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**UNCONFINED COMPRESSION EXPERIMENTS ON TOPOPAH
SPRING MEMBER TUFF AT 22°C AND A STRAIN
RATE OF 10^{-9} s^{-1} : DATA REPORT**

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ABSTRACT

Experiment results are presented for unconfined compressive strength and elastic moduli of tuffaceous rocks from Busted Butte near Yucca Mountain, Nevada. The data have been compiled for the Yucca Mountain Site Characterization Project Site and Engineering Properties Data Base. Experiments were conducted on water-saturated specimens of the potential nuclear waste repository horizon Topopah Spring Member tuff (thermal/mechanical unit TS_w2). The influence of strain rate on mechanical properties of the tuff was examined by loading six specimens in uniaxial compression at a strain rate of 10^{-9} s^{-1} . The experiments performed under ambient pressure and temperature conditions and conformed to Technical Procedure 91, titled "Unconfined Compression Experiments at 22°C and a Strain Rate of 10^{-9} s^{-1} ." The mean and standard deviation values of ultimate strength, Young's modulus and Poisson's ratio determined from these experiments are $85.4 \pm 21.7 \text{ MPa}$, $33.9 \pm 4.6 \text{ GPa}$, and 0.09 ± 0.07 , respectively.

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The work in this report was performed under WBS 1.2.3.2.7.1.3.

The data in this report was developed subject to QA in QAGR S1232713A, PCA 2.0, Task 2.1, the data is qualified and can be used for licensing.

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1.0 INTRODUCTION

An integral part of the licensing procedure for the potential nuclear waste repository at Yucca Mountain, Nevada, involves accurately predicting the *in situ* rheology once the canisters containing the radioactive waste are in place. The data required to successfully model the rheology include thermal and mechanical properties of the potential repository horizon. Mechanical properties of tuff (e.g., elastic moduli and fracture strength) are dependent on water saturation, strain rate, and temperature. In this series of tests, a suite of experiments was performed to help determine the influence of strain rate on the elastic moduli and fracture strength of water-saturated welded tuff at ambient temperature and pressure. Six samples were tested to failure in uniaxial compression at a strain rate of 10^{-9} s^{-1} .

2.0 EXPERIMENTAL PROCEDURE

Six specimens of Topopah Spring Member tuff (specifically thermal/mechanical unit TSw2, as described by Ortiz et al., 1985) collected from an outcrop at Busted Butte, Nevada, were tested to failure in uniaxial compression. The specimens were nominally 50.8 mm in diameter and 101.6 mm in length. The dimensions of the specimens were checked and any deviations from the specifications presented in Yucca Mountain Site Characterization Project (YMP), Sandia National Laboratories (SNL) Technical Procedure (TP) 51, titled "Preparing Cylindrical Samples, Including Inspection of Dimensional and Shape Tolerances," were corrected through remachining. Once the dimensions were verified, the specimens were dried according to TP-65, "Drying Geologic Samples to Constant Weight," and then water saturated per TP-64, "Procedure for Vacuum Saturation of Geologic Core Samples." The dry and saturated bulk densities of each specimen were then calculated by dividing the respective masses by the computed volume. The porosity was then determined from the difference between the saturated bulk density and the dry bulk density.

Prior to any testing, computerized tomography (CT) scans were performed on each specimen. Since CT scans are sensitive to variations in density, this visual representation permits a qualitative examination of the distribution of pores and low density zones throughout the rock specimen. Given the presence of lithophysae and vapor-phase altered zones within the tuff, the CT scan is a particularly useful technique for evaluating the effects these features may have on the mechanical properties of the tuff at the scale examined.

2.1 Ultrasonic Velocity Measurements and Dynamic Elastic Moduli

Prior to the mechanical tests, compressional and two orthogonally polarized shear wave velocities were measured parallel to the core axis for both dry and saturated conditions. These data were used to compute dynamic elastic moduli. These data can be compared with the static moduli collected in the low strain rate deformation tests. The compressional and shear wave velocities were measured in a benchtop apparatus that applied an axial stress of approximately 0.4 MPa to the specimen. This stress ensured coupling between the ultrasonic transducers and the rock specimen. The apparatus is shown in Figure 1.

The compressional and shear wave velocities of the samples were obtained by measuring the one-way travel time of a compressional or shear wave along the rock core axis, subtracting the travel time through the endcaps, and then dividing by the sample length. The source transducers are in the piston used to load the sample and the receiver transducers are located in the base of the apparatus. The source crystal is excited by a fast rise time electrical pulse generated with a pulser/receiver. The crystal produces a broad-band (300-800 kHz) ultrasonic pulse that propagates through the adjacent titanium end piece, through the rock sample along the core axis, through the titanium end piece at the opposite end of the core, and into the receiver crystal. The electrical signal produced by the receiver crystal is amplified and filtered by the receiving section of the pulser/receiver, then fed into a digital oscilloscope. The oscilloscope digitizes the ultrasonic waveform and displays the digitized signal.

The travel times are read directly from the oscilloscope display by picking the first break in the compressional or shear wave signal. There are several techniques by which the first break may be determined. The technique used here was to calculate a threshold voltage that is 1.25% of the overall peak-to-peak amplitude of the first three half-cycles of the signal. The arrival time is picked at that point when this threshold voltage is exceeded relative to the baseline voltage. The resolution of the pick is ± 0.01 microsecond. Time series plots for the compressional and shear waves obtained on each specimen are shown in Appendix A.

The dynamic Young's modulus (E) and Poisson's ratio (ν) are computed from the velocity data. The dynamic elastic moduli are computed as follows:

$$E = [\rho V_s^2 (3V_p^2 - 4V_s^2)] / (V_p^2 - V_s^2)$$

$$\nu = (V_p^2 - 2V_s^2) / [2(V_p^2 - V_s^2)]$$

where

V_p = compressional velocity, (km/s),

V_s = average shear wave velocity (km/s),

ρ = bulk density (g/cc).

Figure 1. Schematic of the Apparatus Used to Measure the Ultrasonic Velocities of Each Sample Prior to Testing. Only the axial measurements were performed.

2.2 Unconfined Compression Experiments

Unconfined compression experiments were performed at a nominal strain rate of 10^{-9} s^{-1} in a servo-controlled deformation apparatus. The capacity of the press is $6.7 \times 10^4 \text{ N}$. The apparatus consisted of a loading frame, a servo-controller, and a data acquisition system.

The servo-controller is a self-contained digital unit that operates in either force or displacement feedback. The unit generates a reference signal for the servo amplifier in one of three possible modes: (1) ramp to upper limit at a constant rate and hold, (2) ramp to lower limit at a constant rate and hold, and (3) saw-tooth between upper and lower limits at a constant rate. The upper and lower limits and the rate are manually set. The rate at which the reference signal is updated can be varied from 10^{-5} to 10^3 times per second. The loading rate or displacement rate of the hydraulic press depends on the range of the feedback transducers. The feedback transducers are conditioned with amplifiers in the servo-control unit and balanced so that the full-scale output of the transducer corresponds to the maximum range of the reference signal generator. The full-scale output (10 volts) is divided into 2^{14} discrete steps. The rate is controlled by varying the time between steps.

During each test, the axial and radial displacements of the specimen are measured with linear variable differential transformers (LVDTs). The strains were calculated from these displacements. Two LVDTs measured the axial displacement. The LVDT barrels were mounted on rings attached directly to the sample as shown in Figure 2. The cores for the displacement transducers are on extended rods that attach to a second ring separated from the first ring by approximately one-half the sample length (50 mm). As the sample shortens, the distance between the rings decreases and is measured by the LVDTs. The average change in the separation between the rings divided by the initial separation gives the axial strain for the sample.

The most direct way to measure radial strain is with the radial displacement gauge developed by David Holcomb and Michael McNamee of SNL, Albuquerque, NM. Their gauge consists of an LVDT mounted in a ring that is spring-loaded against the surface of the sample (Figure 2). The core of the LVDT is connected to the spring. As the sample diameter changes, the spring deflects, changing the position of the core within the barrel of the LVDT in direct proportion to the radial displacement. The change in diameter divided by the original sample diameter gives the radial strain for the sample. The outputs of all three LVDTs are fed into signal conditioners where the signals are demodulated and amplified. The output signal from the conditioner is fed into an A/D converter in the microcomputer and stored.

Axial and Radial Deformation Instrumentation

Figure 2. Schematic of the Apparatus and Setup Used to Measure the Axial and Radial Displacement of the Specimens During the Unconfined Compression Tests.

The force on the test column is measured with an external load cell. The accuracy of the load cell is better than $\pm 0.5\%$ of its full-scale output; the combined linearity and hysteresis is better than 1%.

The position of the hydraulic piston is observed with a direct current displacement transducer (DCDT). This transducer provides feedback control in constant strain rate tests and is continuously monitored along with all the other transducer outputs.

For any experiment, up to 16 outputs from a variety of transducers are monitored. The output from each device is conditioned, amplified, converted to digital format, and recorded as a function of time. The collection rate depends on the rate of change in the test parameters.

For these constant strain rate tests, at 10^{-9} s^{-1} for the tuff specimens and 10^{-5} s^{-1} for the aluminum system checks, the loading frame is operated in displacement feedback. The displacement can be controlled to within $\pm 2 \times 10^{-6} \text{ mm}$ when the system is in the displacement mode.

2.2.1 Detailed Experimental Procedure for Unconfined Compression Experiments

1. Each specimen is prepared as a right circular cylinder with a nominal diameter of 50.8mm and length of 101.6 mm. The dimensions of the cylinder are checked to ensure they conform to the specifications in TP-51.
2. The rock core is visually inspected for any surface irregularities and imperfections which are noted in the logbook.
3. The LVDT ring used to measure the radial displacement is positioned at the midpoint of the sample. The supporting ring for the LVDT is aligned to ensure that the line between the adjusting screw on the ring and the axis of the LVDT core barrel (1) passes through the axis of the sample and (2) is perpendicular to the sample axis (Figure 2).
4. The two rings supporting the axial displacement devices are attached to the specimen. One ring secures the LVDT barrels and the other supports the LVDT core extension rods. The rings are located approximately 25 mm from each end of the specimen. The rings are carefully centered so that they are concentric with the specimen, and parallel to each other and the ends of the sample. Once the rings are in place, the stainless steel extension rods for the LVDT cores are inserted into the LVDT barrels and secured into their support ring. The extension rods are supported with adjusting screws secured with locking nuts.
5. The sample assembly is placed on the base plug of the pressure vessel.
6. The electrical leads of the two axial LVDTs and the radial LVDT are plugged into the connector in the base plug of the pressure vessel. Electrical leads are brought into the pressure vessel with high-pressure electrical connectors. The final mechanical adjustments to the LVDTs are completed. Each LVDT is adjusted so that its amplified output is slightly positive. The gain in analog-to-digital converter has been preselected to accept input voltages in the 0-10 volt range. Consequently, each output must be positive. Note that all the of LVDTs are wired so that their output will be increasingly

- positive during an experiment. Increasing the sample diameter and shortening the sample assembly results in an increasingly positive output voltage.
7. The sample assembly is inserted into a 177.8mm-bore-diameter pressure vessel. The pressure vessel is used as an environmental chamber to isolate the sample and associated instrumentation from any thermal fluctuations in the laboratory.
 8. The piston on the hydraulic ram is advanced and an axial load of approximately 400 N is exerted on the sample assembly. This seats the sample and all elements in the loading column. This procedure is accomplished by operating the servo-controller in force feedback and setting the controller to a force of 400 N. The piston on the hydraulic ram is slowly advanced to exert the preset load.
 9. The double-acting hydraulic ram is locked by closing the solenoid valves at each cylinder port using the *emergency fail-safe* button. The displacement transducer monitoring the piston displacement is adjusted so that its output voltage is zero (0.0) volts. The servo-controller is set to operate in displacement feedback. The solenoid valves are opened, locking the hydraulic cylinder, with the reset button on the fail-safe unit. Using the zero offset control for the displacement transducer, the hydraulic piston is retracted until there is no force on the loading column.
 10. Data acquisition is initiated. The amplified outputs from six transducers are monitored and recorded using a microprocessor-based data acquisition system. The transducers monitored include: two axial LVDTs, one radial LVDT, the piston displacement, the force cell, and the thermocouple. A schematic diagram for the system is shown in Figure 3. The conditioned output signals are presented to an analog-to-digital converter board which resides in the microcomputer. The microcomputer used in these experiments is a PC/XT. The data acquisition program has been adapted to run with drivers for the analog to a digital converter. All channels are sampled continuously. Data is recorded only when the output of one channel deviates from the previous value by more than 10 mV.
 11. The rate controller is set to a displacement rate corresponding to a strain rate of 10^{-9} s^{-1} . After a final check of all the transducer values, the specimen is loaded. For the aluminum calibration tests, the controller is set to a rate corresponding to a strain rate of 10^{-5} s^{-1} .
 12. The experiment is monitored daily and device outputs, as observed from the display panel meters, are recorded manually in the logbook. During the initial stages of the test, observations are more frequent.
 13. Once the sample fails or the experiment is complete, data acquisition is terminated.
 14. The units of stress and strain are derived from the recorded device outputs and the pertinent plots are developed. Axial stress is computed by dividing the axial force by the initial cross-sectional area of the specimen. Axial strain is obtained by dividing the change in average axial displacement of the sample by original separation of the LVDT rings in the axial system. Young's modulus (E) is computed by determining the slope of the least-squares fit line to the axial stress-axial strain data collected between 10 and 50% of the ultimate strength. Radial strain is computed by dividing the radial

**TUFF
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Figure 3. Schematic of the Data Acquisition System Used to Collect and Reduce the Data for the Unconfined Compression Tests.

displacement by the initial sample diameter. Poisson's ratio (ν) is also computed from the data collected between 10 and 50% of the ultimate strength and is defined as the slope of the least-squares fit line to the axial strain-radial strain data over that range.

3.0 EXPERIMENTAL RESULTS

In support of the unconfined compression tests on saturated specimens of tuff, a suite of system checks were performed. These checks were used to evaluate whether the entire experimental apparatus, which consists of the transducers, loading frame, and data acquisition system, are performing as specified. In this study, system checks were performed by conducting an unconfined compression experiment on a specimen of 6061-T6511 aluminum. The aluminum specimen was first machined to the same dimensions as the tuff samples; that is, 50.8 mm in diameter and 101.6 mm in length. The checks were conducted at a strain rate of 10^{-5} s^{-1} . The calibration check was performed before and after each experiment on tuff. There were seven calibration checks performed in this study. The aluminum specimen was loaded to one-half of its published yield strength of 276 MPa and then unloaded while recording the data with the acquisition system. The stress-strain data were then reduced in the same way as the data for the rock specimens. From these data, a Young's modulus and Poisson's ratio was obtained for each check. These data were then compared with the published data for the material. The published values for the aluminum are 69.66 GPa for Young's modulus and 0.33 for Poisson's ratio. System checks were determined to indicate satisfactory system performance when their results were within $\pm 5\%$ of these published values. As an added check, compressional and shear wave velocities were measured on the aluminum specimen, and the dynamic Young's modulus and Poisson's ratio were computed. For aluminum, the dynamic and the static moduli should agree since there is no porosity. The summary data obtained for the system checks are presented in Table 1. The plots for the system checks are presented in Appendix B.

For each uniaxial compression experiment, the following static data were obtained: Young's modulus (E), Poisson's ratio (ν), and ultimate strength. These data are summarized in Table 2. In addition, Table 2 lists the dry and saturated bulk densities (ρ_b), porosity, compressional and shear wave velocities (dry and saturated), and the dynamic elastic moduli (E and ν) for each specimen.

3.1 Ultrasonic Velocity Measurements and Dynamic Elastic Moduli

The measured ultrasonic velocities and the calculated dynamic elastic moduli vary little for these samples. Although the dynamic elastic moduli values differ substantially from the static elastic moduli, the relative magnitude of Young's modulus is generally consistent between methods. The lowest static Young's modulus (26.1 GPa for BB-10AE-49W-SNL) corresponds to the lowest saturated dynamic Young's modulus (38.5 GPa) for the same sample. The two samples having the highest static Young's modulus also have the highest values of saturated dynamic Young's modulus. No correlation exists for the

Table 1. System Check Data Summary

Aluminum Standard: 6061-T6511 / ID: C-NER-MI-1-A

Check ID	Completion Date	Young's modulus (GPa)	Poisson's ratio
C1A1214	12-14-90	69.68	0.34
C1A0104	01-04-91	70.79	0.34
C1A0301	03-01-91	70.34	0.34
C1A0718	07-18-91	71.23	0.33
C1A0930	09-30-91	70.77	0.34
C1A1210	12-10-91	70.29	0.34
C1A0123	01-23-92	70.85	0.34
Mean:		70.56	0.34
Standard Deviation:		0.504	0.005
Accepted Value:		69.66	0.33

Ultrasonic Velocities and Dynamic Elastic Moduli

P Wave = 6.396 km/s S1 Wave = 3.125 km/s S2 Wave = 3.126 km/s

E = 71.02 GPa

$\nu = 0.34$

Table 2. Tuff Data Summary

Sample ID	BB-10AE-5X-SNL	BB-10AE-6Y-SNL	BB-10AE-11Y-SNL	BB-10AE-11Z-SNL	BB-10AE-24Z-SNL	BB-10AE-49W-SNL
Ultimate Strength (MPa)	81.2	92.9	97.4	87.2	108.5	45.3
Static E (GPa) ¹	32.4	38.8	34.1	33.6	38.1	26.1
Static ν ¹	0.01	0.13	0.11	0.12	0.16	(-0.01) ²
Dry ρ_b (g/cc) ¹	2.28	2.28	2.29	2.29	2.30	2.25
Saturated ρ_b (g/cc)	2.40	2.39	2.38	2.39	2.40	2.37
Porosity (%)	12.0	10.8	9.0	10.0	10.4	11.7
Dry P-Wave Velocity (km/s)	4.634	4.656	4.496	4.612	N/A	4.535
Dry S1-Wave Velocity (km/s)	2.843	2.837	2.769	2.795	N/A	2.728
Dry S2-Wave Velocity (km/s)	2.836	2.836	2.764	2.794	N/A	2.732
Saturated P-Wave Velocity (km/s)	4.647	4.670	4.490	4.614	4.636	4.535
Saturated S1-Wave Velocity (km/s)	2.753	2.784	2.666	2.688	2.747	2.541
Saturated S2-Wave Velocity (km/s)	2.753	2.782	2.664	2.694	2.725	2.504
Dry Dynamic E (GPa)	44.10	44.25	41.89	43.21	N/A	40.83
Dry Dynamic ν	0.20	0.21	0.20	0.21	N/A	0.22
Saturated Dynamic E (GPa)	44.73	45.34	41.52	42.93	44.30	38.52
Saturated Dynamic ν	0.23	0.23	0.23	0.24	0.23	0.28

¹ ν = Poisson's ratio / E = Young's modulus / ρ_b = Bulk density

² See Section 3.2 for explanation.

Poisson's ratio values.

The compressional wave velocity is typically faster for the saturated condition in these samples, although the magnitude of the difference is low (0 to 0.3%). The shear wave velocities are much more sensitive to the saturation condition and are always slower when the samples are saturated. The shear wave anisotropy in these samples is also quite low.

3.2 Unconfined Compression Experiments

The mechanical properties of the six samples vary over a broad range. Data for individual samples are presented on the Data Compilation Forms in Appendix C. The data plots are presented in Appendix D. The table below shows the variability in the results of the unconfined compression experiments. The variability in the ultimate strength (45.3 to 108.5 MPa) is largely due to heterogeneities, such as lithophysal cavities, in the tuff. The range is much narrower (81.2 to 108.5 MPa) when the data from sample BB-10AE-49W-SNL is not included.

Table 3. Summary of Static Mechanical Properties

	<u>Mean</u>	<u>Standard Deviation</u>
Ultimate Strength (MPa):	85.4	21.7
Young's Modulus (GPa):	33.9	4.59
Poisson's Ratio:	0.09	0.067

The particularly weak sample (BB-10AE-49W-SNL) is a good example of the inhomogeneous nature of this tuff and its response to testing illustrates the value of CT scans as a qualitative measure of rock core heterogeneity. A visual inspection of this sample had failed to discern the presence of any large heterogeneities. However, a large lithophysal opening with an associated vapor-phase altered zone was observed from the CT scan and it was seen to cut nearly the entire diameter of the sample. This zone of weakness was the controlling factor in the low strength of this sample. It is also very likely the major factor in the very low Poisson's ratio determined for this sample.

The ultimate strengths of these samples vary relative to their porosities, which is consistent with the detailed analysis of their relationship by Price and Bauer, 1985. Samples having a higher porosity typically have lower strengths. This relationship is generally maintained for Young's modulus as well.

Poisson's ratio is lower than had been expected for these rocks. Also, as can be seen from the plots of axial strain-radial strain (Appendix D), there was typically very little radial strain measured early on in the loading sequence. This phenomenon was investigated and the cause could not be traced to procedural or experiment set-up techniques.

4.0 REFERENCES

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Price, R. H., and S. J. Bauer, 1985, "Analysis of Elastic and Strength Properties of Yucca Mountain Tuff, Nevada," in: *Research and Engineering Applications in Rock Masses*, Vol. 1, Proceedings of 26th U.S. Symposium on Rock Mechanics, Eileen Ashworth (ed.), 1985, p. 89-96. (HQS.880517.1697)

Appendix A

Velocity Time Series Plots

Well: BUSTED BUTTE
 Sample: 10AE-5X Length: 3.999 inch Fluid: DRY
 Conf Pr: 0.00 psi Pore Pr: 0.00 psi Temp: 23.00 C
 File: 5XDRY Pick: Manual 11-21-90 15:3:48
 Operator: Peter J. Boyd TP-91 Dry Velocities
 Bench Test Prior to Low Strain Rate Experiment per EP-0002 Rev. D.

Well: BUSTED BUTTE
Sample: 10AE-5X Length: 10.158 cm Fluid: WATER SATURATED
Conf Pr: 0.00 psi Pore Pr: 0.00 psi Temp: 23.00 C
File: 5XSAT Pick: Manual 5-29-92 15:1:22
Operator: Peter J. Boyd TP-91 Saturated Velocities
Prior to Low Strain Rate Experiment per EP-0002 Rev. D.
2-5-206 22:28:16

Well: BUSTED BUTTE
 Sample: 10AE-6Y Length: 4.000 inch Fluid: DRY
 Conf Pr: 0.00 psi Pore Pr: 0.00 psi Temp: 23.00 C
 File: 6YDRY Pick: Manual 11-21-90 15:18:16
 Operator: Peter J. Boyd TP-91 Dry Velocities
 Bench Test Prior to Low Strain Rate Experiment per EP-0002 Rev. D.

Well: BUSTED BUTTE
 Sample: 10AE-6Y Length: 10.160 cm Fluid: WATER SATURATED
 Conf Pr: 0.00 psi Pore Pr: 0.00 psi Temp: 23.00 C
 File: 6YSAT Pick: Manual 5-29-92 15:4:24
 Operator: Peter J. Boyd TP-91 Saturated Velocities
 Prior to Low Strain Rate Experiment per EP-0002 Rev. D.
 2-5-206 22:28:16

Well: BUSTED BUTTE
 Sample: 10AE-11Y Length: 4.000 inch Fluid: DRY
 Conf Pr: 0.00 psi Pore Pr: 0.00 psi Temp: 23.00 C
 File: 11YDRY Pick: Manual 11-21-90 15:34:42
 Operator: Peter J. Boyd TP-91 Dry Velocities
 Bench Test Prior to Low Strain Rate Experiment per EP-0002 Rev. D.

Well: BUSTED BUTTE
 Sample: 10AE-11Y Length: 10.160 cm Fluid: WATER SATURATED
 Conf Pr: 0.00 psi Pore Pr: 0.00 psi Temp: 0.00 C
 File: 11YSAT Pick: Manual 3-12-91 10:5:46
 Operator: Peter J. Boyd TP-91 Saturated Velocities
 Prior to Low Strain Rate Experiment per EP-0002 Rev. D
 3-12-91 9:49:50

Well: BUSTED BUTTE
 Sample: 10AE-11Z Length: 4.000 inch Fluid: DRY
 Conf Pr: 0.00 psi Pore Pr: 0.00 psi Temp: 23.00 C
 File: 11ZDRY Pick: Manual 11-21-90 15:45:30
 Operator: Peter J. Boyd TP-91 Dry Velocities
 Bench Test Prior to Low Strain Rate Experiment per EP-0002 Rev. D.

Well: BUSTED BUTTE
 Sample: 10AE-11Z Length: 10.160 cm Fluid: WATER SATURATED
 Conf Pr: 0.00 psi Pore Pr: 0.00 psi Temp: 22.00 C
 File: 11ZSAT Pick: Manual 6-4-91 9:14:56
 Operator: Peter J. Boyd TP-91 Saturated Velocities
 Prior to Low Strain Rate Experiments per EP-0002 Rev. D
 6-4-91 9:14:56

Well: BUSTED BUTTE
Sample: 10AE-24Z Length: 10.158 cm Fluid: WATER SATURATED
Conf Pr: 0.00 psi Pore Pr: 0.00 psi Temp: 0.00 C
File: 24ZSAT Pick: Manual 9-17-91 13:52:52
Operator: Peter J. Boyd TP-91 Saturated Velocities
Prior to Low Strain Rate Experiments per EP-0002 Rev. D
9-17-91 13:52:52

Well: BUSTED BUTTE
Sample: 10AE-49W Length: 10.158 cm Fluid: DRY
Conf Pr: 0.00 psi Pore Pr: 0.00 psi Temp: 22.00 C
File: 49WDRY Pick: Manual 9-17-91 14:13:8
Operator: Peter J. Boyd TP-91 Dry Velocities
Prior to Low Strain Rate Experiment per EP-0002 Rev. D
9-17-91 14:13:8

Well: BUSTED BUTTE
 Sample: 10AE-49W Length: 10.158 cm Fluid: WATER SATURATED
 Conf Pr: 0.00 psi Pore Pr: 0.00 psi Temp: 22.00 C
 File: 49WSAT Pick: Manual 11-26-91 16:30:40
 Operator: Peter J. Boyd TP-91 Saturated Velocities
 Prior to Low Strain Rate Experiment per EP-0002 Rev. D
 11-26-91 16:30:40

Appendix B

System Check Data Plots

Appendix C
Data Compilation Forms

YUCCA MOUNTAIN PROJECT
MECHANICAL PROPERTIES DATA COMPILATION FORM FOR THE YMP PROJECT SEPDB

PART 1. SAMPLE LOCATION AND IDENTIFICATION

SAMPLE ID: BB-10AE-5X-SNL

EXPERIMENTAL PROCEDURE: EP-0002

SAMPLE ORIGIN: Busted Butte

SAMPLE INTERVAL (ft): Outcrop

PART 2. PARAMETERS

YOUNG'S MODULUS: 32.4 GPa

POISSON'S RATIO: 0.01

DIFFERENTIAL STRESS AT FAILURE: 81.2 MPa

AXIAL STRAIN AT FAILURE: 2.91 millistrain

AXIAL STRAIN RATE: $4.7 \times 10E(-9)$ (a) /s

ARE THE PARAMETERS CONTINUED ON ANOTHER PAGE? No

PART 3. EXPERIMENT CONDITIONS

EXPERIMENT TECHNIQUE: TP-91 "Unconfined Compression Experiments at
22° C and a Strain Rate of $10E(-9)s^{-1}$ "

SAMPLE LENGTH: 3.999 / 101.6 in/mm

SAMPLE DIAMETER: 2.000 / 50.8 in/mm

A: BULK VOLUME ($\pi \times r^2 \times h$): 205.9 cc

B: OVEN DRY MASS: 469.48 g

C: SATURATED MASS: 493.08 g

D: DRY BULK DENSITY (B/A): 2.28 g/cc

E: SATURATED BULK DENSITY (C/A): 2.40 g/cc

POROSITY (E-D), WHERE WATER DENSITY = 1.0 g/cc: 12.0 %

PORE FLUID TYPE: Distilled Water

CONFINING PRESSURE: Ambient

PORE PRESSURE: Ambient

TEMPERATURE: Ambient

OVEN DRY ULTRASONIC VELOCITIES:

P: 4.634 km/s S1: 2.843 km/s S2: 2.836 km/s [E=44.10 GPa / PR=0.20]

SATURATED ULTRASONIC VELOCITIES:

P: 4.647 km/s S1: 2.753 km/s S2: 2.753 km/s [E=44.73 GPa / PR=0.23]

EXPERIMENT DURATION: 191 Hours (a)

PART 4. REFERENCE AND SUPPORTING INFORMATION

DRMS DATA SET ID: 51 / L02-4 / 6 / 87

DATA REPORT NUMBER: SAND92-1810

DATE TESTING COMPLETED: 12-26-90

THIS DCF COMPLETED BY: Peter J. Boyd

ORGANIZATION: New England Research, Inc.

COMMENTS:

(a) See DR #91-11 for an explanation of the incorrect strain rate.

YUCCA MOUNTAIN PROJECT
MECHANICAL PROPERTIES DATA COMPILATION FORM FOR THE YMP PROJECT SEPDB

PART 1. SAMPLE LOCATION AND IDENTIFICATION

SAMPLE ID: BB-10AE-6Y-SNL

EXPERIMENTAL PROCEDURE: EP-0002

SAMPLE ORIGIN: Busted Butte

SAMPLE INTERVAL (ft): Outcrop

PART 2. PARAMETERS

YOUNG'S MODULUS: 38.8 GPa

POISSON'S RATIO: 0.13

DIFFERENTIAL STRESS AT FAILURE: 92.86 MPa

AXIAL STRAIN AT FAILURE: 2.24 millistrain

AXIAL STRAIN RATE: $0.88 \times 10E(-9)$ /s

ARE THE PARAMETERS CONTINUED ON ANOTHER PAGE? No

PART 3. EXPERIMENT CONDITIONS

EXPERIMENT TECHNIQUE: TP-91 "Unconfined Compression Experiments at
22° C and a Strain Rate of $10E(-9)s^{-1}$ "

SAMPLE LENGTH: 4.000 / 101.6 in/mm

SAMPLE DIAMETER: 2.001 / 50.8 in/mm

A: BULK VOLUME ($\pi \times r^2 \times h$): 206.1 cc

B: OVEN DRY MASS: 470.46 g

C: SATURATED MASS: 492.72 g

D: DRY BULK DENSITY (B/A): 2.28 g/cc

E: SATURATED BULK DENSITY (C/A): 2.39 g/cc

POROSITY (E-D), WHERE WATER DENSITY = 1.0 g/cc: 10.8 %

PORE FLUID TYPE: Distilled Water

CONFINING PRESSURE: Ambient

PORE PRESSURE: Ambient

TEMPERATURE: Ambient

OVEN DRY ULTRASONIC VELOCITIES:

P: 4.656 km/s S1: 2.837 km/s S2: 2.836 km/s [E=44.25 GPa / PR=0.21]

SATURATED ULTRASONIC VELOCITIES:

P: 4.670 km/s S1: 2.784 km/s S2: 2.782 km/s [E=45.34 GPa / PR=0.23]

EXPERIMENT DURATION: 878 Hours

PART 4. REFERENCE AND SUPPORTING INFORMATION

DRMS DATA SET ID: 51 / L02-4 / 6 / 87

DATA REPORT NUMBER: SAND92-1810

DATE TESTING COMPLETED: 2-16-91

THIS DCF COMPLETED BY: Peter J. Boyd

ORGANIZATION: New England Research, Inc.

COMMENTS:

YUCCA MOUNTAIN PROJECT
MECHANICAL PROPERTIES DATA COMPILATION FORM FOR THE YMP PROJECT SEPDB

PART 1. SAMPLE LOCATION AND IDENTIFICATION

SAMPLE ID: BB-10AE-11Y-SNL

EXPERIMENTAL PROCEDURE: EP-0002

SAMPLE ORIGIN: Busted Butte

SAMPLE INTERVAL (ft): Outcrop

PART 2. PARAMETERS

YOUNG'S MODULUS: 34.1 GPa

POISSON'S RATIO: 0.11

DIFFERENTIAL STRESS AT FAILURE: 97.4 MPa

AXIAL STRAIN AT FAILURE: 4.42 millistrain

AXIAL STRAIN RATE: $9.5 \times 10E(-10)$ /s

ARE THE PARAMETERS CONTINUED ON ANOTHER PAGE? No

PART 3. EXPERIMENT CONDITIONS

EXPERIMENT TECHNIQUE: TP-91 "Unconfined Compression Experiments at
22°C and a Strain Rate of 10E(-9)s⁻¹"

SAMPLE LENGTH: 4.000 / 101.6 in/mm

SAMPLE DIAMETER: 2.000 / 50.8 in/mm

A: BULK VOLUME ($\pi \times r^2 \times h$): 205.9 cc

B: OVEN DRY MASS: 471.37 g

C: SATURATED MASS: 489.94 g

D: DRY BULK DENSITY (B/A): 2.29 g/cc

E: SATURATED BULK DENSITY (C/A): 2.38 g/cc

POROSITY (E-D), WHERE WATER DENSITY = 1.0 g/cc: 9.0 %

PORE FLUID TYPE: Distilled Water

CONFINING PRESSURE: Ambient

PORE PRESSURE: Ambient

TEMPERATURE: Ambient

OVEN DRY ULTRASONIC VELOCITIES:

P: 4.496 km/s S1: 2.769 km/s S2: 2.764 km/s [E=41.89 GPa / PR=0.20]

SATURATED ULTRASONIC VELOCITIES:

P: 4.490 km/s S1: 2.666 km/s S2: 2.664 km/s [E=41.52 GPa / PR=0.23]

EXPERIMENT DURATION: 1066 Hours

PART 4. REFERENCE AND SUPPORTING INFORMATION

DRMS DATA SET ID: 51 / L02-4 / 6 / 87

DATA REPORT NUMBER: SAND92-1810

DATE TESTING COMPLETED: 5-4-91

THIS DCF COMPLETED BY: Peter J. Boyd

ORGANIZATION: New England Research, Inc.

COMMENTS:

YUCCA MOUNTAIN PROJECT
MECHANICAL PROPERTIES DATA COMPILATION FORM FOR THE YMP PROJECT SEPDB

PART 1. SAMPLE LOCATION AND IDENTIFICATION

SAMPLE ID: BB-10AE-11Z-SNL

EXPERIMENTAL PROCEDURE: EP-0002

SAMPLE ORIGIN: Busted Butte

SAMPLE INTERVAL (ft): Outcrop

PART 2. PARAMETERS

YOUNG'S MODULUS: 33.6 GPa

POISSON'S RATIO: 0.12

DIFFERENTIAL STRESS AT FAILURE: 87.2 MPa

AXIAL STRAIN AT FAILURE: 2.77 millistrain

AXIAL STRAIN RATE: $1.2 \times 10E(-9)$ /s

ARE THE PARAMETERS CONTINUED ON ANOTHER PAGE? No

PART 3. EXPERIMENT CONDITIONS

EXPERIMENT TECHNIQUE: TP-91 "Unconfined Compression Experiments at
22°C and a Strain Rate of $10E(-9)s^{-1}$ "

SAMPLE LENGTH: 4.000 / 101.6 in/mm

SAMPLE DIAMETER: 2.001 / 50.8 in/mm

A: BULK VOLUME ($\pi \times r^2 \times h$): 206.1 cc

B: OVEN DRY MASS: 471.31 g

C: SATURATED MASS: 491.92 g

D: DRY BULK DENSITY (B/A): 2.286 g/cc

E: SATURATED BULK DENSITY (C/A): 2.386 g/cc

POROSITY (E-D), WHERE WATER DENSITY = 1.0 g/cc: 10.0 %

PORE FLUID TYPE: Distilled Water

CONFINING PRESSURE: Ambient

PORE PRESSURE: Ambient

TEMPERATURE: Ambient

OVEN DRY ULTRASONIC VELOCITIES:

P: 4.612 km/s S1: 2.795 km/s S2: 2.794 km/s [E=43.21 GPa / PR=0.21]

SATURATED ULTRASONIC VELOCITIES:

P: 4.614 km/s S1: 2.688 km/s S2: 2.694 km/s [E=42.93 GPa / PR=0.24]

EXPERIMENT DURATION: 724 Hours

PART 4. REFERENCE AND SUPPORTING INFORMATION

DRMS DATA SET ID: 51 / L02-4 / 6 / 87

DATA REPORT NUMBER: SAND92-1810

DATE TESTING COMPLETED: 8-21-91

THIS DCF COMPLETED BY: Peter J. Boyd

ORGANIZATION: New England Research, Inc.

COMMENTS:

YUCCA MOUNTAIN PROJECT
MECHANICAL PROPERTIES DATA COMPILATION FORM FOR THE YMP PROJECT SEPDB

PART 1. SAMPLE LOCATION AND IDENTIFICATION

SAMPLE ID: BB-10AE-24Z-SNL

EXPERIMENTAL PROCEDURE: EP-0002

SAMPLE ORIGIN: Busted Butte

SAMPLE INTERVAL (ft): Outcrop

PART 2. PARAMETERS

YOUNG'S MODULUS: 38.1 GPa

POISSON'S RATIO: 0.16

DIFFERENTIAL STRESS AT FAILURE: 108.5 MPa

AXIAL STRAIN AT FAILURE: 3.04 millistrain

AXIAL STRAIN RATE: $1.1 \times 10E(-9)$ /s

ARE THE PARAMETERS CONTINUED ON ANOTHER PAGE? No

PART 3. EXPERIMENT CONDITIONS

EXPERIMENT TECHNIQUE: TP-91 "Unconfined Compression Experiments at
22°C and a Strain Rate of 10E(-9)s⁻¹"

SAMPLE LENGTH: 3.999 / 101.6 in/mm

SAMPLE DIAMETER: 1.999 / 50.8 in/mm

A: BULK VOLUME ($\pi \times r^2 \times h$): 205.7 cc

B: OVEN DRY MASS: 472.20 g

C: SATURATED MASS: 493.67 g

D: DRY BULK DENSITY (B/A): 2.30 g/cc

E: SATURATED BULK DENSITY (C/A): 2.40 g/cc

POROSITY (E-D), WHERE WATER DENSITY = 1.0 g/cc: 10.4 %

PORE FLUID TYPE: Distilled Water

CONFINING PRESSURE: Ambient

PORE PRESSURE: Ambient

TEMPERATURE: Ambient

OVEN DRY ULTRASONIC VELOCITIES:

P: N/A km/s S1: N/A km/s S2: N/A km/s [E=N/A GPa / PR=N/A]

SATURATED ULTRASONIC VELOCITIES:

P: 4.636 km/s S1: 2.747 km/s S2: 2.725 km/s [E=44.30 GPa / PR=0.23]

EXPERIMENT DURATION: 1029 Hours

PART 4. REFERENCE AND SUPPORTING INFORMATION

DRMS DATA SET ID: 51 / 102-4 / 6 / 87

DATA REPORT NUMBER: SAND92-1810

DATE TESTING COMPLETED: 11-14-91

THIS DCF COMPLETED BY: Peter J. Boyd

ORGANIZATION: New England Research, Inc.

COMMENTS:

YUCCA MOUNTAIN PROJECT
MECHANICAL PROPERTIES DATA COMPILATION FORM FOR THE YMP PROJECT SEPDB

PART 1. SAMPLE LOCATION AND IDENTIFICATION

SAMPLE ID: BB-10AE-49W-SNL

EXPERIMENTAL PROCEDURE: EP-0002

SAMPLE ORIGIN: Busted Butte

SAMPLE INTERVAL (ft): Outcrop

PART 2. PARAMETERS

YOUNG'S MODULUS: 26.1 GPa

POISSON'S RATIO: (-0.01)

DIFFERENTIAL STRESS AT FAILURE: 45.3 MPa

AXIAL STRAIN AT FAILURE: 4.91 millistrain

AXIAL STRAIN RATE: $1.1 \times 10E(-9)$ /s

ARE THE PARAMETERS CONTINUED ON ANOTHER PAGE? No

PART 3. EXPERIMENT CONDITIONS

EXPERIMENT TECHNIQUE: TP-91 "Unconfined Compression Experiments at
22°C and a Strain Rate of $10E(-9)s^{-1}$ "

SAMPLE LENGTH: 3.999 / 101.6 in/mm

SAMPLE DIAMETER: 2.001 / 50.8 in/mm

A: BULK VOLUME ($\pi \times r^2 \times h$): 206.1 cc

B: OVEN DRY MASS: 464.29 g

C: SATURATED MASS: 488.45 g

D: DRY BULK DENSITY (B/A): 2.25 g/cc

E: SATURATED BULK DENSITY (C/A): 2.37 g/cc

POROSITY (E-D), WHERE WATER DENSITY = 1.0 g/cc: 11.7 %

PORE FLUID TYPE: Distilled Water

CONFINING PRESSURE: Ambient

PORE PRESSURE: Ambient

TEMPERATURE: Ambient

OVEN DRY ULTRASONIC VELOCITIES:

P: 4.535 km/s S1: 2.728 km/s S2: 2.732 km/s [E=40.83 GPa / PR=0.22]

SATURATED ULTRASONIC VELOCITIES:

P: 4.543 km/s S1: 2.541 km/s S2: 2.504 km/s [E=38.52 GPa / PR=0.28]

EXPERIMENT DURATION: 669 Hours

PART 4. REFERENCE AND SUPPORTING INFORMATION

DRMS DATA SET ID: 51 / 102-4 / 6 / 87

DATA REPORT NUMBER: SAND92-1810

DATE TESTING COMPLETED: 1/14/92

THIS DCF COMPLETED BY: Peter J. Boyd

ORGANIZATION: New England Research, Inc.

COMMENTS:

Appendix D

Tuff Data Plots

Appendix E

Information from the Reference Information Base Used in this Report

This report contains no information from the Reference Information Base.

Candidate Information for the Reference Information Base

This report contains no information for the Reference Information Base.

Candidate Information for the Geographic Nodal Information Study and Evaluation System

**This report contains no information for the Geographic Nodal
Information Study and Evaluation System.**

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT

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**DATE
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11 / 23 / 93

END