

DEVELOPMENT OF A ROCK JOINT DYNAMIC SHEAR TEST APPARATUS

Prepared for
Nuclear Regulatory Commission
Contract NRC-02-88-005

Prepared by
Center for Nuclear Waste Regulatory Analyses
San Antonio, Texas

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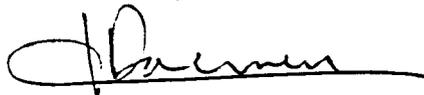
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TABLE OF CONTENTS

LIST OF FIGURES AND TABLES.....	iii
ACKNOWLEDGEMENTS	iv
1.0 INTRODUCTION.....	1
2.0 DESIGN PHILOSOPHY	2
3.0 DESCRIPTION OF APPARATUS.....	3
3.1 General.....	3
3.2 Normal Load System.....	3
3.3 Horizontal Load System.....	6
3.4 Instrumentation and Control.....	6
3.5 Data Acquisition and Processing.....	11
3.6 Specimen Preparation.....	11
4.0 PSEUDOSTATIC DEMONSTRATION TESTS.....	15
4.1 Objective.....	15
4.2 Artificial Specimen.....	15
4.3 Test Matrix and Procedures.....	16
4.4 Results	16
5.0 PRELIMINARY DYNAMIC TESTS.....	21
5.1 Earthquake Motion Simulation.....	21
5.2 Preliminary Results.....	22
6.0 CONCLUSIONS.....	26
7.0 REFERENCES.....	27
8.0 APPENDIX	
A - Procedure for Obtaining Seismic Rock Mechanics Test Specimens From the Field	
B - Procedure for Assembling and Testing Jointed-Rock Tuff Specimens Using a Dynamic Simulator Which Produces Dynamic Shear and Compressive Normal Loads	

LIST OF FIGURES AND TABLES

<u>Figure</u>	<u>Page</u>
1 Dynamic Shear Test Apparatus.....	4
2 Assembly and Instrumentation Diagram.....	5
3 Excitation and Control Block Diagram.....	8
4 Location of Relative Displacement Sensors on Specimen Lower Block.....	9
5 Calibration Curve for Proximator Channel 5.....	9
6 Calibration Curve for Proximator Channel 6.....	13
7 Calibration Curve for Proximator Channel 7.....	13
8 Calibration Curve for LVDT Channel 12.....	14
9 Calibration Curve for LVDT Channel 13.....	14
10a Joint Closure Variation With Pseudostatic Normal Stress.....	19
10b Influence of Shear Displacement on Joint Normal Displacement Under Combined Pseudostatic Load.....	19
11 Performance of Concrete Under Combined Pseudostatic Normal Load.....	20
12 Frictional Characteristic of Concrete Under Combined Pseudostatic Load.....	20
13a Acceleration Response Spectrum At Upper Specimen Block.....	23
13b Velocity Response Spectrum At Upper Specimen Block.....	23
14a Unfiltered Acceleration At Upper Specimen Block.....	24
14b Filtered Acceleration At Upper Specimen Block.....	24
15a Unfiltered Acceleration Response Spectrum At Upper Specimen Block.....	25
15b Filtered Acceleration Response Spectrum At Upper Specimen Block.....	25
 <u>Table</u>	
1 Instrumentation Channel Identification.....	7

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The rock joint dynamic shear test apparatus is being developed as part of the Seismic Rock Mechanics Project under the Center for Nuclear Waste Regulatory Analyses research program. Overall direction of this project is provided by A. H. Chowdhury of the CNWRA.

Primary technical design, development, installation, and operation of the facility were provided by D. D. Kana and D. C. Scheidt of SwRI, Division 04. They were aided by A. M. Pickens, D. E. Massey, and other technicians of Division 04. Detailed design and drafting of engineering drawings were provided by J. K. Dean of Division 06, while technical support and preparation of test procedures were provided by B. W. Vanzant of Division 06. Fabrication of mechanical parts was provided by the SwRI Machine Shop.

Technical consultation and interpretation of data were provided by B. H. G. Brady of ITASCA, and by S. M. Hsiung of the CNWRA.

1.0 INTRODUCTION

Task 2 of the Seismic Rock Mechanics Project being conducted by the CNWRA includes various activities whose objective is the laboratory characterization of the static and dynamic behavior of jointed rock specimens. Details of this task as well as all other aspects of the project are outlined by Hsiung, et al. (1989). A review of the current state-of-the-art from which these task requirements evolved has been published by Kana, et al. (1989). To elaborate, the objective of Task 2 is to develop experimental data for characterization of joints in tuff and for determining dynamic behavior of elements of jointed welded tuff to evaluate analytical models identified in other tasks of the project. Basically, the requirements are to determine jointed rock behavior under pseudostatic conditions, under various appropriate dynamic loading conditions, and especially under repeated episodes of dynamic loading conditions which arise from earthquakes or other underground loading conditions.

One major requirement of Task 2 includes the design, development, installation, and operation of a rock joint dynamic shear test apparatus. It is to have the capability of measuring responses which can be used to quantify the properties of rock joints when subject to various prescribed dynamic conditions. Both full scale specimens extracted from field sites and later, scale model specimens are to be accommodated by the apparatus. Although some related tests have been accomplished with previously reported rock mechanics test devices [Gillette, et al. (1983) and Crawford and Curran (1981)], none of this previous work has included the range of dynamic conditions required by this project.

The purpose of this report is to describe the design, assembly, calibration, and operation of this new dynamic shear test apparatus. Some results from pseudostatic demonstration tests and preliminary earthquake runs are included. The intent is to present a documentation of the status of this apparatus, and indications of its capabilities to accomplish all of the related objectives of the Seismic Rock Mechanics Project.

2.0 DESIGN PHILOSOPHY

The philosophy incorporated into the rock joint dynamic shear test apparatus consists of providing a simulation of various dynamic motions of a rock joint and measurement of the reaction forces associated with each type of imposed motion. In effect, the apparatus is to simulate a single joint element of a rock mass segment, and to characterize its behavior under various types of static and dynamic loads. Thus, a jointed rock specimen is subjected to a static normal load which represents the normal component of the in-situ stress field, and the associated joint closure is measured. Then, a dynamic shear motion is applied, and the corresponding dynamic shear force is determined, while the normal load is maintained and any normal motion is measured. The results are used to characterize the joint behavior under a variety of prescribed dynamic conditions which are anticipated to occur at the Yucca Mountain site. The results of these tests also are to be used for direct evaluation of corresponding analytical model representations of a rock joint specimen element.

It is recognized that the full range of tests required by the Seismic Rock Mechanics Project varies from very large, down to quite small full scale loads, and ultimately a corresponding range of scale model loads which remains yet to be determined. However, it is anticipated that the scale model loads generally will be near the lower end of the full scale load range. The initial design and installation of the apparatus described herein were based on use of available components where possible. As a result, the described apparatus has the capability of accommodating most, but not all of the required tests. Those test runs which require the highest loads will require an increase in load capacity of the horizontal actuator and associated components. The ultimate design will include the capability of interchanging horizontal shear actuators during a test series on a given specimen, without having to disturb the specimen itself. Thus, a very wide range of force and control will be available for each specimen.

3.0 DESCRIPTION OF APPARATUS

3.1 General

In order to perform direct dynamic shear tests for joints in tuff materials, a servocontrolled test apparatus with combined normal and direct shear capability was designed, fabricated, and assembled at Southwest Research Institute. Figure 1 shows two photographic views of the loading apparatus, in which major subcomponents are identified. These photographs are supplemented by two corresponding assembly drawings shown in Figure 2.

The apparatus consists of vertical and horizontal servocontrolled loading actuators, reaction frames, shear box fixtures, and finally an instrumented jointed tuff specimen. The loading capacity for each of the three vertical actuators is 30,000 lbs and is 20,000 lbs for the horizontal actuator. An alternate horizontal actuator and associated load cell of 50,000 lbs capacity will also be available later for higher load requirements. The horizontal actuator can be operated in either load or displacement control mode. Several loading patterns such as harmonic load and displacement, ground shock and earthquake time histories can be generated through the use of a function generator. Each actuator is equipped with a 25,000 lb capacity load cell for monitoring the applied forces. The instrumentation for monitoring the applied normal load is arranged to provide an analog output for the sum of the three load cells, as well as for the individual signals. The bottom shear box was designed to house a specimen with maximum dimensions of 12 x 8 x 4 in. The top shear box houses a specimen with maximum dimensions of 8 x 8 x 4 in. Both are grouted in their respective specimen boxes. The bottom shear box and other fixed devices are bolted to a 4-foot x 7-foot x 6-inch thick steel base plate for rigidity. The horizontal translation of the top shear box along the direction of shearing is guided through three rollers between the top shear box and normal load frame. It is also guided through side rollers not shown in Figures 1 and 2. Thus, the normal load frame and the side rollers prevent rotation of the vertical actuators (and therefore also the top specimen block) about a vertical axis perpendicular to the direction of shearing.

3.2 Normal Load System

Normal compression is applied to the specimen by three vertical actuators set at 120° about the specimen's vertical centerline. These actuators act through individual load cells whose output is summed and used as the control signal. Thus, the total normal load is controlled at a preselected static or slowly ramped value. This total resultant load is ultimately applied to the specimen via the normal load frame which acts on the three normal load rollers,

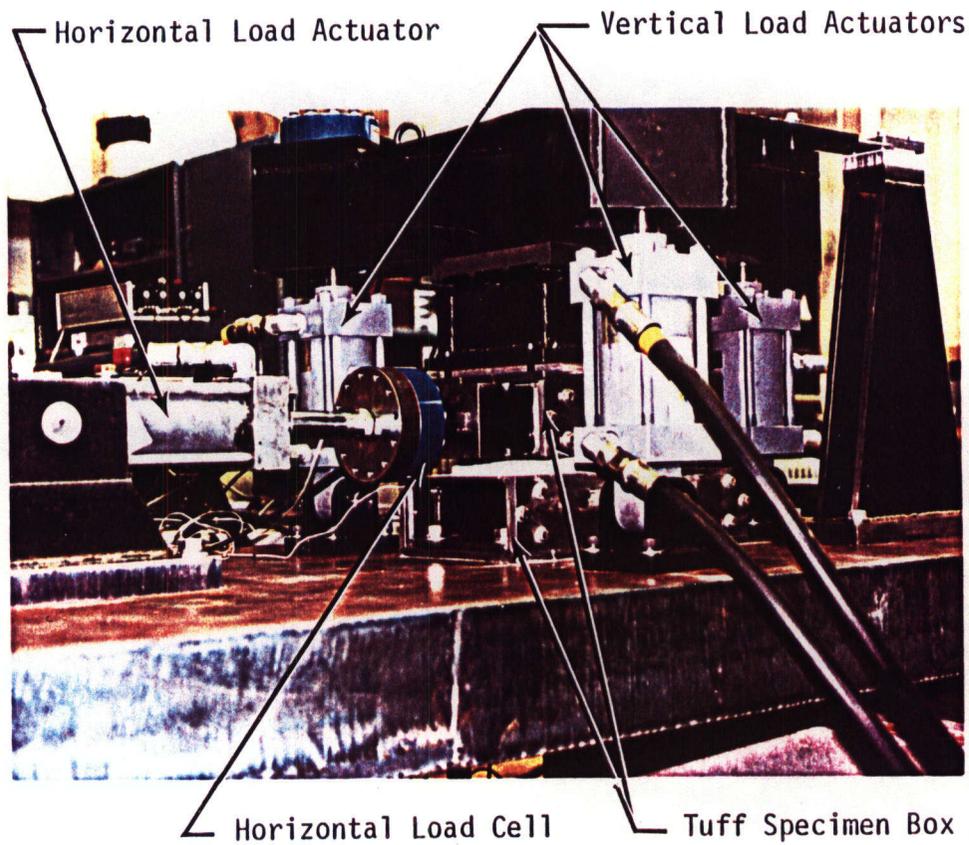
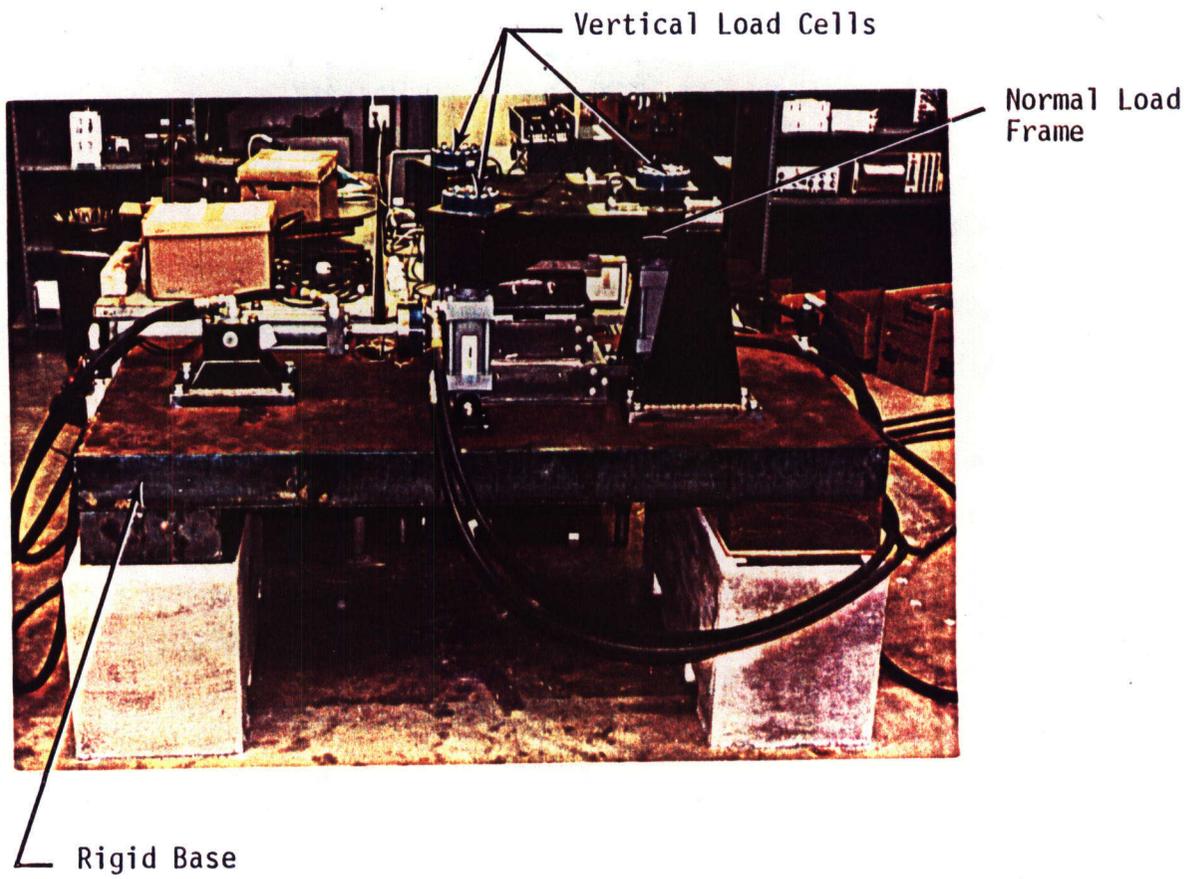
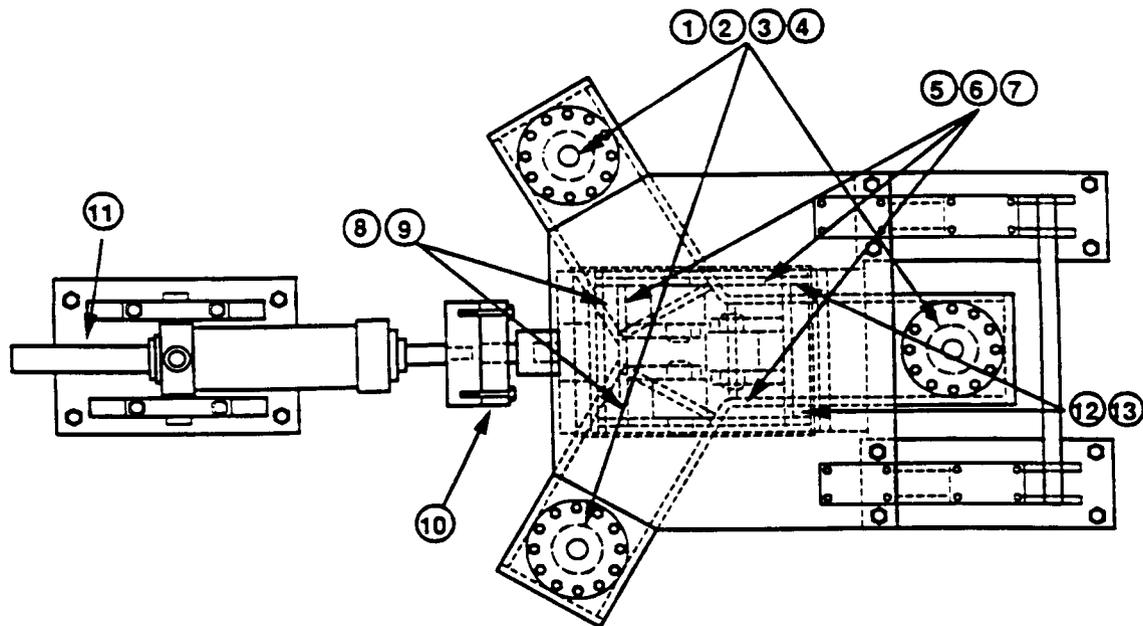
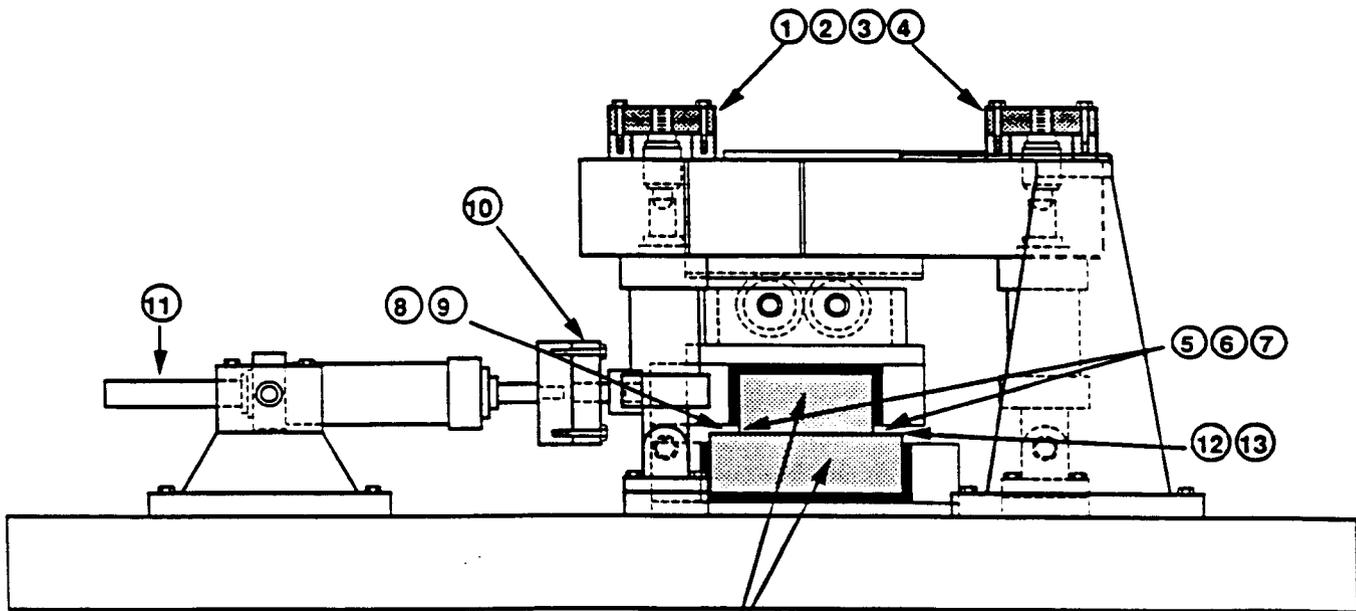


Figure 1. Dynamic Shear Test Apparatus



TOP VIEW

Note: Numbers refer to channels identified in Table 1



TUFF
SAMPLE

SIDE VIEW

Figure 2. Assembly and Instrumentation Diagram

(see top view of Figure 2) and thereby on the upper specimen box. The line of action for this normal load is through the null position of the upper specimen box. Thus, the normal load frame is constrained to three degrees of freedom:

- (1) Vertical translation
- (2) Rotation about the horizontal axis in line with the shear
- (3) Rotation about the horizontal axis transverse to the shear

These constraints are assured by two double flexures which connect the normal load frame to a fixed reaction brace, and by the two side roller assemblies, which act on the upper specimen box. Thus, the upper specimen block is constrained to these same three degrees of freedom, plus a fourth, which is translation in the direction of shear.

As indicated in Figure 2, each of the three vertical actuators is pinned at the bottom to a clevis which is bolted to the base plate. At the top, each is connected to its associated load cell through a spherical coupling. This arrangement is consistent with the three degrees of freedom identified above. Furthermore, for quick disassembly, the three actuator pins are removed, the two double flexures are detached, and the entire normal load frame with actuators attached can be hoisted up away from the specimen/roller box assembly.

3.3 Horizontal Load System

The horizontal actuator produces direct shear to the upper specimen box via the horizontal load cell, which acts through a spherical coupling. This coupling allows for slight misalignment in the horizontal shearing motion. It also allows for elevation changes of the upper specimen due to vertical load, joint surface roughness, and progressive wear. Control of the horizontal actuator load is based on the horizontal relative shear displacement, as will be described in the next paragraph.

3.4 Instrumentation and Control

Instrumentation channels are identified in Figure 2 and Table 1, and the associated excitation and control block diagram is shown in Figure 3. The locations of various relative displacement sensors on the specimen are shown in Figure 4.

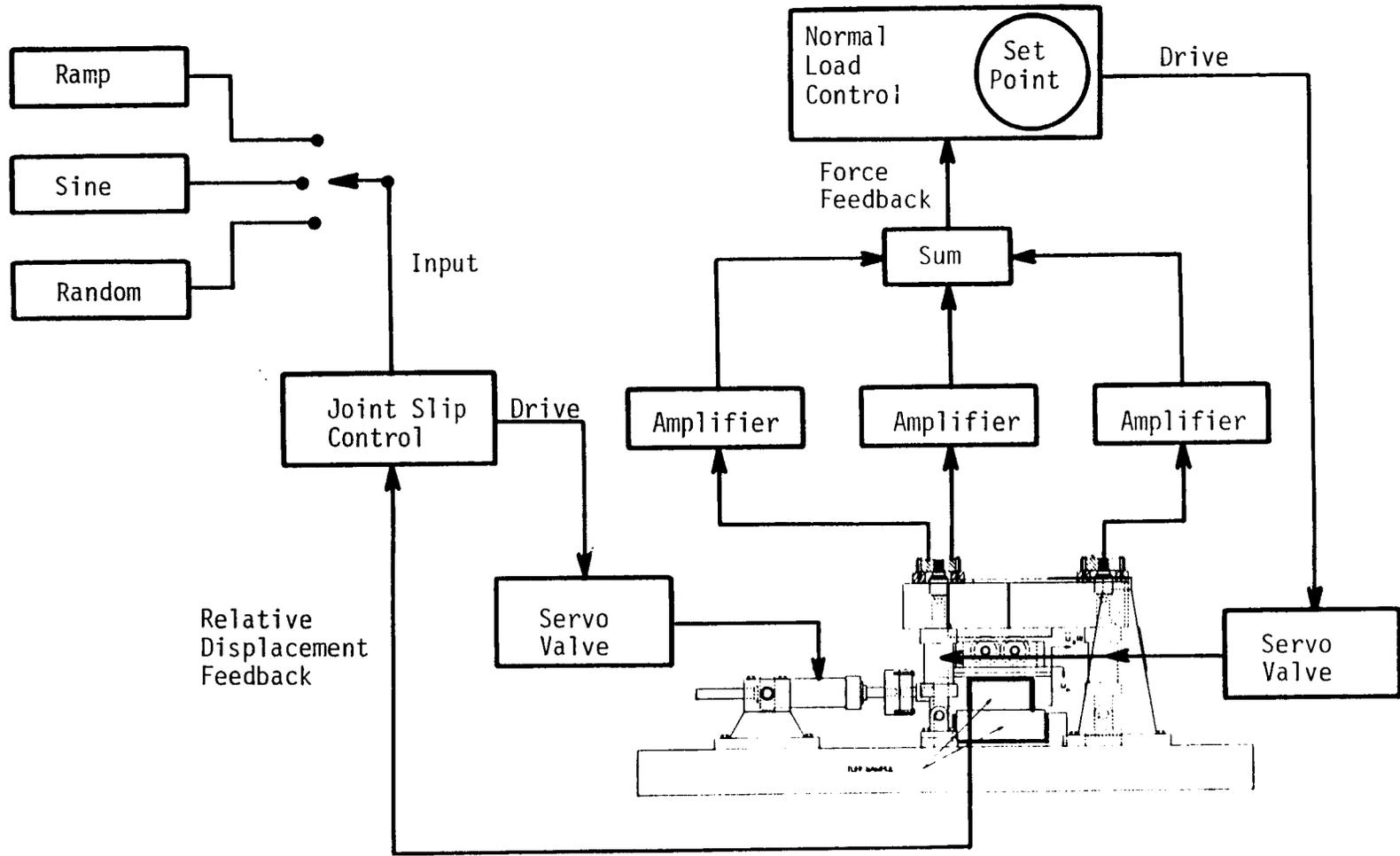
All load cells are typical commercial strain gage units with dominant sensitivity to tension/compression along one axis. Reaction to the applied static normal load is measured

TABLE 1

INSTRUMENTATION CHANNEL IDENTIFICATION

- 1 - Vertical Load Cell No. 1
- 2 - Vertical Load Cell No. 2
- 3 - Vertical Load Cell No. 3
- 4 - Analog Summation of Total Vertical Normal Load
- *5 - Vertical Relative Specimen Displacement at Right of Lower Specimen Block
- *6 - Vertical Relative Specimen Displacement at Near Left of Lower Specimen Block
- *7 - Vertical Relative Specimen Displacement at Far Left of Lower Specimen Block
- 8 - Horizontal Acceleration at Near Left of Upper Specimen Block
- 9 - Horizontal Acceleration at Near Right of Upper Specimen Block
- 10 - Horizontal Load Cell
- 11 - Horizontal Actuator Displacement
- *12 - Horizontal Displacement of Top Block Relative to Bottom Block at Far Right Corner
- *13 - Horizontal Displacement of Top Block Relative to Bottom Block at Far Left Corner

* Note: See Figure 4 for Exact Locations



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Figure 3. Excitation and Control Block Diagram

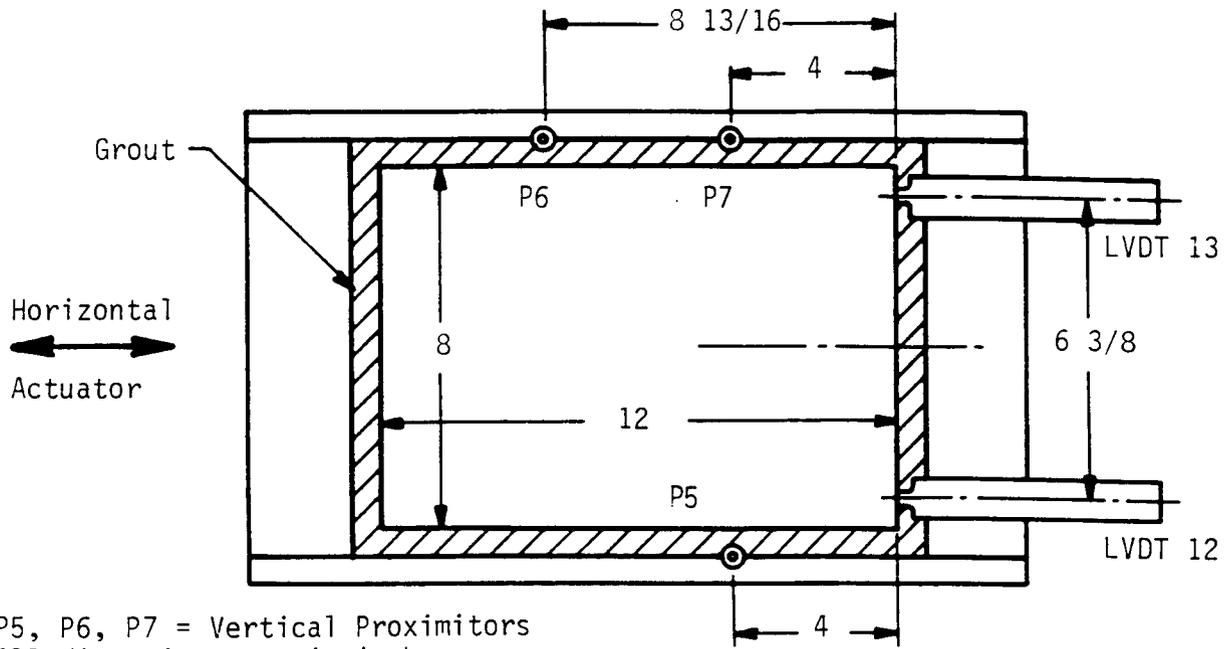


Figure 4. Location of Relative Displacement Sensors on Specimen Lower Block

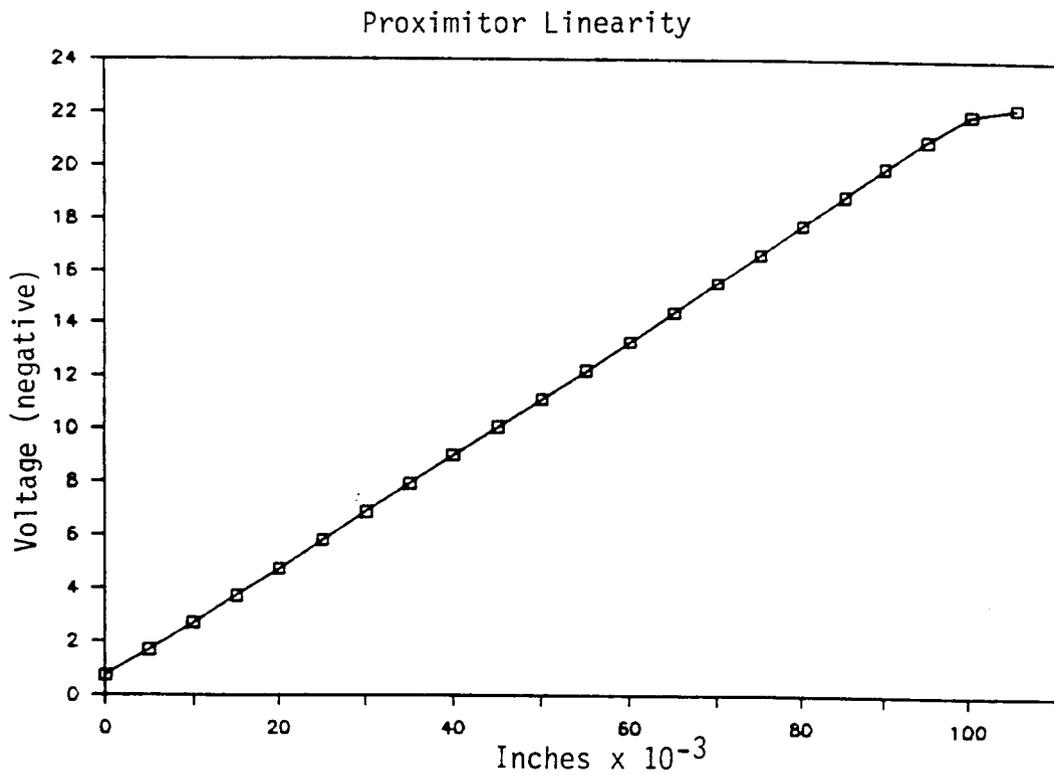


Figure 5. Calibration Curve for Proximitors Channel 5

in terms of relative vertical displacements of the two blocks at three locations of the interface near the interface. Measurements near the interface are desirable to reduce the effects of slack or lack of strength in the grout. For this, the transducers are of proximity (noncontacting) eddy-current sensing type, since horizontal movement of the two surfaces must be allowed, but only vertical displacement changes must be sensed. Hence, the three vertical measurement points can be used to resolve the rigid body displacement of the upper block relative to the lower specimen block, according to the first three degrees of freedom identified above.

For this demonstration, the transducer body was mounted on the upper edge of the side of the lower specimen box (in the 1-inch gap between the lower and upper box edges). The target was mounted on the exposed portion of the side of the upper specimen block, near the interface. Hereafter, the transducer body will be mounted on the side edge of the upper specimen block, and the target will be mounted on the side edge of the lower specimen block. This arrangement would appear to provide a better resolution of the upper block rigid body relative displacement.

The horizontal accelerometers are mounted directly by bonding onto the upper specimen block. Thus, they provide one measure of upper block absolute motion at the near end of the block. All horizontal displacement transducers are Linear Variable Differential Transformers (LVDT's), and any one can be used for horizontal displacement control. One device is located on the horizontal actuator ram. However, to account for potential slack in the linkages and grout, two of the devices are located on the far side of the specimen blocks and are installed so as to measure horizontal displacement of the upper block relative to the lower block. An average of these two represents a measure of the fourth and final degree of freedom of the upper block, and can be compared with a preselected input source, which depends on the dynamic motion desired. However, for the present demonstration tests, the horizontal actuator ram displacement (Channel 11) was used for control. Types of displacement control to be used are as follows:

Pseudostatic - A slow (20 min.) ramp is applied to the relative displacement, while the force required is simultaneously recorded.

Stepped Velocity - A drive signal is generated so that when applied to the actuator, the relative shear velocity (differentiated shear displacement) simulates a multilevel stepped velocity level.

Steady State Cyclic - A sine wave drive signal is applied. Frequency, amplitude, and duration are based on the anticipated performance of the surface.

Earthquake Simulation - A drive signal is generated such that a specified velocity response spectrum is nominally matched for a given time duration. Compliance is verified by computing the velocity response spectrum from the time-integrated relative horizontal acceleration signal. Use of a velocity, rather than acceleration, response spectrum is specified since it is anticipated to be most representative of the frequency range that will be most significant to the physical shear process that occurs.

Rockburst and Explosive Shock - A procedure similar to that for earthquake simulations is used.

Calibration of load cells is performed in a commercial hydraulic apparatus with digital voltage readout. Accuracy is within $\pm 1.0\%$. Calibration of vertical proximity eddy-current transducers is performed by placing the sensors in an adjustable displacement device with micrometer head, and reading the displacement increments and associated voltages. The three corresponding calibration curves are shown in Figures 5-7, and are seen to be quite linear. Similar curves for the two horizontal relative displacement LVDT's are shown in Figures 8 and 9. It can be seen that one LVDT (Ch. 12) is somewhat nonlinear. This result caused some problems which will be discussed later. Horizontal accelerometers were calibrated by comparison of their output with an NBS standard accelerometer, while being excited on an electrodynamic shaker.

3.5 Data Acquisition and Processing

The thirteen channels of data identified in Table 1 are sampled and recorded directly on the hard disk of a 640K memory personal computer with a 40 megabyte hard disk and diskette option. This system also contains a special math coprocessor and high speed card option. Software has been implemented which allows sampling of data at preselected rates and times, which are required by the various types of dynamic tests described above. Data are ultimately transferred to a diskette for further processing and plotting on other digital computers.

3.6 Specimen Preparation

A series of actual specimens of jointed components are presently being acquired from a suitable site. A detailed procedure for extraction of these specimens was developed, and is being used. This procedure is presented in Appendix A of this report. For this discussion, it will simply be said that a jointed-rock specimen pair is received and mounted into the upper and lower specimen boxes, when they are detached from the test apparatus. Details of the

assembly and grouting procedure can be obtained from Appendix B. Both upper and lower specimen boxes are designed so that about a 1/2-inch gap for grout exists on five faces of each specimen half, and a 1-inch gap occurs between the box edges of the assembled specimen unit. Thus, the specimen interface must fall within the 1-inch gap. The 1/2-inch thickness for the grout may be reduced by the use of spacer plates, if so desired at a later date. Once the grout has cured, the specimen is instrumented, all parts of the specimen boxes and roller box are assembled, and the specimen unit is bolted onto the base plate for testing. Information about the grout will be presented in the next section.

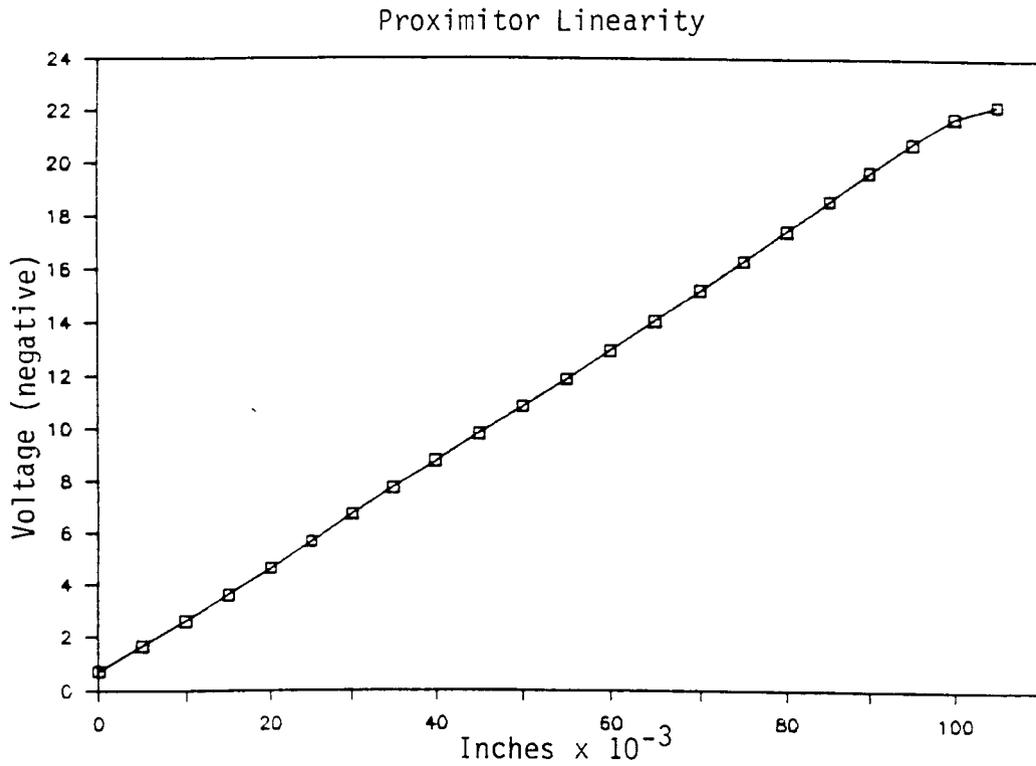


Figure 6. Calibration Curve for Proximitor Channel 6

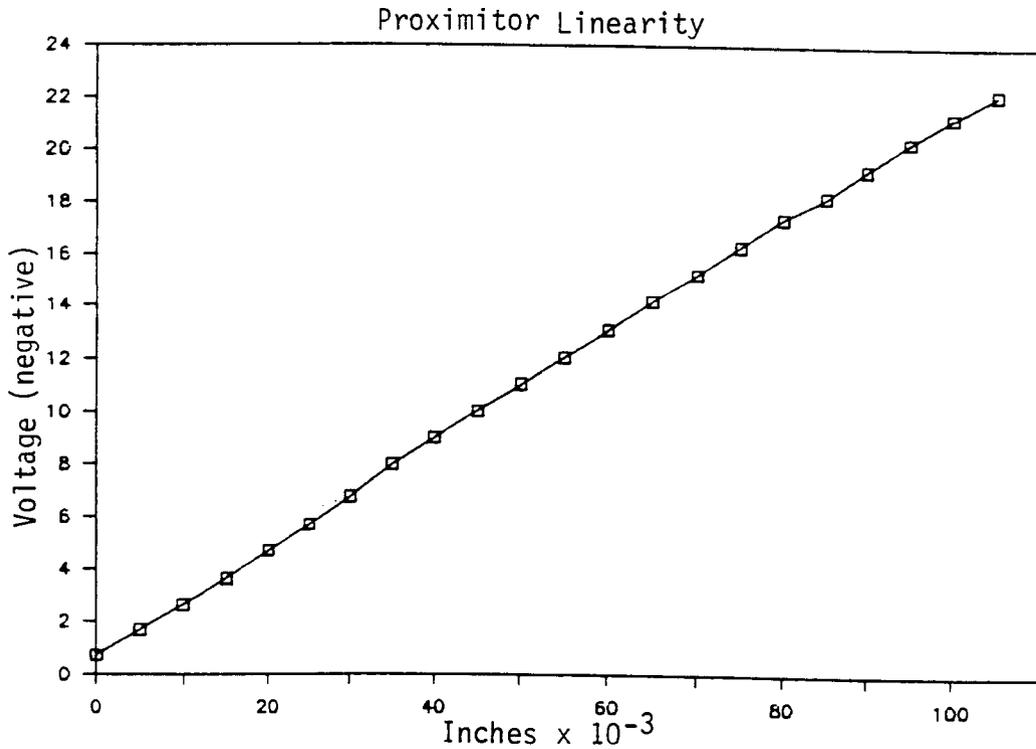


Figure 7. Calibration Curve for Proximitor Channel 7

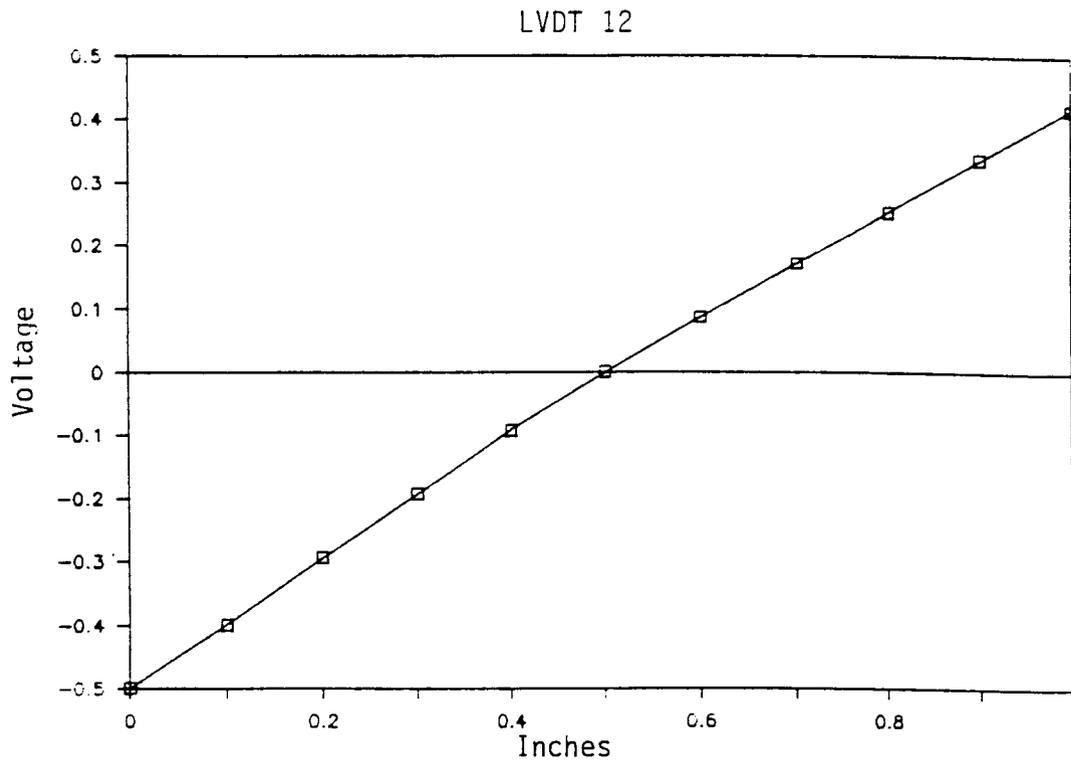


Figure 8. Calibration Curve for LVDT Channel 12

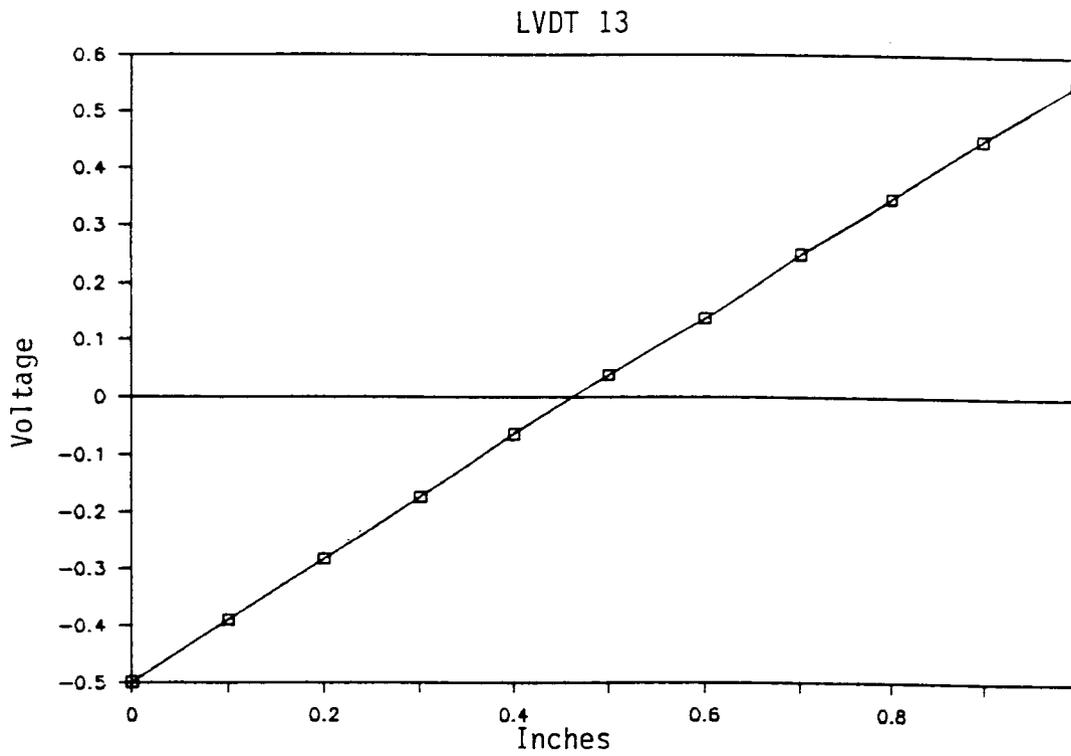


Figure 9. Calibration Curve for LVDT Channel 13

4.0 PSEUDOSTATIC DEMONSTRATION TESTS

4.1 Objective

A series of tests were conducted to demonstrate the capability of the apparatus. From Section 3.4, it can be seen that a variety of actual tests is ultimately contemplated. These tests vary from the relatively simple pseudostatic tests to the more complex earthquake simulations. Therefore, a demonstration test series with an artificial specimen was conducted by starting with a representative pseudostatic series. Some preliminary evaluations of seismic tests will be described in the next section.

4.2 Artificial Specimen

An artificial specimen was cast from ordinary handyman rapid-set concrete mix. However, it was necessary to adjust the contact area of the specimen, since at first only a 20,000 lb horizontal actuator has been available. (This available actuator was used initially in the development of the apparatus to minimize costs. Furthermore, it is intended to be used for all lower force range tests, so that better control at the lower levels can be achieved. It will be interchanged with a 50,000 lb actuator later, before attempting to conduct the tests with higher capacity requirements.) Thus, a normal size 8 x 12 x 4 inch lower specimen was cast and mated with a 6 x 6 x 4 inch upper specimen (i.e., instead of a normal 8 x 8 x 4 inch specimen). The reduction in area allowed use of a relatively high normal stress applied to the joint surface at lower total vertical load. Thus, the requirement for horizontal load was also reduced accordingly.

The specimen grout was designed to be at least as strong as the specimen material itself. For these demonstration tests, the following mix of materials was used:

Portland Cement	10 lb
Sand	25 lb
Lomard (Water Reducer)	50 gm
Water	3.5 lb

These ingredients were mixed for 15 minutes in a commercial mixer before working into the specimen box. The grout was allowed to cure for at least 72 hours. Grout for actual tuff specimens remains yet to be determined.

4.3 Test Matrix and Procedures

A matrix for pseudostatic tests with a 6 x 6 inch specimen was developed as follows:

Normal Stress (MPa)	0.5	1.0	1.5	2.0	4.0	6.0
Vertical Load (lb)	2,610	5,220	7,813	10,440	20,880	31,320
Horizontal Load (lb) at 35°	1,828	3,656	5,484	7,312	14,624	21,936

The horizontal load anticipated was based on an assumed 35° friction angle. With this it could be seen that maximum capacity of the present horizontal actuator would be exceeded somewhere between 4.0 and 6.0 MPa vertical stress.

Tests were implemented according to the test procedure given in Appendix B, which can be consulted for details. Basically, data were acquired for a sequence which consisted of one-minute at the unloaded and null positions, one-minute ramp up to the full vertical load with the horizontal null position, and finally a 20-minute ramp of the horizontal displacement from null to 1.0 inch maximum. All channels were sequentially sampled at 25kHz at 5-second intervals. At the end, the vertical load was released, the horizontal system retracted back to the null position, and the apparatus was readied for the next higher loading sequence. In all cases, the horizontal loading was toward the horizontal actuator.

During the test sequence, it was found that the horizontal actuator locked up with the 5.0 MPa vertical load (i.e., the horizontal actuator capacity was exceeded). As a result, a complete run was obtained at 4.5 MPa, while only vertical data were acquired at 5.0 and 6.0 MPa. Of course, these limitations will ultimately be eliminated with the installation of a 50,000 lb horizontal actuator.

4.4 Results

The product of a properly designed and executed direct shear test on a joint is a set of data which permits characterization of its deformation and strength properties. Data reduction results in determination of the parameters which are represented in various joint deformation models. For the static test conducted in the current demonstration exercise, the basic properties sought from the test are the deformation characteristic under normal load, the shear deformation characteristic and the limiting shear strength as a function of normal stress.

Important joint properties such as the dilatancy under shear deformation and the peak and residual strength characteristics are defined in terms of these components of a joint deformation model.

Data generated in the test on the joint in a concrete block were reduced in a way consistent with that described by Goodman (1976). This involved presentation of joint closure and shear resistance as a function of shear displacement for the various values of applied normal stress, and identification of the corresponding values of the peak and residual shear strengths. These could then be used to determine the relation between joint normal stress and shear strength.

In the analysis, data output from the acquisition system on the direct shear apparatus was transferred to a spreadsheet generated using the "Quattro" proprietary package. Parameters defining the test configuration were then used in the spreadsheet to calculate the states of stress and displacement on the joint surface at various stages of the load path. In calculating the applied normal stress, the individual loads applied by the three vertical actuators were summed, and the surface area of the specimen was used to determine the average normal stress, σ_n , distributed over the surface. No attempt was made to take account of any non-uniformity in the distribution of normal stress. Similarly, in determining the joint closure under applied normal stress and during joint shear, the average vertical compression of the joint was calculated from the three measurements of vertical displacement. In calculating the joint shear displacement, the transducer mounted on the horizontal actuator was used to provide the reference value of this parameter. This transducer was selected because there appeared to be irregular measurements indicated by the LVDT mounted directly on the specimen. These results may have occurred because they reflect detailed movements of the specimen blocks, and will be evaluated later.

In all cases of reducing the test data, initial offsets in the measured parameter values were taken into account in calculating forces and displacements applied or mobilized in the test load path. However, when calculating joint closure, no account was taken of vertical displacement arising from compression of the intact material of the block.

The response of the joint throughout the load path described in Section 4.3 is summarized in Figures 10 and 11. In Figure 10a, joint closure is plotted against applied normal stress, for loading to a normal stress of 6 MPa. It is observed that complete closure

of the joint is apparently not achieved. While there is some contribution to vertical displacement from compression of the intact concrete, the plot suggests an asymptotic approach to a closure limit.

Plots of joint normal deformation versus shear displacement for the six completed phases of the test load path (corresponding to nominal $\sigma_n = 0.5, 1, 1.5, 2, 4,$ and 4.5 MPa respectively) are presented in Figure 10b. For each plot, the magnitude of u_n at zero shear displacement represents the joint closure obtained from application of the normal stress. Two different styles of joint normal deformation during shear are represented in the plots. For nominal applied normal stresses of 0.5, 1.0, and 2.0 MPa, the slopes of the u_n versus u_s plots are relatively flat throughout the range of u_s , while for the higher normal stress levels, significant closure develops during the applied shear displacement.

A notable point concerning the normal displacement during joint shear is that closure continued to develop as shear displacement progressed. This is different from typical natural joints, which are to some extent dilatant in shear at the normal stress levels employed in these tests.

The plots of shear stress versus shear displacement at the various applied normal stress levels are shown in Figure 11. These results are typical of those obtained in direct shear tests on smooth joints, such as those presented by Jaeger (1971). Apart from the slight anomalies in the plots for $\sigma_n = 1.0$ and 2.0 MPa, at a particular normal stress, the shear resistance of the joint increases monotonically with shear displacement. The absence of peak-residual behavior in the plots is characteristic of smooth joints. It is also notable that the slopes of the plots are all quite similar, which is also consistent with published data on shear tests on smooth joints.

In Figure 12, the joint shear strengths at the various normal stress levels are plotted against the normal stresses. It is observed that the plot is linear, with no intercept on the shear stress axis. Such a plot is typical of the shear strength of smooth joints, where strength is controlled by a simple Coulomb friction law. The angle of friction for the joint, determined from the line of best fit, is about 37° . This is a reasonable average value for a joint in siliceous sedimentary rock, which the concrete approximates.

The general conclusion from this demonstration test is that when allowance is made for the artificial composition of the host specimen, the direct shear apparatus returns results which are consistent with shear tests on natural joints. With the unique capabilities of this shear machine, the results from this demonstration provide a basis for proceeding to determine the static and dynamic properties of natural joints in tuff.

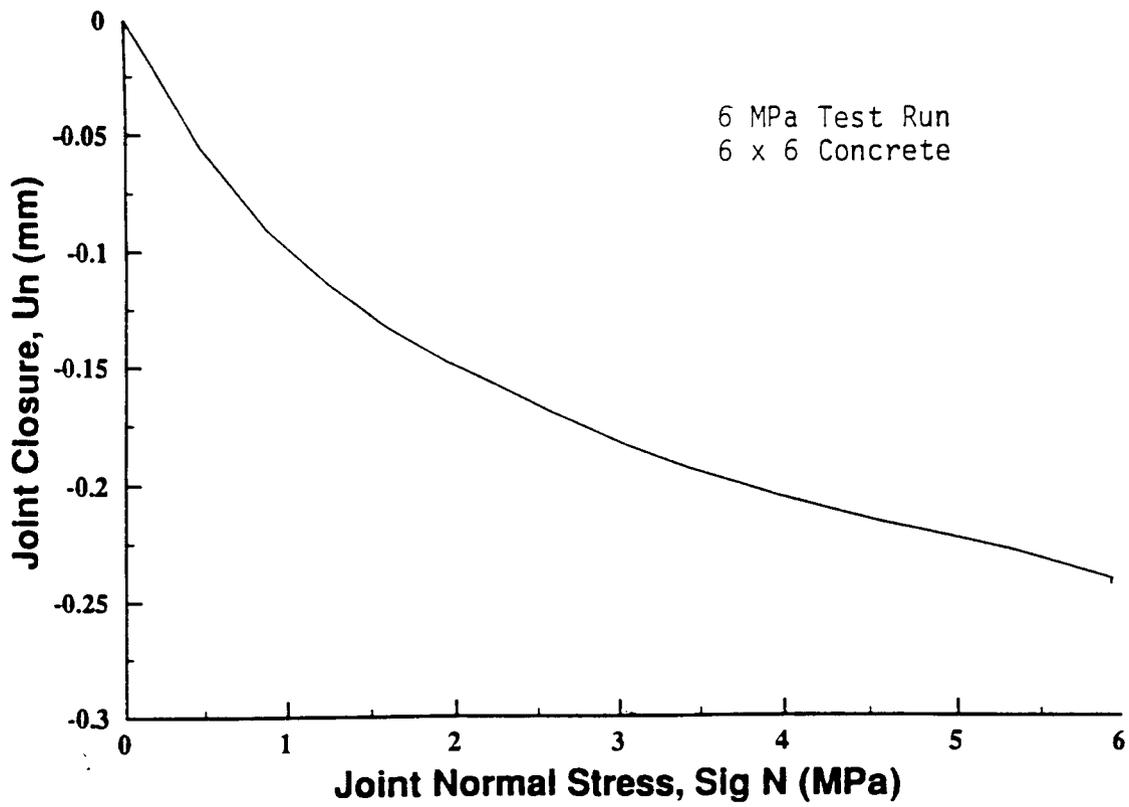


Figure 10a. Joint Closure Variation With Pseudostatic Normal Stress

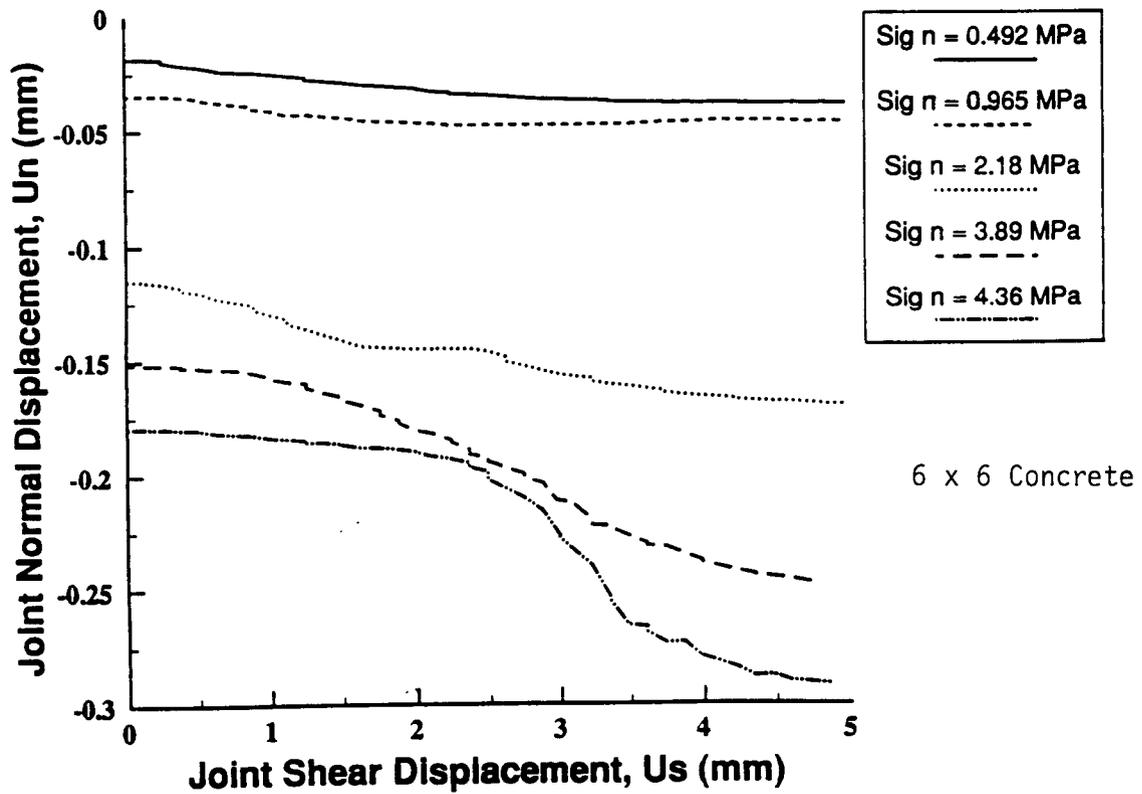


Figure 10b. Influence of Shear Displacement on Joint Normal Displacement Under Combined Pseudostatic Load

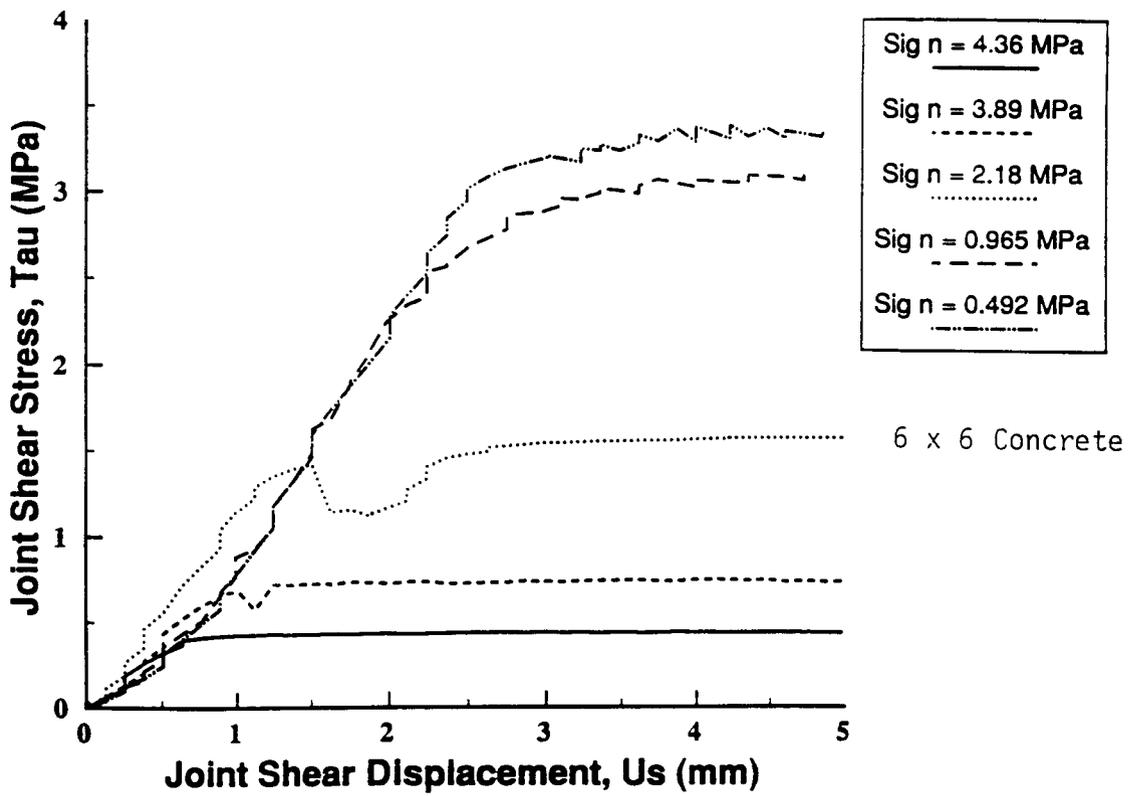


Figure 11. Performance of Concrete Under Combined Pseudostatic Normal Load

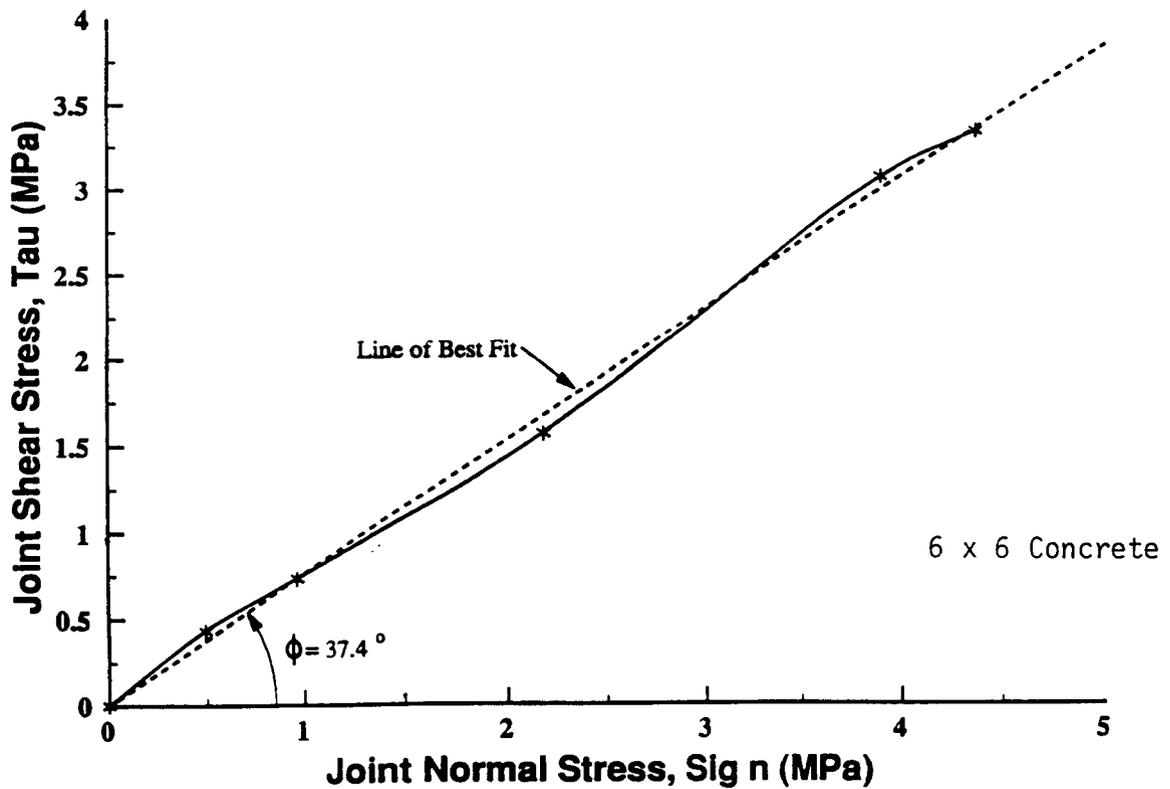


Figure 12. Frictional Characteristic of Concrete Under Combined Pseudostatic Load

5.0 PRELIMINARY DYNAMIC TESTS

5.1 Earthquake Motion Simulation

Section 3.4 lists several types of dynamic shear tests which will eventually be conducted with the apparatus. The most complex of these dynamic tests requires the matching of a test response spectrum to a specified response spectrum. At this point in the program, the actual specified response spectra have not yet been finalized. Therefore, a demonstration of the capability of the apparatus was based on a NRC Regulatory Guide 1.60 earthquake ground surface response spectrum, which probably has wider frequency content than that of a subsurface spectrum. Time duration of an earthquake is also longer than that for rockburst or explosive ground shock. Thus, it was felt that production of a representative earthquake time history with the apparatus at this point was sufficient to demonstrate its capability, since all other types of dynamic tests are simpler, and essentially included within the requirements for producing earthquake simulations.

Generation of a test time history whose response spectrum matches a specified response spectrum within given limits is a complex process than can be accomplished several different ways for laboratory simulations. It is complicated by the fact that a displacement control drive signal must be generated for the horizontal actuator, which has itself an electrohydraulic transfer function, which varies with frequency. The acceleration signal from the upper specimen block is normally used to compute the test response spectrum, which is then compared with the required spectrum, and this displacement drive signal must then be adjusted to provide any required corrections.

The synthesis process described above has been computerized, and is carried out in the present apparatus with software that has been used for a variety of earthquake simulations in earlier work. Details of this process are provided by Unruh (1982). Essentially, the iteration process is carried out in thirty-two 1/6-Octave frequency bands between 1 and 50 Hz. In each of these frequency bands the program includes a transient narrow band random signal whose level is ramped up in 5 seconds, held for 15 seconds, and then is ramped down in 10 seconds. During the iteration process, each of these 32 narrow band random signals is multiplied by a suitable coefficient, and all are then added together to form the aggregate displacement drive signal. The value of the respective coefficients is successively adjusted so that the test response spectrum matches the required response spectrum, as described above.

5.2 Preliminary Results

The process described above was first carried out on the same specimen described in Section 4.2 by computing the acceleration response spectrum for response measured at Channel 9 of the instrumentation (i.e., acceleration on the upper specimen block). For simplicity, the test was carried out with only nominal vertical load on the specimen. Figure 13 shows test response spectra (TRS) computed from the direct measured acceleration, and the velocity after analog time integration. It can be seen that the test signal contains much more higher frequency content than does the required response spectrum (RRS). This occurred even though zero input was used in those frequency bands. Thus, this energy is generated by a nonlinear process, which was identified with the grinding of the rock interface during the motion.

The occurrence of the grinding process was visualized during the design of the test apparatus, but the degree of its affect on the measured acceleration is even more than initially anticipated. Therefore, some accounting of this affect in matching of spectra based on motion measured at a distance from the source is in order. In effect, the grinding process in the test apparatus is analogous to what occurs at the focus of an earthquake, but the higher frequencies generated are filtered as a function of measurement distance from the source.

At first, a reduction of the high energy effects was attempted by integrating the acceleration response to obtain velocity, which is less affected by higher frequency content. This velocity signal was then used to compute a response spectrum for comparison with the required pseudorelative velocity spectrum (which only approximates actual velocity). The results are shown in Figure 13b. It can be seen that a somewhat better matching of the data can be achieved, but the essential feature of excessive energy at higher frequencies is still present.

The results of a much more promising approach for matching of data are shown in Figures 14 and 15. For this demonstration, another test run was performed, and the measured acceleration signal was low-pass filtered below 10Hz with a 24dB/octave slope. This cut-off frequency was chosen simply because no energy was input to the drive signal above that point. The time histories of the unfiltered and filtered signals are shown in Figure 14, while the response spectra computed from them are shown in Figure 15. It is obvious that this approach will allow a match of the data. However, the exact cut-off frequency should be based on source proximity of the actual measured site data. Details of such information remain to be determined before simulated earthquake dynamic test runs are attempted.

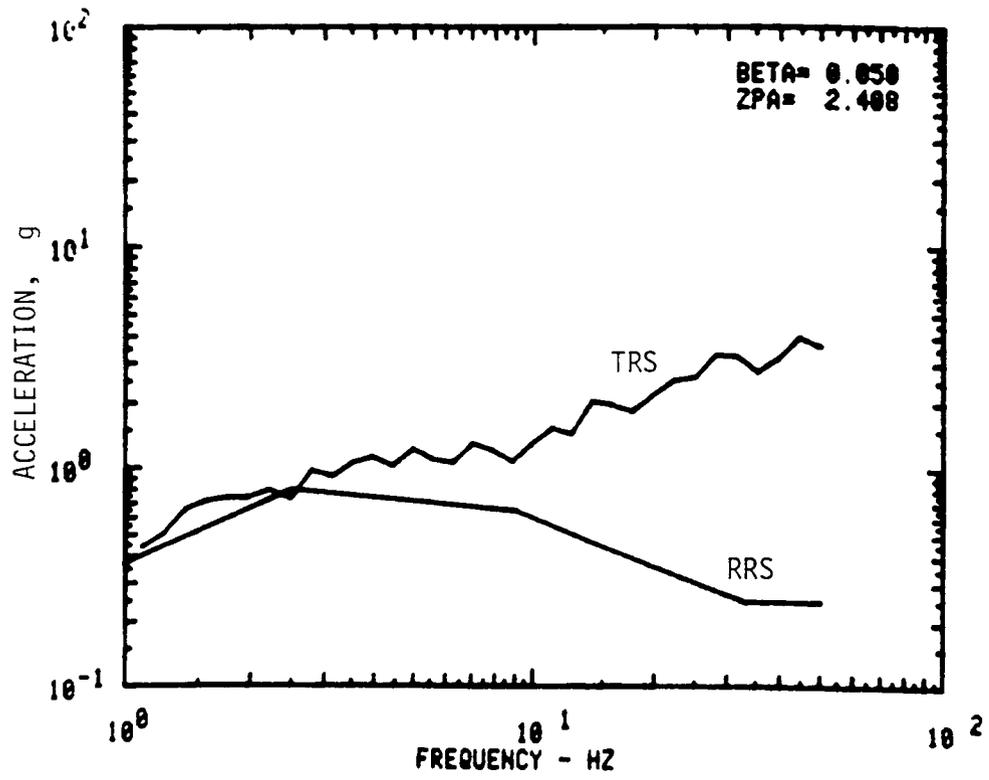


Figure 13a. Acceleration Response Spectrum At Upper Specimen Block

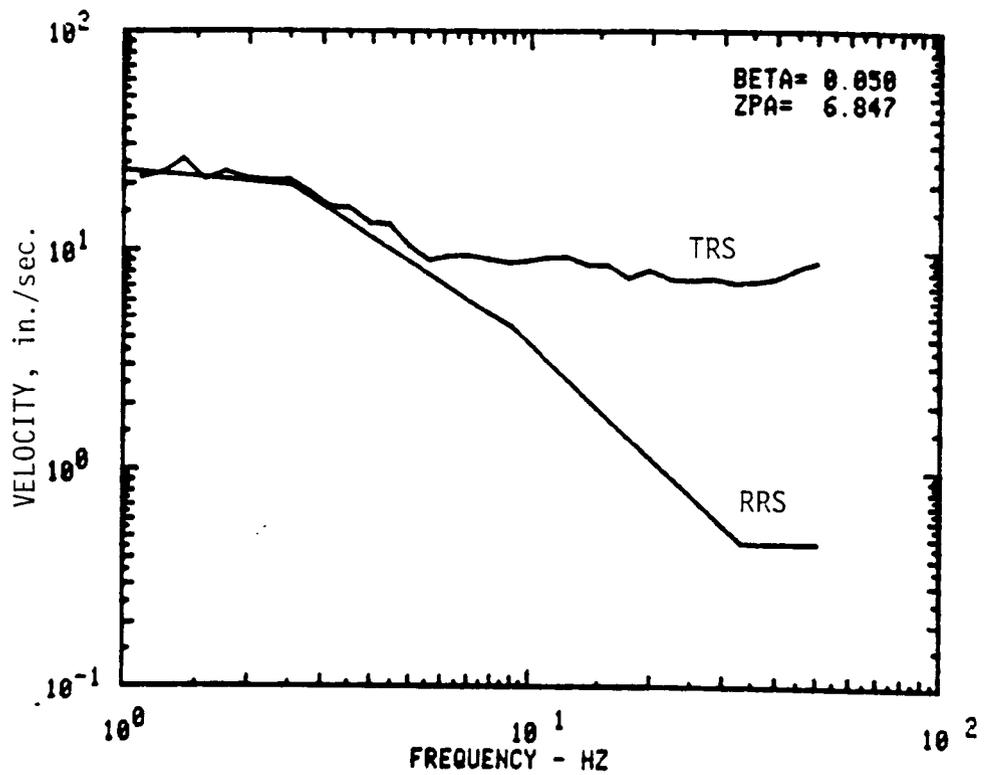


Figure 13b. Velocity Response Spectrum At Upper Specimen Block

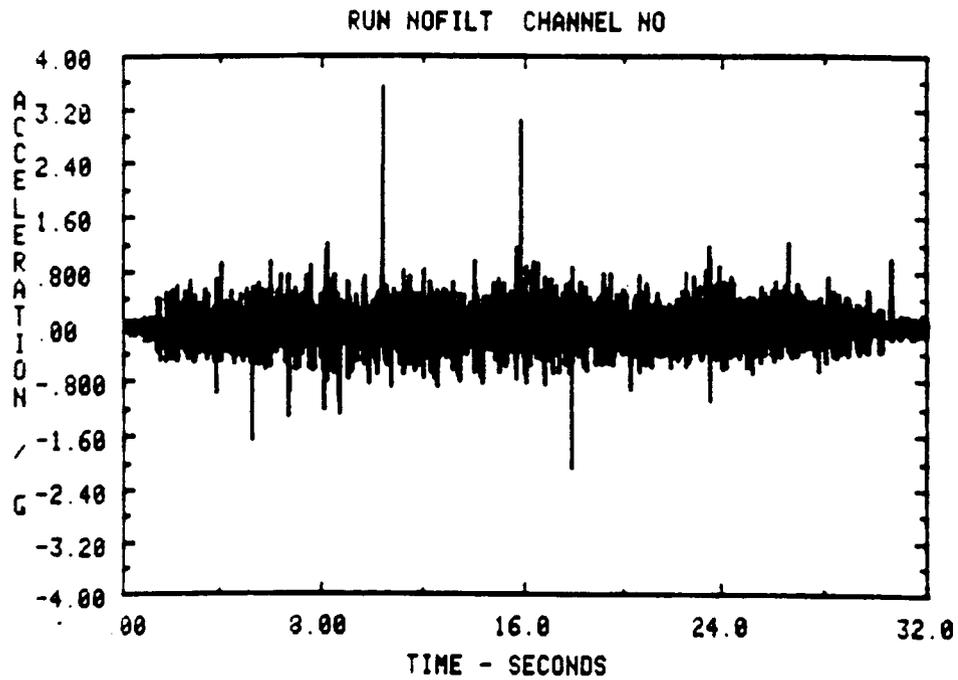


Figure 14a. Unfiltered Acceleration At Upper Specimen Block

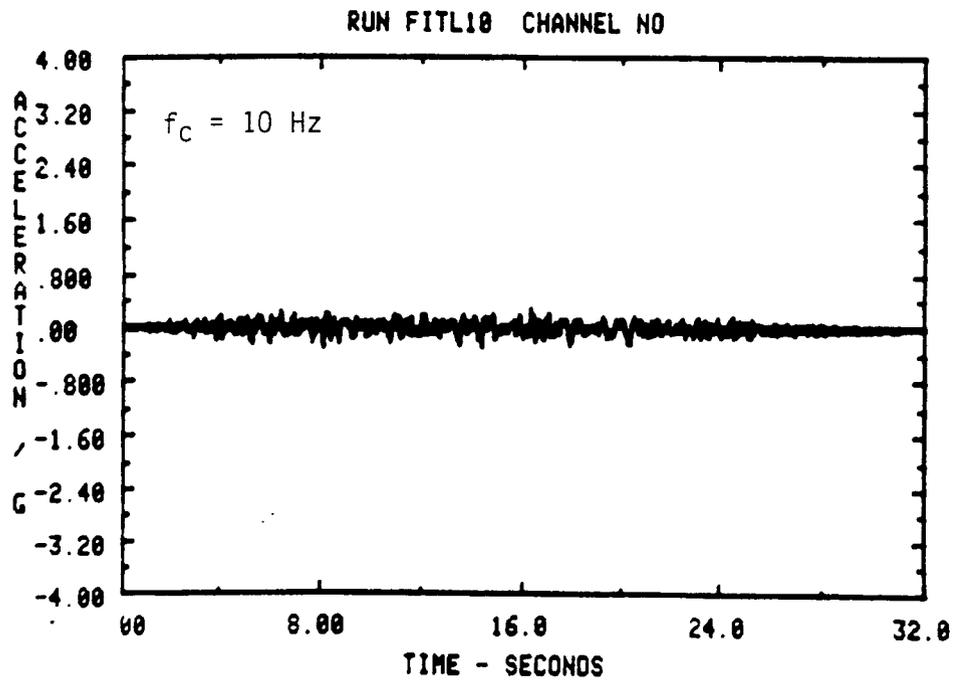


Figure 14b. Filtered Acceleration At Upper Specimen Block

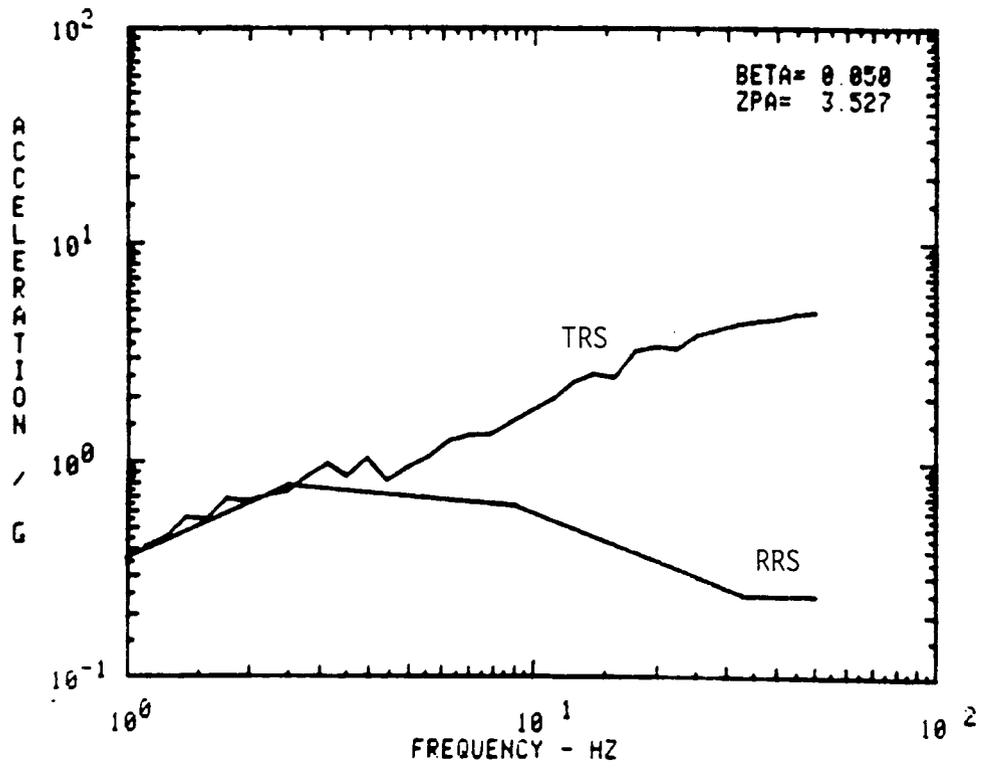


Figure 15a. Unfiltered Acceleration Response Spectrum At Upper Specimen Block

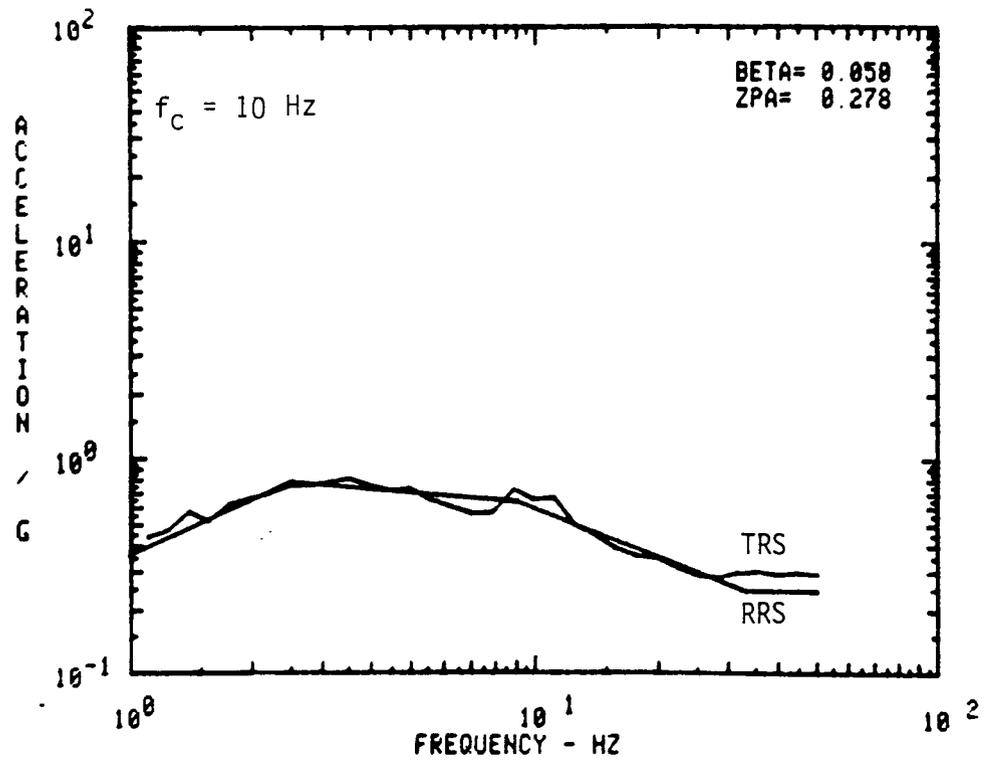


Figure 15b. Filtered Acceleration Response Spectrum At Upper Specimen Block

6.0 CONCLUSIONS

Various conclusions can now be drawn on the capability of this apparatus to perform its intended function. These conclusions are presented with no regard to order. They are all of equal importance in the further conduct of tests with the dynamic shear test apparatus.

All indications point to a resounding success in the ability of the apparatus to perform at all levels up to about 7.0 MPa vertical load. Although the demonstration tests allowed loads of only about half this level (with an 8 x 8 inch specimen), there was no evidence of excessive strain on the system. Therefore, design of the larger horizontal actuator modification should proceed while testing of various specimens at lower capacities can proceed.

The currently used LVDT's were 1-inch range, and one included a calibration nonlinearity. These devices will be replaced with 2-inch range LVDT's which have better linearity over a greater range. Furthermore, the effect of controlling the horizontal displacement at the specimen, rather than at the actuator ram, will also be evaluated.

It appears that the grinding action during joint shear will have a substantial impact on specifications for some of the dynamic tests required by this project. Preliminary earthquake type data indicate that matching of a filtered acceleration response spectrum will be required for a valid simulation. Procedures and hardware necessary for carrying out such tests have been shown to be adequate. However, the exact details remain to be adjusted somewhat, depending on the nature of site data from which a required response spectrum will be generated. In particular, a relationship between filter cut-off frequency and measured distance from a source remains to be established. Use of this filter process will probably be required on all dynamic tests to be conducted. These details must be resolved by the time the schedule calls for tests of this type.

7.0 REFERENCES

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APPENDIX A

**Procedure for Obtaining Seismic Rock Mechanics
Test Specimens From the Field**

**CENTER FOR NUCLEAR WASTE
REGULATORY ANALYSES**

TECHNICAL OPERATING PROCEDURE

Proc. TOP-006

Revision 0

Page 2 of 9

PROCEDURE FOR OBTAINING SEISMIC ROCK MECHANICS TEST SPECIMENS
FROM THE FIELD

1. Purpose

The purpose of this procedure is to outline requirements for obtaining test specimens from the field for use in evaluating joint properties of tuff rock in the laboratory.

2. Scope and Application

This procedure describes the methods and equipment necessary for extricating specimens from a field/ground/quarry source, the requirements for selecting and obtaining specimens, packaging, shipping, and storage requirements, and field data/identification requirements.

2.1 Applicable Documents and References

The following documents form a part of this procedure to the extent they apply:

- 2.1.1 Center Technical Operating Procedures;
- 2.1.2 Center Quality Assurance Manual (CQAM);
- 2.1.3 Center Project Plan for Seismic/Rock Mechanics Project or other Center Project Plans;
- 2.1.4 Technical reports and publications relating to items of consequence in this procedure.

2.2 Acceptable Specimens

The specimens described in this procedure are to be used to establish and characterize rock-joint properties of rock. Accordingly, specimens selected and obtained from the field shall have naturally occurring joints or fractures across the specimen which, to the extent practicable, have not been disturbed in the process of removing and transporting it.

**CENTER FOR NUCLEAR WASTE
REGULATORY ANALYSES**

TECHNICAL OPERATING PROCEDURE

Proc. TOP-006

Revision 0

Page 3 of 9

3. Responsibility

- (1) The cognizant Principal Investigator of the project shall be directly responsible for the implementation of this procedure. In cases where the Principal Investigator is not a member of the CNWRA, the Project/Element Manager shall retain this responsibility.
- (2) The cognizant Principal Investigator shall be responsible for the compilation, storage, and retrieval of records prepared in response to this procedure.
- (3) The Center Director of Quality Assurance is responsible for providing independent surveillance, review or audits to verify implementation of this procedure.

4. Equipment

- 4.1 Prying equipment: crow bars, wrecking bars, wedges, sledge hammers, shovels, coring bits, rock drills, etc.
- 4.2 Surface preparation equipment: rock hammers, stone chisels, chain saws with rock-cutting blades, etc.
- 4.3 Shipping equipment: banding straps and applicators, wooden pallets (including boltable pairs of boards with bolts), protective fiber mats, identification tags with wire straps, plastic bags or wrapping material (with tape) of thickness sufficient to maintain integrity during shipping and storage, etc.
- 4.4 Miscellaneous equipment: rock bolts, measuring scales, magnifying glass, Brunton compass, etc.

5. Procedure

5.1 Description

An identification tag number shall be given to each specimen and the following information (to the extent that it is

**CENTER FOR NUCLEAR WASTE
REGULATORY ANALYSES**

TECHNICAL OPERATING PROCEDURE

Proc. TOP-006

Revision 0

Page 4 of 9

known) shall be recorded on CNWRA Form RM/S-1.89, and incorporated into Center field notebook before the specimen is removed:

- 5.1.1 Identification Number: A unique number assigned by the Principal Investigator.
- 5.1.2 Location: state, county, landowner name, quarry name, geographic coordinates (e.g., latitude and longitude).
- 5.1.3 Stratigraphic Unit: member, formation, group, system.
- 5.1.4 Identification of the horizon or bed from which the specimen will be collected in relation to other horizons or beds present at the outcrop, exposure, or excavation surface.
- 5.1.5 Description of the specimen lithology - rock, color, texture, porosity, mineralogy, structure, and rock type.
- 5.1.6 Description of the joint orientation(s) (dip and strike), mineral coatings, joint opening width, lateral extent, apparent relief (roughness).
- 5.1.7 Rock properties: density, strength, permeability, porosity.
- 5.1.8 Approximate specimen size: in inches - length (l) and width (w) and height (h).
- 5.1.9 Field or laboratory notebooks shall contain the following identification information: date of entry; full name, initials, or assigned stamp of person(s) performing work, and any additional information pertinent to the field work. See Center Quality Assurance Procedure QAP-001 on Scientific and Laboratory Notebooks for specific requirements of controlled Center notebooks.

CENTER FOR NUCLEAR WASTE
REGULATORY ANALYSES

TECHNICAL OPERATING PROCEDURE

Proc. TOP-006

Revision 0

Page 5 of 9

5.2 Removal

Specimen removal shall be accomplished as deemed feasible following visual inspection of the target area(s), exposed formation surfaces, or residual materials.

5.2.1 Specimen size: It is desirable that specimens be such that:

5.2.1.1 A naturally occurring joint in the specimen will allow a proper laboratory specimen to be obtained. It is desirable that this naturally occurring joint be approximately in the middle plane of the specimen in the test configurations.

5.2.1.2 The size of the specimen to be taken from the field will be specified by the Principal Investigator/Project Manager.

5.2.2 The target specimen shall be:

5.2.2.1 Marked to indicate orientation prior to removal.

5.2.2.2 Removed from the ground by prying with an appropriate tool, and/or cutting with a saw or drilling a perimeter for subsequent prying.

5.2.2.3 Lifted from the ground in a manner so as to maintain the surfaces of the joint-bounded blocks in contact and to protect the target joint from damage.

5.2.2.4 Measured and examined for suitability for eventual shaping into an acceptable laboratory specimen.

CENTER FOR NUCLEAR WASTE
REGULATORY ANALYSES

TECHNICAL OPERATING PROCEDURE

Proc. TOP-006

Revision 0

Page 6 of 9

5.3 Shipping

Acceptable specimens shall be:

5.3.1 Banded to a pallet in a manner whereby they may be lifted without affecting the coherence of the joints.

5.3.1.1 Fiber mats or other stress-distributing material may be used to protect the specimen from the bands.

5.3.1.2 Handles may be attached to the banding material on the pallets. The pallets may be doubled with spaces, so that a fork lift, or similar power equipment, may be used to lift the specimen.

5.3.1.3 Boards in pairs, connected by bolts, may be used as clamps to ensure that the specimen does not split at the joint during transport. (Care must be exercised to ensure that the bolts are not excessively tightened so as to alter the joint due to the application of compressive stresses).

5.3.2 Tagged for shipment to a destination appropriate for laboratory preparation or to a designated storage area.

6. Identification and Storage

6.1 All specimens to be stored shall be packaged in plastic bags to protect against atmospheric alteration of the rock material and its properties. (It may prove expedient to package most, if not all, of the specimens in the field.)

6.2 All specimens to be stored shall be tagged with a plastic envelope marked (using indelible fluid) on the outside with

CENTER FOR NUCLEAR WASTE
REGULATORY ANALYSES

TECHNICAL OPERATING PROCEDURE

Proc. TOP-006

Revision 0

Page 7 of 9

the specimen Identification number (I.D.#). The plastic envelope shall be wired to the pallet or through the strap. The plastic envelope shall contain the information (to the extent that it is available) outlined in Form CNWRA-RM/S-1.89.

7. Deviation from Procedures

Although Center Technical Operating Procedures and other Center-prescribed procedures will be utilized and the characterizations documented, deviation from established and controlled procedures may be necessary. In such cases, no deviation and nonconformance report is required. Prior to a deviation from this procedure, the Principal Investigator or Element Manager shall approve of the change. Concurrence of the deviation given shall be obtained in writing from the same group approving the original procedure, and those approvals shall be in the scientific notebook.

8. Records

8.1 The laboratory notebook or other device used to record the results of geological characterizations shall contain the following information:

- (1) Date
- (2) Full name, initials or assigned stamp of individual(s) performing the characterization work
- (3) Method of characterization utilized, including any deviation from established procedures
- (4) Identification Number of specimen, if applicable (This number should be entered at the top of the page).
- (5) Equipment used
- (6) Results

**CENTER FOR NUCLEAR WASTE
REGULATORY ANALYSES
TECHNICAL OPERATING PROCEDURE**

Proc. TOP-006

Revision 0

Page 8 of 9

8.2 Each laboratory project task will have its own controlled laboratory notebook with bound and numbered pages, or another method to capture the results of the work. The lab notebook is the responsibility of the Principal Investigator until project completion or termination. At that point, the project lab notebook(s) are retained as are other results, in appropriate Center files as primary evidence of work accomplishment. Copies of lab notebook pages may be made, but the lab notebook remains Center property.

8.3 Records generated in the implementation of this procedure shall be maintained by the Center as objective evidence of the proper implementation of this procedure.

9. Control of Samples

Geologic samples under the control of the Center shall be kept in a cabinet or equivalent container if not being utilized in project work, a test, or being characterized.

CENTER FOR NUCLEAR WASTE
REGULATORY ANALYSES

Proc. TOP-006

Revision 0

TECHNICAL OPERATING PROCEDURE

Page 9 of 9

I.D. No. _____

FIELD SAMPLE SPECIMEN INFORMATION
Field Information

1. Location: County, State _____
Landowner _____
Quarry Name _____
2. Geologic Information: Member _____
Formation _____
Group _____
System _____
3. Rock Description: Lithology _____
Structure _____
Texture _____
Mineralogy _____
Color _____
Grain Size _____
Comments _____
4. Joint Description: Orientation _____
Width _____
Lateral Extent _____
Apparent Relief _____
Mineral Coating _____
5. Rock Properties:
- | Parameter: | How Obtained: | Units: |
|--------------------|---------------|--------|
| Density _____ | _____ | _____ |
| Strength _____ | _____ | _____ |
| Permeability _____ | _____ | _____ |
| Porosity _____ | _____ | _____ |
| Other: _____ | _____ | _____ |
| _____ | _____ | _____ |
6. Specimen: Size - l _____", w _____", h _____", (S.I. ___ x ___ x ___)
Joint - length _____", Gap Size _____"
7. Sketch and Comments: Date Stored _____

Signed _____
Cognizant Technical Staff

Date _____

INSTRUCTIONS: Fill-in above to the extent that it is known on indicated date and include copy in the laboratory notebook.

CNWRA Form RM/S-1.89

APPENDIX B

**Procedure for Assembling and Testing Jointed-Rock Tuff
Specimens Using a Dynamic Simulator Which Produces
Dynamic Shear and Compressive Normal Loads**

**CENTER FOR NUCLEAR WASTE
REGULATORY ANALYSES**

Proc. TOP-007

Revision 0

TECHNICAL OPERATING PROCEDURE

Page 1 of 16

Title **PROCEDURE FOR ASSEMBLING AND TESTING JOINTED-ROCK TUFF SPECIMENS USING A DYNAMIC SIMULATOR WHICH PRODUCES DYNAMIC SHEAR AND COMPRESSIVE NORMAL LOADS**

EFFECTIVITY AND APPROVAL

Revision 0 of this procedure became effective on JANUARY 31, 1990. This procedure consists of the pages and changes listed below.

<u>Page No.</u>	<u>Change</u>	<u>Date Effective</u>
ALL	--	1/31/90

Supersedes Procedure No. **NONE.**

Approvals

Written By 	Date 1/31/90	Technical Review 	Date 1/31/90
Quality Assurance 	Date 1/31/90	Cognizant Director 	Date 1/31/90

CNWRA Form TOP-1

CENTER FOR NUCLEAR WASTE
REGULATORY ANALYSES

TECHNICAL OPERATING PROCEDURE

Proc. TOP-007

Revision 0

Page 2 of 16

PROCEDURE FOR ASSEMBLING AND TESTING JOINTED-ROCK
TUFF SPECIMENS USING A DYNAMIC SIMULATOR
WHICH PRODUCES DYNAMIC SHEAR AND
COMPRESSIVE NORMAL LOADS

1. Purpose

The purpose of this procedure is to outline requirements for assembling field samples into a dynamic simulator and for conducting shear tests to evaluate joint properties of tuff rock in the laboratory.

2. Scope and Applications

This procedure applies to jointed tuff rock specimens tested in a simulator, having controllable normal compressive and dynamic shear loads. It defines procedures for calibrating instrumentation and control equipment, conduct of tests and associated data acquisition, and specifies documentation necessary to substantiate monitored responses of the test sample.

2.1 Applicable Documents and References

The following documents form a part of this procedure to the extent they apply:

- 2.1.1 Center Technical Operating Procedures, including TOP-006 - Procedure For Obtaining Seismic Rock Mechanics Test Specimens From The Field;
- 2.1.2 Center Quality Assurance Manual (CQAM);
- 2.1.3 Center Project Plan for Seismic Rock Mechanics Project (Draft Revision 1, October 1989);
- 2.1.4 Technical reports and publications relating to items of consequence in this procedure;
- 2.1.5 Center Report No. CNWRA 90-005, "Development of a Rock Joint Dynamic Shear Test Apparatus," January 1990;
- 2.1.6 SwRI Nuclear Projects Operating Procedure XII-EE-101-6, "Calibration of Structural Dynamics and Environmental Testing Test Equipment;"

CENTER FOR NUCLEAR WASTE
REGULATORY ANALYSES

TECHNICAL OPERATING PROCEDURE

Proc. TOP-007
Revision 0
Page 3 of 16

2.1.7 SwRI Nuclear Projects Operating Procedure No. XI-EE-101-3.
"Seismic Test of Electrical and Mechanical Equipment."

2.2 Acceptable Specimens

The specimens described in this procedure are to be used to conduct laboratory tests on elements of jointed rock specimens. Acceptable specimens shall be obtained, treated, and handled as outlined in TOP-006.

3. Responsibility

3.1 The Principal Investigator of the project shall be directly responsible for the implementation of this procedure. In cases where the Principal Investigator is not a member of the CNWRA, the Project/Element Manager shall retain this responsibility.

3.2 Test personnel are responsible for performing the test activities in accordance with this procedure.

4. Description Of Equipment To Be Used For Rock Joint Interface Dynamic Shear Tests

4.1 General

A complete description of the dynamic test apparatus to which this procedure applies can be obtained from Center Report No. CNWRA 90-005 (Section 2.1.5). Herein for reference, only a brief description is provided.

A servocontrolled test apparatus with combined normal and direct shear capability designed, fabricated, and assembled specifically to perform direct dynamic shear tests (described in this procedure) on joints in tuff materials shall be used. Figure 1 shows top and side views of the loading apparatus, while Figure 2 schematically depicts the excitation and control system. The apparatus consists of vertical and horizontal servocontrolled loading actuators, reaction frames, and shear box fixtures. A tuff specimen with a naturally occurring joint serves as the test item.

The loading capacity for each of the three vertical actuators is 30,000 lbs and is 20,000 lbs for the horizontal actuator. (An alternate horizontal actuator and associated load cell of 50,000 lbs capacity is available for higher load requirements.) The horizontal actuator can be operated in either load or displacement control mode. Loading patterns such as harmonic load and displacement as well as ground shock and earthquake time

CENTER FOR NUCLEAR WASTE
REGULATORY ANALYSES

TECHNICAL OPERATING PROCEDURE

Proc. TOP-007
Revision 0
Page 4 of 16

histories can be generated through the use of a function generator. Each actuator is equipped with a 25,000 lb capacity load cell for monitoring the applied forces. The set up for monitoring the applied normal load is such that the output is an average value of the three load cells.

The bottom shear box is designed to house a specimen with maximum dimensions of 12 x 8 x 4 in. The top shear box is to house a mating specimen with maximum dimensions of 8 x 8 x 4 in. Both are grouted in their respective specimen boxes. The bottom shear box is bolted to a thick steel plate for base rigidity. Horizontal translation of the top shear box along the direction of shearing is guided by three rollers between the top shear box and top plate. (It can also be guided by side rollers not shown in Figure 1.) A normal load frame is installed in alignment with the horizontal actuator to prevent or limit horizontal translation of the top plate along the direction of shearing. This frame and the action of the side rollers prevent rotation of the vertical actuators (and therefore also the top specimen block) about a vertical axis perpendicular to the direction of shearing. Only translation displacement is input during the test after vertical loads are applied.

4.2 Normal Load System

Normal compression is applied to the specimen by three vertical actuators positioned at 120° about the specimen's vertical centerline. These actuators act through individual load cells whose output is summed and used as the control signal. Thus, the total normal load is controlled at a preselected static or slowly ramped or increasing value. This total load is ultimately applied to the specimen via the normal load frame which acts on the three normal load rollers, and thereby on the upper specimen box. Thus, the normal load frame is constrained to three degrees of freedom:

- a) Vertical translation
- b) Rotation about the horizontal axis inline with the shear
- c) Rotation about the horizontal axis transverse to the shear

These constraints are assured by two double flexures which connect the normal load frame to a fixed reaction brace, and by the two side roller assemblies, which act on the upper specimen box. These degrees of freedom allow for proper alignment of the test specimen prior to application

CENTER FOR NUCLEAR WASTE
REGULATORY ANALYSES

TECHNICAL OPERATING PROCEDURE

Proc. TOP-007

Revision 0

Page 5 of 16

of the horizontal load, and during wear at the interface. Thus, the upper specimen block is constrained to these same three degrees of freedom, plus a fourth, which is translation in the direction of shear.

Response to the applied normal load is measured in terms of vertical relative displacements of the two blocks at three locations of the interface. For this, the transducers are of (noncontacting) proximity type, since horizontal movement of the two surfaces must be allowed, but vertical displacements only are to be sensed. Three relative vertical measurement points are used to resolve the rigid body displacement of the upper block relative to the lower block, according to the three degrees of freedom enumerated above.

4.3 Horizontal Load System

The horizontal actuator produces direct shear to the upper specimen box via the horizontal load cell. Upper block horizontal acceleration is measured by left-side and right-side accelerometers, located on the loading end of the upper block. The displacement control signal (Figure 1) actually is the relative horizontal displacement of the two specimen blocks, as measured at the left and right sides of the block interface. The average is used as the control signal. This signal represents the fourth and final degree of freedom of the upper block, and is compared with a preselected input source, which depends on the dynamic motion desired:

- 4.3.1 Pseudostatic - A slow (20 to 30 min.) increasing ramp is applied to the relative displacement, while the force required is simultaneously recorded.
- 4.3.2 Stepped Velocity - A drive signal is generated so that when this signal is applied to the actuator, the relative shear velocity (differentiated shear displacement) simulates a multilevel stepped velocity level.
- 4.3.3 Steady State Cyclic - A sine wave drive signal is applied. Frequency, amplitude, and duration are based on anticipated performance of the surface.
- 4.3.4 Earthquake Simulation - A drive signal is generated such that a specified acceleration response spectrum is nominally matched for a given time duration. Compliance is verified by computing the response spectrum from the filtered relative horizontal

CENTER FOR NUCLEAR WASTE
REGULATORY ANALYSES

TECHNICAL OPERATING PROCEDURE

Proc. TOP-007

Revision 0

Page 6 of 16

acceleration signal. Use of a filtered response spectrum is specified since it is anticipated to be most representative of site spectra based on far field data.

- 4.3.5 Rockburst and Explosive Shock - A procedure similar to that for earthquake simulations is used.

5. Procedure for Assembling and Testing

In order to accomplish the tests, it is necessary to assemble the test specimen properly and then mount it in the dynamic simulator.

5.1 Tuff Test Specimen Assembly Procedure

- 5.1.1 The prepared tuff specimen package shall be received nominally-trimmed with upper and lower blocks banded together as a mated unit. The unit shall also be banded to a shipping pad as required by TOP-006.
- 5.1.2 Hoist the specimen package onto a table surface by using attachments to the shipping pad.
- 5.1.3 Cut the shipping pad bands and specimen unit bands.
- 5.1.4 Separate the upper and lower specimen blocks at the natural joint and measure the joint roughness coefficient as defined in the Center Project Plan for the Seismic Rock Mechanics Project.
- 5.1.5 Bolt the lower specimen box together with the three small aluminum spacer blocks in place.
- 5.1.6 Pour about 3/4-inch of grout into the lower specimen box.
- 5.1.7 Using hoist and straps, lift the lower specimen block from the shipping pad and settle it into the lower specimen box. Guide settlement of the lower specimen block so that spacing to the inside of the box walls is nominally equal all around. (As the block settles onto the spacers, some grout will extrude upward around the bottom of the block.) Remove the hoisting straps.
- 5.1.8 Pour grout to the top edge of the lower specimen box and allow it to cure.

CENTER FOR NUCLEAR WASTE
REGULATORY ANALYSES

TECHNICAL OPERATING PROCEDURE

Proc. TOP-007

Revision 2

Page 7 of 16

- 5.1.9 Place the upper specimen back onto the lower specimen so that the natural joint interfaces are properly remated.
 - 5.1.10 Install four rubber seals around the edge of the specimen unit interface.
 - 5.1.11 Bolt four sides of the upper specimen box together with the top left off.
 - 5.1.12 Lower this bolted part of the upper specimen box past the sides of the upper specimen until the box sides squeeze the rubber seal between the edges of the upper and lower boxes. Install the two side plates. (This requires compression of the seal down to the spacer and aligns the upper and lower halves of the box so that spacing between the sides of the upper specimen and the upper box walls is nominally equal all around.)
 - 5.1.13 Fill the upper box with grout to the top edge of the upper box.
 - 5.1.14 Bolt the top plate to the top of the upper box. (Note that some excess grout should extrude through upper plate holes.) Wipe away the excess, and allow the grout to cure.
 - 5.1.15 This constitutes one completed Tuff Test Specimen.
- 5.2 Tuff Test Apparatus Assembly Procedure
- 5.2.1 Hoist the Tuff Test Specimen onto the test base and align it with the retainer bolt holes.
 - 5.2.2 Install retainer bolts through the lower box.
 - 5.2.3 Attach the horizontal actuator/load-cell assembly to the upper specimen box.
 - 5.2.4 Bolt the roller assembly to the top of the upper specimen box.
 - 5.2.5 Hoist the normal load frame and vertical actuator assembly into position so that the roller guides are centered onto three rollers of the roller assembly. (The bottom attachment holes of the three vertical actuators should match with the clevis holes on the base plate and the normal load frame flexure holes should match with the holes in the normal load frame reaction fixture.)

CENTER FOR NUCLEAR WASTE
REGULATORY ANALYSES

TECHNICAL OPERATING PROCEDURE

Proc. TOP-007

Revision 0

Page 8 of 16

- 5.2.6 Attach three vertical actuators by means of pins at clevises on the base plate.
- 5.2.7 Bolt the two flexures to the normal load frame reaction fixture.
- 5.2.8 Detach the two side plates from the specimen boxes.
- 5.2.9 Remove the rubber seals and clean the specimen interface area.
- 5.2.10 Verify that all instrumentation and equipment is within proper calibration cycles. Perform calibrations according to SwRI Nuclear Projects Operating Procedure XII-EE-101-6, "Calibration of Structural Dynamics and Environmental Testing Test Equipment" (See 2.1.6) and Center Report No. CNWRA 90-005, "Development of a Rock Joint Interface Dynamic Shear Test Apparatus" (See 2.1.5). Calibration of noncontacting displacement detectors is accomplished by a direct comparison of their output with a physical measurement.
- 5.2.11 Attach all instrumentation to the apparatus and to the data acquisition unit as shown in Figure 1. The following order shall be used for data acquisition.
- 5.2.11.1 1) Vertical load cell No. 1
 - 5.2.11.2 2) Vertical load cell No. 2
 - 5.2.11.3 3) Vertical load cell No. 3
 - 5.2.11.4 4) Sum of three vertical loads
 - 5.2.11.5 5) Relative vertical displacement detector No. 1
 - 5.2.11.6 6) Relative vertical displacement detector No. 2
 - 5.2.11.7 7) Relative vertical displacement detector No. 3
 - 5.2.11.8 8) Upper specimen block horizontal accelerometer No. 1
 - 5.2.11.9 9) Upper specimen block horizontal accelerometer No. 2

CENTER FOR NUCLEAR WASTE
REGULATORY ANALYSES

TECHNICAL OPERATING PROCEDURE

Proc. TOP-007

Revision 0

Page 9 of 16

- 5.2.11.10 10) Horizontal load cell
- 5.2.11.11 11) Horizontal actuator displacement
- 5.2.11.12 12) Specimen relative horizontal displacement
LVDT No. 1
- 5.2.11.13 13) Specimen relative horizontal displacement
LVDT No. 2
- 5.2.12 Attach the side guide roller assemblies.
- 5.2.13 Verify that the appropriate excitation equipment is connected
according to Figure 2 and is ready for test.
- 5.2.14 Proceed with the specified load test.
- 5.3 Vertical Pseudostatic Load Test Procedure
 - 5.3.1 Prior to the initiation of the test, the Principal Investigator shall
determine test parameters; throughput calibration voltages,
anticipated channel gain levels, data acquisition sampling levels
and rates, vertical load ramp generator limits, and maximum load
level.
 - 5.3.2 Program the data acquisition unit for calibration. Apply
throughput calibration voltages on all appropriate channels and
record the output on the data acquisition unit. Verify the
correctness of data on the monitor by comparing it with input
values.
 - 5.3.3 Visually verify that all appropriate channel gains are set for the
anticipated levels, and make laboratory data log entry.
 - 5.3.4 Program the data acquisition unit for appropriate sampling levels
and rates.
 - 5.3.5 Set limits on the vertical load ramp generator.
 - 5.3.6 Start the test and visually monitor results as the test proceeds.
 - 5.3.7 Stop the test at a preselected load level.

**CENTER FOR NUCLEAR WASTE
REGULATORY ANALYSES**

TECHNICAL OPERATING PROCEDURE

Proc. TOP-007

Revision 0

Page 10 of 16

- 5.3.8 Release the vertical load and secure the apparatus and data disk unless further horizontal testing is to be done. Make entries in the laboratory data log.
- 5.3.9 Remove the Tuff Test Specimen by reversing the apparatus assembly procedure.
- 5.3.10 Measure joint roughness coefficient as defined in the Center Project Plan for Seismic Rock Mechanics Project. Inspect for any specimen/grout fracturing.
- 5.4 Combined-Axis Pseudostatic Load Test Procedure
- 5.4.1 Prior to the initiation of the test, the Principal Investigator shall determine test parameters; throughput calibration voltages, anticipated channel gain levels, data acquisition sampling levels and rates, vertical load ramp generator limits, and maximum load level.
- 5.4.2 Program the data acquisition unit for calibration. Apply throughput calibration voltages on all channels and record the output on the data acquisition unit. Visually verify correctness of data on the monitor.
- 5.4.3 Visually verify that all channel gains are set for the anticipated levels, and make the laboratory data log entries.
- 5.4.4 Program the data acquisition unit for appropriate sampling levels and rate.
- 5.4.5 Set limits on the vertical load ramp generator and the horizontal displacement ramp generator.
- 5.4.6 Apply the vertical load to a preselected value and monitor the results. Wait one minute before proceeding while continuing to acquire data.
- 5.4.7 Start the horizontal displacement ramp and monitor results as the test proceeds.
- 5.4.8 Stop the test at a preselected relative horizontal displacement level.

**CENTER FOR NUCLEAR WASTE
REGULATORY ANALYSES**

TECHNICAL OPERATING PROCEDURE

Proc. TOP-007

Revision 0

Page 11 of 16

5.4.9 Release the vertical load and secure the apparatus and data disk. Make Scientific Notebook entries.

5.4.10 Remove the Tuff Test Specimen by reversing the apparatus assembly procedure.

5.4.11 Measure joint roughness coefficient as defined in the Center Project Plan for Seismic Rock Mechanics Project. Inspect for any specimen/grout fracturing.

5.5 Combined-Axis Dynamic Load Test Procedure

5.5.1 Prior to the initiation of the test, the Principal Investigator shall determine test parameters; horizontal displacement generator programming, horizontal actuator settings, earthquake simulation spectrum (or other shock response spectrum), throughput calibration voltages, anticipated channel gain levels, data acquisition sampling levels and rate, vertical load ramp generator limits, and vertical load.

5.5.2 Program the horizontal displacement generator according to the type of motion to be simulated:

5.5.1.1 Generate the stepped-velocity test displacement drive signal with the waveform generator and store the signal on analog tape for input to the horizontal actuator.

5.5.1.2 Set the steady-state cyclic motion amplitude, frequency, and number of cycles on a waveform generator for input to the horizontal actuator.

5.5.1.3 Generate an earthquake simulation drive signal for input to the horizontal actuator. (This displacement signal is designed so that the horizontal shear motion produced on the Tuff Specimen corresponds to a prescribed acceleration response spectrum for motion anticipated to occur at the Yucca Mountain site.) The actuator drive signal shall be developed by means of a digital computer program according to SwRI Nuclear Projects Operating Procedure No. XI-EE-101-3, "Seismic Tests of Electrical and Mechanical Equipment" (See 2.1.7). The actuator drive signal shall first be recorded on analog tape and then input to the

**CENTER FOR NUCLEAR WASTE
REGULATORY ANALYSES**

TECHNICAL OPERATING PROCEDURE

Proc. TOP-007

Revision 0

Page 12 of 16

horizontal actuator to produce a simulated 30-second earthquake motion on the upper specimen block. Verification of the adequacy of the motion shall be accomplished by computation of the response spectrum for the filtered measured horizontal acceleration and comparison with the prescribed response spectrum.

- 5.5.1.4 Generate a rockburst simulation drive signal for input to the horizontal actuator by means of a procedure similar to that for the earthquake simulation. A prescribed rockburst acceleration response spectrum and duration shall be used as the basis for the test.
- 5.5.1.5 Generate an explosive shock simulation drive signal for input to the horizontal actuator by means of a procedure similar to that for the earthquake simulation. A prescribed explosive acceleration response spectrum and duration shall be used as the basis for the test.
- 5.5.2 Program the data acquisition unit for calibration. Apply throughput calibration voltages on all channels and record the output on the data acquisition unit. Verify correctness of data on monitor by comparing them with input values.
- 5.5.3 Verify that all channel gains are set for the anticipated levels, and make laboratory data log entries.
- 5.5.4 Program the data acquisition unit for appropriate sampling levels and rate.
- 5.5.5 Set appropriate limits on the vertical load ramp generator.
- 5.5.6 Apply the vertical load to a preselected value and monitor the results. Wait one minute before proceeding while continuing to acquire data.
- 5.5.7 Start the horizontal dynamic event and monitor results as the test proceeds.
- 5.5.8 At the end of the dynamic event, compute the test response spectrum, release the vertical load, and secure the apparatus and data disk. Make Scientific Notebook entries.

CENTER FOR NUCLEAR WASTE
REGULATORY ANALYSES

TECHNICAL OPERATING PROCEDURE

Proc. TOP-007

Revision 0

Page 13 of 16

5.5.9 Remove the Tuff Test Specimen by reversing the apparatus assembly procedure.

5.5.10 Measure joint roughness coefficient as defined in the Center Project Plan for Seismic Rock Mechanics Project. Inspect for any specimen/grout fracturing.

6. Used Sample Storage

6.1 Specimen identification tags given or applied to the test specimen prior to its being assembled into the test apparatus shall be saved while the specimen is being tested.

6.2 After the specimen has been consumed or the test completed, the specimen shall again be stored in a plastic bag and tagged or identified with its original identification tags. Additional tags and information shall include:

6.2.1 Date of Seismic testing

6.2.2 Test parameters and specimen response

7. Deviation from Procedure

During the course of test activities, deviation from this procedure may be necessary. In such cases, no deviation and nonconformance report is required. Prior to a deviation from this procedure, the Principal Investigator or Element Manager shall approve the change. Approval shall be documented in the Scientific Notebook containing the tests performed using the approved deviations. Approval from the other groups approving the base procedure shall be obtained and documented in the Scientific Notebook.

8. Records

8.1 The Scientific Notebook used to record the results of geological characterizations shall contain the following information:

8.1.1 Date

8.1.2 Full name, initials or assigned stamp of individual(s) performing the characterization work

8.1.3 Method of characterization utilized, including any deviation from established procedures

CENTER FOR NUCLEAR WASTE
REGULATORY ANALYSES

TECHNICAL OPERATING PROCEDURE

Proc. TOP-007

Revision 0

Page 14 of 16

8.1.4 Identification Number of specimen, if applicable (This number should be entered at the top of each page)

8.1.5 Equipment used

8.1.6 Results

8.2 Each laboratory project task will have its own controlled Scientific Notebook with bound and numbered pages, or another method to capture the results of the work. The notebook is the responsibility of the Principal Investigator until project completion or termination. At that point, the notebook(s) shall be retained, as are other results, in appropriate Center files as primary evidence of work accomplishment. Copies of lab notebook pages may be made, but the lab notebook remains Center property.

8.3 Records generated in the implementation of this procedure shall be maintained in accordance with CQAM Section 17, "QA Records," and retained for three years.

9. Control of Samples

Seismic rock mechanics samples/specimens under the control of the Center shall be kept in a cabinet or equivalent container when not being used in a project test, being prepared for a test, or being characterized. These requirements shall apply to both new and used/tested specimens.

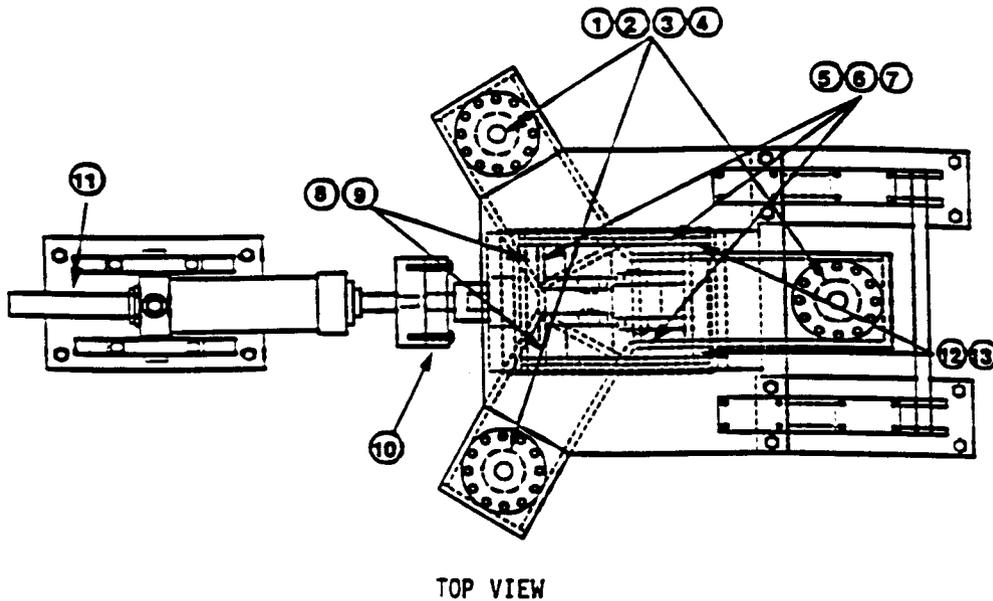
CENTER FOR NUCLEAR WASTE
REGULATORY ANALYSES

TECHNICAL OPERATING PROCEDURE

Proc. TOP-007

Revision 0

Page 15 of 16



Note: Numbers refer to data channels outlined in Section 5.2.11

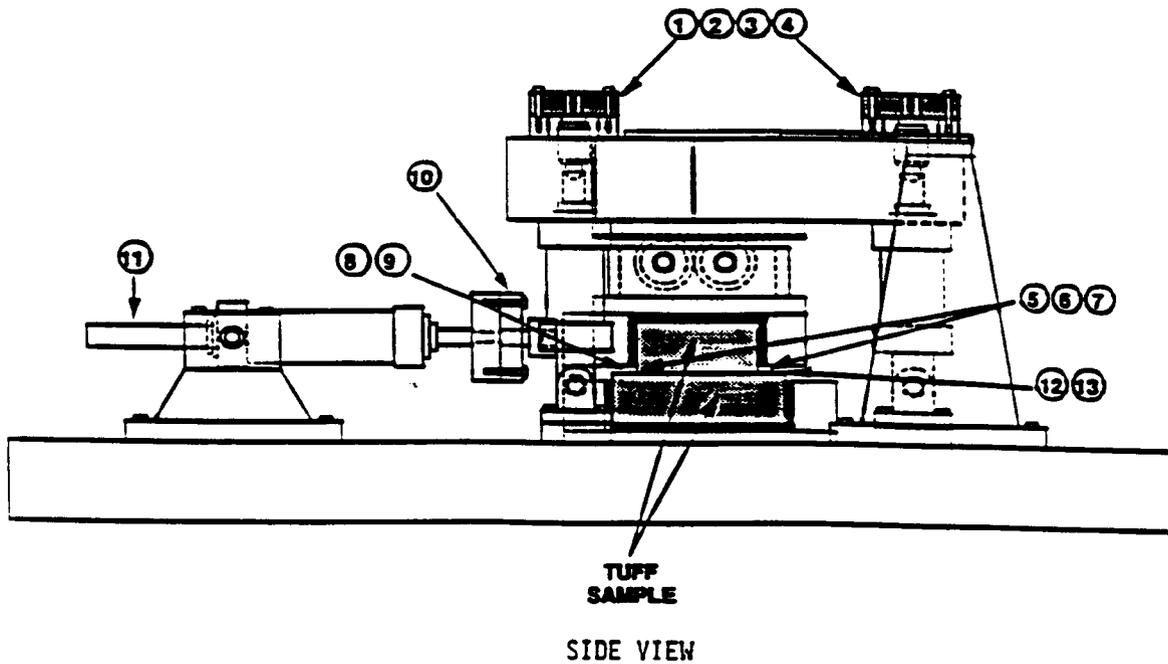


Figure 1. Instrumentation Position Identification

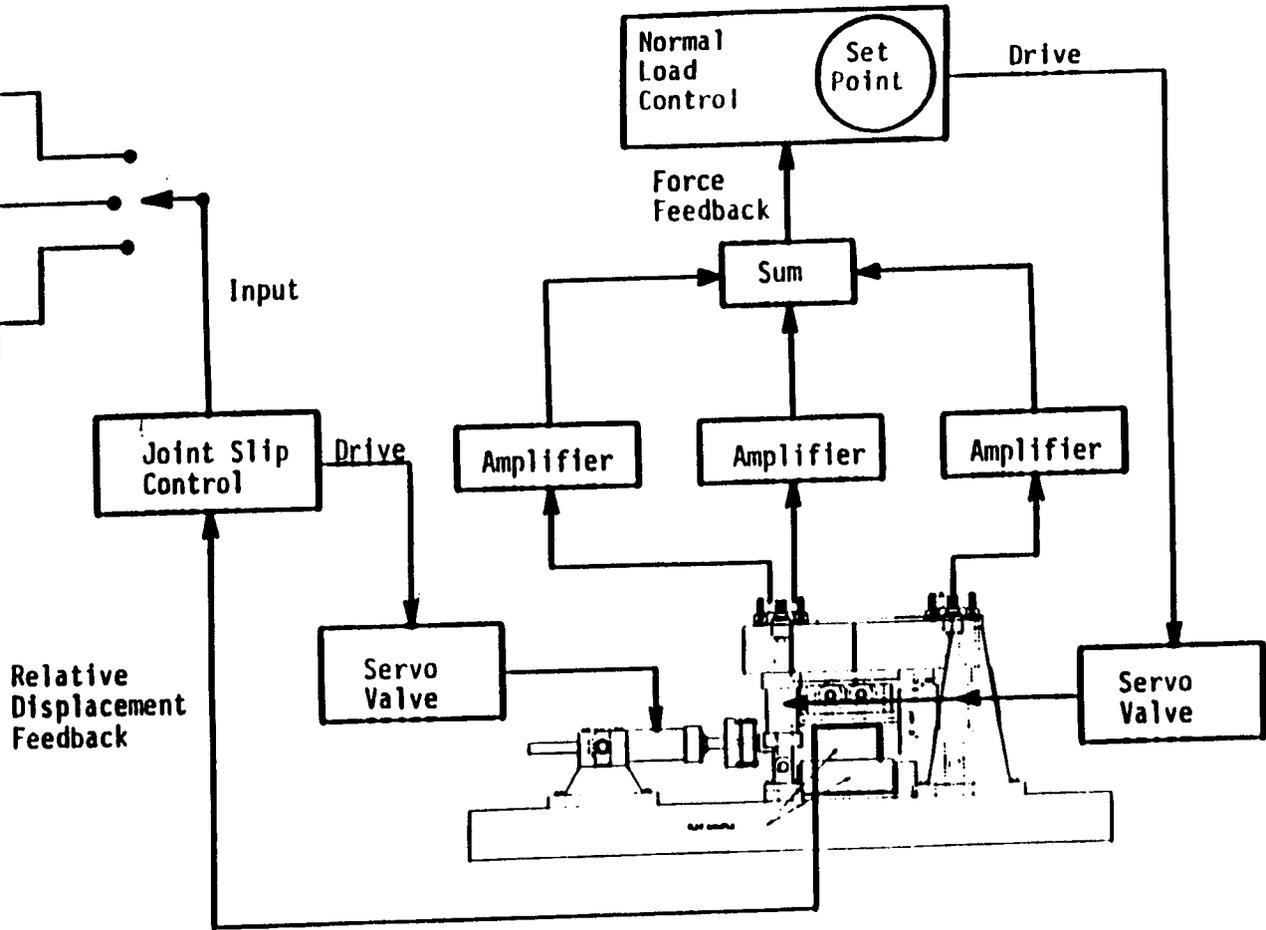


Figure 2. Excitation and Control Block Diagram

CENTER FOR NUCLEAR WASTE
REGULATORY ANALYSES

TECHNICAL OPERATING PROCEDURE

Proc. TOP-007

Revision 0

Page 16 of 16