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# A METHOD FOR EVALUATING STRUCTURAL TRANSDUCERS USED IN TYPE B PACKAGE TESTING*

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## INTRODUCTION

The Nuclear Waste Policy Act of 1982 (NWPA) tasked the U.S. Department of Energy (DOE) with establishing and operating a comprehensive, integrated system for disposal of the nation's spent nuclear fuel and high-level radioactive waste and established the Office of Civilian Radioactive Waste Management (OCRWM) within DOE to fulfill that responsibility. A key component of the disposal program is the development and operation of a transportation system to move the waste from its present locations to disposal facilities. A fleet of casks capable of transporting the waste by truck, rail, or barge is being developed.

As a result of an agreement between DOE and the Nuclear Regulatory Commission (NRC), each cask must be certified by the NRC. To meet these requirements, OCRWM is undertaking a program to design, test, certify, and fabricate a variety of cask systems. Design verification tests will be performed by the cask contractor to demonstrate design safety and to aid in cask certification by the NRC.

During Type B packaging design verification testing designers may verify analytical calculations with instrumentation data. Many packagings are tested with accelerometers and strain gages, collectively known as transducers, that measure structural response. Accelerometers measure acceleration and strain gages measure surface strain at the mounted location. This paper describes a method developed for OCRWM to evaluate various transducers of these two types that have been suggested for use in design verification testing. Typically transducers are characterized by the manufacturer under laboratory conditions. In this program ruggedness, failure frequency, repeatability, and manufacturer's data under field and laboratory conditions were investigated. Specific cask model tests require transducers with specific ranges; transducers of the selected types were procured with ranges appropriate for this test.

## TEST PROGRAM DESCRIPTION

The evaluation of selected accelerometers and strain gages was separated into categories as shown in Figure 1. Accelerometers were evaluated by calibration, shock, and impact testing. Static

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loading and impact testing were used to evaluate strain gages. Multiple tests were performed to provide statistically significant data. The following sections will describe each type of testing.

## ACCELEROMETER CALIBRATION TESTING

The amplitude linearity and frequency response are two important characteristics of an accelerometer that are calibrated by the manufacturer. Data acquisition system design requires amplitude linearity (Walter, 1978). Performance over the required range of frequencies is verified by frequency response calibration. Accelerometers to be evaluated were procured with calibration certificates. Multiple calibrations were performed at Sandia National Laboratories (SNL) and compared to the manufacturer's calibration.

Amplitude linearity must remain essentially constant over the measurement range. Calibration over a range of acceleration levels provides a measure of amplitude linearity. The output of the accelerometer at each specified acceleration level divided by the acceleration level gives the accelerometer sensitivity. Linearity is expressed as the percent deviation from a least squares straight line fit of the sensitivities over the measurement range. Deviations of less than $\pm 3$ percent of the accelerometer range provide amplitude linearity. Amplitude sensitivity calibrations were performed at SNL by two methods: centrifuge and shock by the drop ball technique. Comparisons to manufacturer's calibrations were then made.

The accelerometer is subjected to an acceleration level over a broad range of frequencies for frequency response calibration. For this type of calibration the transducer sensitivity is determined from the output of the accelerometer at the specified frequency divided by the acceleration level. The accelerometer sensitivity is referenced to the output at 100 Hz. The frequency response of an accelerometer is the deviation in sensitivity with respect to frequency. The accelerometer is considered to have "flat" frequency response when the variation in sensitivity versus frequency deviates no more than 5 percent from the base sensitivity at 100 Hz. If the data from the accelerometer falls within this frequency band, the accelerometer is considered to have linear response in the frequency domain. Frequency response calibrations were performed at SNL by the shaker table technique at ambient temperature and at -20°F. Comparisons to manufacturer's calibrations were then made.

## ACCELEROMETER SHOCK TESTING

Cask impact testing produces a shock input to accelerometers and the accelerometers, in turn, produce an output representative of the input. Shock testing, under closely controlled conditions, was performed on each accelerometer. The tests consisted of a series of shocks to each of three sets of accelerometers. At least three accelerometers of each type and two reference accelerometers calibrated as primary standards were mounted on a common test fixture. This fixture was mounted on a 10,000 g MTS vertical shock frame shown in Figure 2 which produces controlled impulses of various amplitudes. The fixture was shocked three times at each of three levels: 1000, 5000, and 10,000 gs. This procedure was repeated for each of the remaining two sets. Calibration was performed on each set before and after testing. The acceleration versus time data for each accelerometer was compared to data from the reference accelerometers. Representative data from a 1000 g shock is shown in Figure 3.

## STRAIN GAGE STATIC TESTING

Typically, installed strain gages are not calibrated on large structures. Instead, reliance is placed on the person installing the gages to follow the manufacturer's specifications. The first type of strain gage testing focused on static testing which evaluated performance during low loading rates. It also provided a verification of the acceptability of the installation procedures.

A series of 10 tests was conducted on 10 individual aluminum cylinders fabricated from aluminum 6061-T0 tube conforming to QQ-A-200/8. The cylinders were 24 inches in length with inner and outer diameters of 3.58 and 5.42 inches, respectively. Strain gages of each type were installed around the outer circumference at positions located 6, 12, and 18 inches from the bottom to measure axial and hoop strain as shown in Figure 4.

Axial compression was conducted on a 220,000 pound capacity MTS compression/ tension test machine. The static crush test of each unit consisted of two parts. During the first portion of testing, load was applied four times to approximately 80 percent of yield strength of the material. A representative plot of load versus time for elastic loading is shown in Figure 5. Next, load was applied through the elastic range and extending to 2 percent strain. Figure 6 shows a representative plot of load versus time for the plastic range loading. Strain, load, and displacement data were recorded during each test. Evaluation of strain gage types consisted of comparison of data at similar circumferential positions on the test cylinder.

## IMPACT TESTING

Both accelerometers and strain gages were installed on a test unit to evaluate their behavior during impact testing. The structural code benchmark unit described in "Structural Code Benchmarking: Impact Response Resulting from the Regulatory Nine-meter Drop" (Glass et al., 1985) was selected as the test unit to provide an economical test which produces varying strain levels and accelerations with rapid amplitude changes. The cylinders were fabricated from aluminum 6061-T0 tube conforming to QQ-A-200/8. They were 45 inches in length with inner and outer diameters of 3.58 and 5.42 inches, respectively. The tests consisted of a series of nine guided drops of nine individual test units, as shown in Figure 7, onto the unyielding target located at the SNL 2500 foot aerial cable facility in Coyote Test Field (Uncapher, 1983). The lowest point on the guided units was positioned 32 feet 4 inches above the target so that the impact velocity was 44 feet/second. The additional height was required to compensate for guide wire friction.

The test units were instrumented with strain gages around the outer circumference at positions located 1, 3, and 5 inches from the impacting end to measure axial and hoop strain. Accelerometers to be evaluated were installed on the top surface of the test unit as shown in Figure 8. Three sets of at least three accelerometers of each type were designated as a "set." Each "set" was tested three times as shown in Table 1. Calibration of each set was performed before and after each test. Representative unfiltered strain gage and accelerometer data from the tests is shown in Figures 9 and 10.

Table 1. Accelerometer Utilization Chart

| Set Number | Impact Test Number 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | X | | | X | | | X | | |
| 2 | | X | | | X | | | X | |
| 3 | | | X | | | X | | | X |

Data from this evaluation were compared to the structural code benchmark test data. Strain data at similar locations were compared following the testing. The accelerometer data were compared to data from the same type of accelerometer as well as all other types of accelerometers being evaluated.

Additionally, important insights relating to operational characteristics of types of accelerometers are gained during field testing. Calibration and post-test electrical checks yield information about transducer survival under field test conditions.

## QUALITY ASSURANCE

Detailed written test procedures were prepared for this testing that provided for recording of all data, step-by-step instructions, and quality assurance holdpoints. The test procedures used for this activity were:

- TEP-TPD Program Document
- TEP-QAPP Quality Assurance Plan
- TEP-1 Shock Test
- TEP-2 Crush Test
- TEP-3 Drop Test
- TEP-4 Inspection
- TEP-5 Instrumentation Installation

## FUTURE ACTIVITY

A round robin test series with another national laboratory is planned. Six dynamic impact tests with the benchmark cylinders would be performed. Three of the cylinders would be instrumented by SNL personnel; the remaining three would be instrumented at the other national laboratory. Data from this evaluation would provide information about installation techniques, data acquisition equipment, and test facilities related to transducer performance.

## CONCLUSION

A method for evaluating structural transducers for Type B package testing was developed to measure the performance of accelerometers and strain gages proposed for use in design verification testing. The accelerometers were evaluated by calibration, shock, and impact testing. Static loading and impact testing were used to evaluate strain gages. The evaluation process included comparisons of manufacturer's accelerometer calibration data with SNL accelerometer calibration data, accelerometer shock test data at controlled levels with primary standard accelerometer data, static strain gage data at similar circumferential locations on the test unit, and dynamic accelerometer and strain gage data with structural code benchmark test data. The dynamic test transducers data were compared to data from the same type of transducer as well as other types being evaluated. The evaluations performed in this program could be performed with other types of accelerometers and strain gages. Analysis of the data is in progress and will be reported early in 1990.

## REFERENCES


Glass, R. E., et al., *"Structural Code Benchmarking: Impact Response Resulting from the Regulatory Nine-meter Drop,"* Proceedings of the Symposium on Waste Management, Tucson, AZ, March 24-28, 1985.

Uncapher, W. L., *"Packaging Test Capabilities of the SNL Aerial Cable Facility,"* Proceedings of the Seventh International Symposium on Packaging and Transportation of Radioactive Materials, New Orleans, LA, May 15-20, 1983.

Walter, P. L., Limitations and Corrections in Measuring Dynamic Characteristics of Structural Systems, Sandia National Laboratories Report, Albuquerque, NM, SAND78-1015, October 1978.

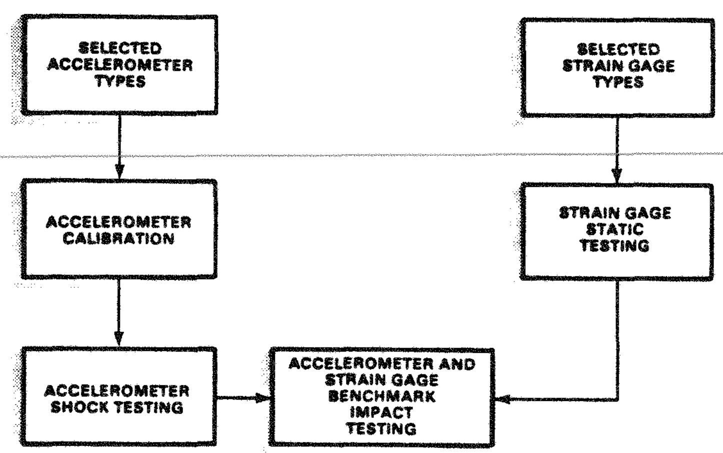


Figure 1. Flow Diagram for Instrumentation Evaluation

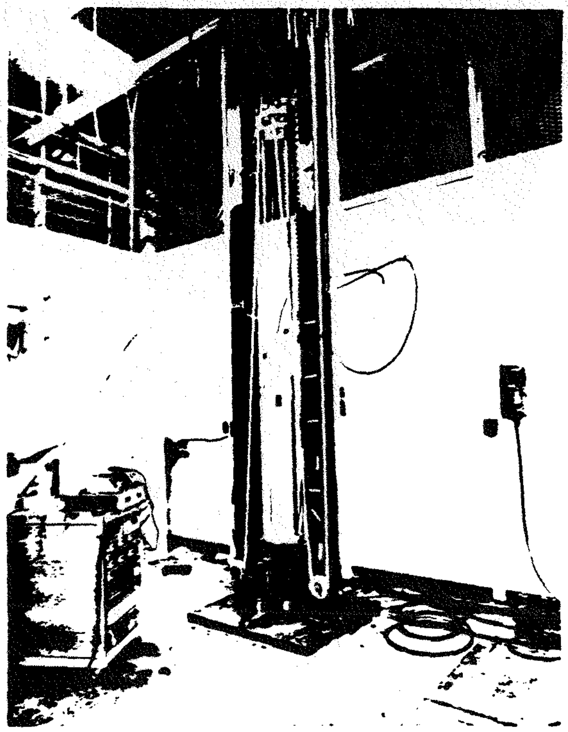

Figure 2. 10,000 G MTS Vertical Shock Frame

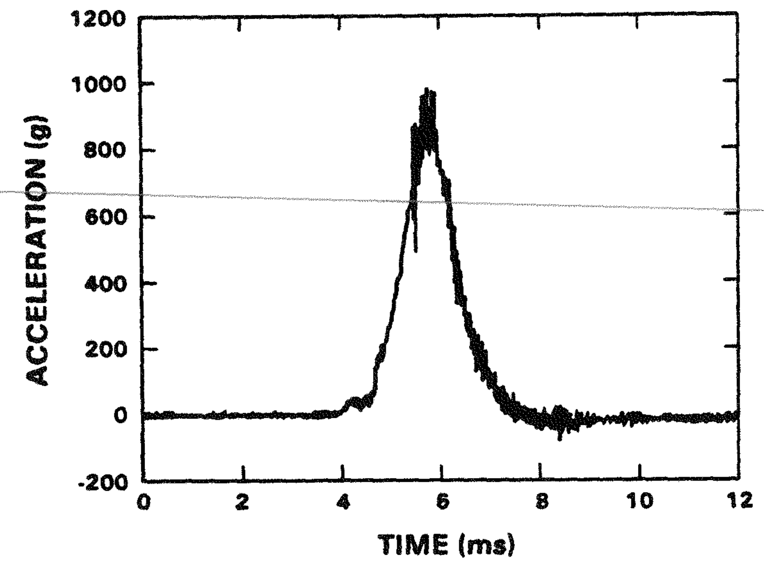


Figure 3. Representative Data From 1000 G Shock

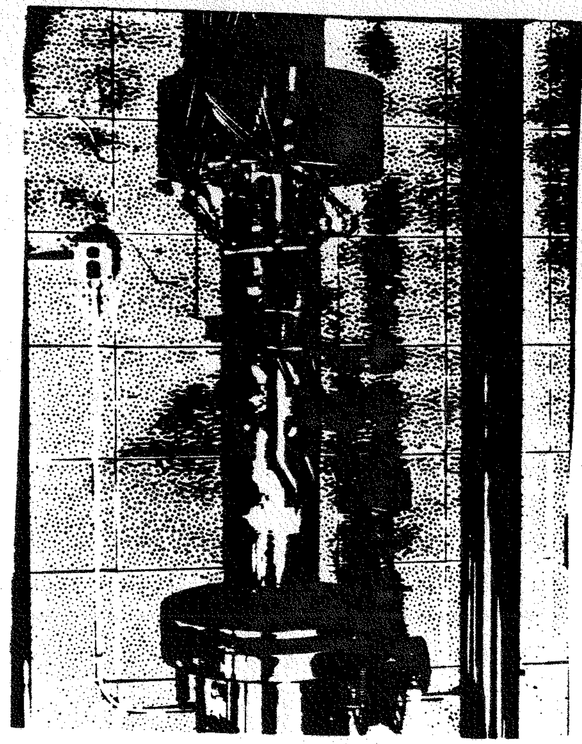

Figure 4. Strain Static Test Unit

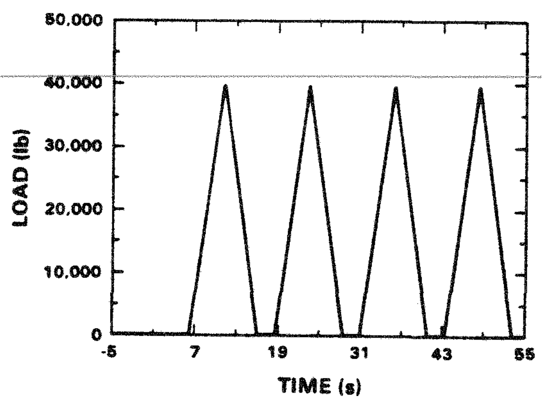


Figure 5. Representative Elastic Load Data

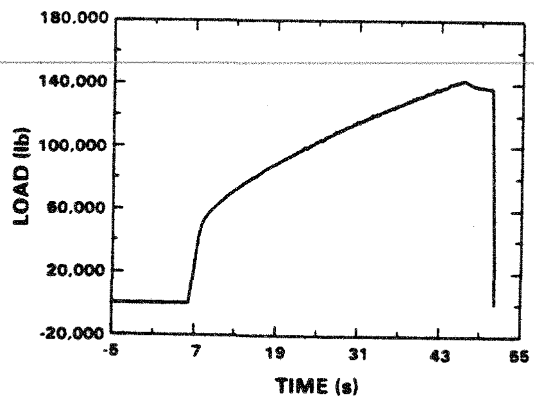


Figure 6. Representative Plastic Load Data


Figure 7. Impact Test Unit

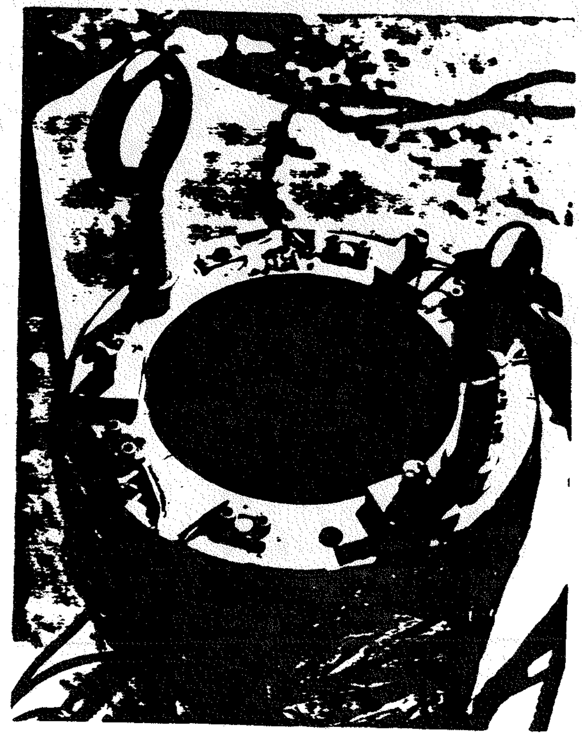

Figure 8. Impact Test Accelerometers

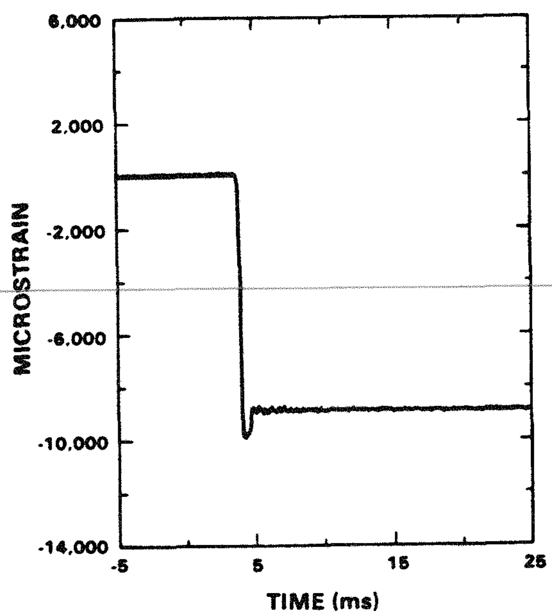


Figure 9. Representative Dynamic Test Strain Gage Data

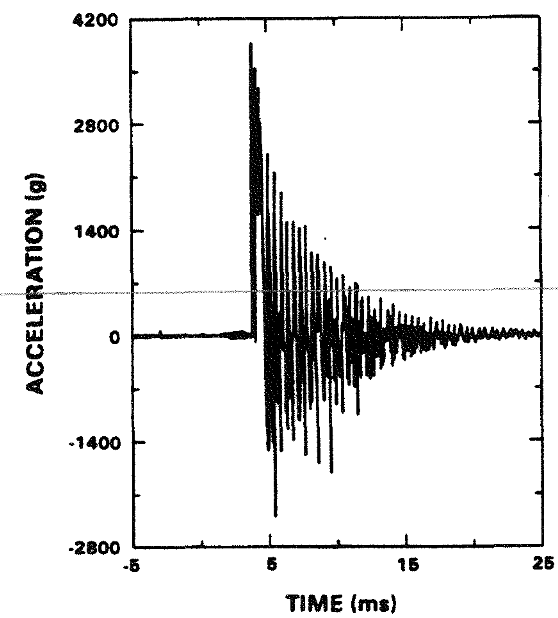


Figure 10. Representative Dynamic Test Accelerometer Data