analysis, for the seismic engineering of surface and subsurface facilities by the Surface Facilities Operations and Engineered Barrier Systems Operations groups. . They are relevant to Performance Confirmation investigations. The field work in this work plan is monitored by the BSC Test Coordination Office (TCO) within “Ranch” area near Yucca Mountain.

14 References

- Anooshehpour, A., J. N. Brune and David H. Von Seggern (2002): Constraints on ground motion at Yucca Mountain provided by precarious rocks, DOE/UCCSN Cooperative Agreement.
- Anooshehpour, A., J.N. Brune and Y. Zeng (2004), Methodology for obtaining constraints on ground motion from precariously balanced rocks, *Bull. Seism. Soc. Am.*, 94, 285-303.