NUREG/CR-4097
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Printed March 1985

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Test Series 4: Seismic-Fragility Tests of Naturally-Aged Exide EMP-13 Battery Cells

Lloyd L. Bonzon, Donald B. Hente

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550
for the United States Department of Energy
under Contract DE-AC04-76DP00789

Prepared for

U. S. NUCLEAR REGULATORY COMMISSION

SF2900 (18-8)

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TEST SERIES 4: SEISMIC-FRAGILITY TESTS OF
NATURALLY-AGED EXIDE EMP-13 BATTERY CELLS

March 1985

Lloyd L. Bonzon
Donald B. Hente

Sandia National Laboratories
Albuquerque, New Mexico 87185
Operated by
Sandia Corporation
for the
U.S. Department of Energy

Appendices Prepared by

Bharat M. Kukreti
Jerry Schendel
James D. Tulk
W. John Janis
David A. Black
Gordon D. Paulsen
Brian D. Aucoin

Ontario Hydro
Toronto, Ontario, Canada
Performed under Sandia Contract No. 47-4077

Prepared for
Electrical Engineering Instrumentation and Control Branch
Division of Engineering Technology
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555
Under Memorandum of Understanding 40-550-75
NRC FIN No. A-1051

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Related Publications in this Series

- L. L. Bonzon and D. B. Hente, "Test Series 1: Seismic-Fragility Tests of Naturally-Aged Class 1E Gould NCX-2250 Battery Cells," SAND84-1737, NUREG/CR-3923, Sandia National Laboratories, Albuquerque, New Mexico, September 1984.
- L. L. Bonzon and D. B. Hente, "Test Series 2: Seismic-Fragility Tests of Naturally-Aged Class 1E Exide FHC-19 Battery Cells," SAND84-2628, NUREG/CR-4095, Sandia National Laboratories, Albuquerque, New Mexico, March 1985.
- L. L. Bonzon and D. B. Hente, "Test Series 3: Seismic-Fragility Tests of Naturally-Aged Class 1E C&D LCU-13 Battery Cells," SAND84-2629, NUREG/CR-4096, Sandia National Laboratories, Albuquerque, New Mexico, March 1985.
- L. L. Bonzon and D. B. Hente, "Test Series 4: Seismic-Fragility Tests of Naturally-Aged Exide EMP-13 Battery Cells," SAND84-2630, NUREG/CR-4097, Sandia National Laboratories, Albuquerque, New Mexico, March 1985.
- L. L. Bonzon and D. B. Hente, "Seismic-Fragility Baseline Tests of New Class 1E Battery Cells," SAND84-2631, NUREG/CR-4098, Sandia National Laboratories, Albuquerque, New Mexico. (To be published.)
- L. L. Bonzon and D. B. Hente, "Age-Related Degradation of Naturally-Aged Class 1E Battery Cells," SAND84-2632, NUREG/CR-4099, Sandia National Laboratories, Albuquerque, New Mexico. (To be published.)

ABSTRACT

The seismic-fragility of naturally-aged nuclear station safety-related batteries is of interest for two reasons: (1) to determine actual failure modes and their thresholds and (2) to determine the validity of using the electrical capacity of individual cells as an indicator of the "end-of-life" of a battery if subjected to a seismic event. This report, the fourth in a test series of an extensive seismic research program, covers the testing of 27-year old lead-antimony Exide EMP-13 cells from the Shippingport Atomic Power Station.

The Exide cells were tested in two configurations using a tri-axial shake table: single-cell tests, rigidly mounted; and multicell (five-cell) tests, mounted in a typical battery rack. In general the test philosophy was to monitor the electrical properties (including discharge capacity) of cells through a graduated series of increasing zero period accelerations (ZPA) g-level steps until either the shake-table limits were reached or until electrical "failure" of the cells occurred.

A total of nine electrically active cells was used in the two different cell configurations. None of the nine cells failed during the actual seismic tests when a range of ZPAs up to 1.5 g was imposed. Subsequent discharge capacity tests of five of the cells showed, however, that none of the cells could deliver the accepted standard of 80% of their rated electrical capacity for three hours. In fact, none of the five cells could deliver more than a 33% capacity.

Two of the seismically tested cells, and one untested, low-capacity cell were disassembled for examination and metallurgical analyses. The inspection showed the cells to be in poor condition. The negative plates in the vicinity of the bus connections were extremely weak, the positive buses were corroded and brittle, negative and positive active material utilization was extremely uneven, and corrosion products littered the cells. These conditions, plus loss of negative grid material, clogged electrolyte channels, and positive plate surfaces choked with positive grid corrosion products all contributed to the low postseismic capacities.

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FORWARD AND ACKNOWLEDGEMENTS

This work was performed at the Ontario Hydro Research Center, Toronto, Ontario, Canada, under Sandia National Laboratories (SNL) contract 47-4077. It covers the period from July 1, through December 31, 1984. The SNL technical project monitors are Lloyd L. Bonzon and Donald B. Hente.

The overall development and execution of this program were carried out by Mr. B. M. Kukreti assisted by Mr. J. Schendel of the Electrical Design Department. Dr. James D. Tulk of the Applied Structural and Solid Mechanics Section, Mechanical Research Department, provided the expertise in seismic technology and coordinated the research activities. Messrs. D. A. Black and G. D. Paulsen of the Mechanical Testing and Development Section, Mechanical Research Department, provided expertise in seismic testing. Messrs. W. John Janis and B. D. Aucoin of the Chemical Research Department performed the seismic testing and the subsequent cell disassembly.

EXECUTIVE SUMMARY

The seismic-fragility of naturally-aged nuclear station safety-related batteries is of interest for two reasons: (1) to determine actual failure modes and their thresholds and (2) to determine the validity of using the electrical capacity of individual cells as an indicator of the "end-of-life" of a battery if subjected to a seismic event. This report, the fourth in a test series of an extensive seismic research program, covers the testing of 27-year old lead-antimony Exide EMP-13 cells from the Shippingport Atomic Power Station.

The Exide cells were tested in two configurations using a tri-axial shake table: single-cell tests, rigidly mounted; and multicell (five-cell) tests, mounted in a typical battery rack. In general the test philosophy was to monitor the electrical properties (including discharge capacity) of cells through a graduated series of increasing zero period accelerations (ZPA) g-level steps until either the shake-table limits were reached or until electrical "failure" of the cells occurred.

A total of nine electrically active cells was used in the two different cell configurations. None of the nine cells failed during the actual seismic tests when a range of ZPAs up to 1.5 g was imposed. Subsequent discharge capacity tests of five of the cells showed, however, that none of the cells could deliver the accepted standard of 80% of their rated electrical capacity for three hours. In fact, none of the five cells could deliver more than a 33% capacity.

Two of the seismically tested cells, and one untested, low-capacity cell were disassembled for examination and metallurgical analyses. The examination showed the cells to be in poor condition. The negative plates in the vicinity of the bus connections were extremely weak, the positive buses were corroded and brittle, negative and positive active material utilization was extremely uneven, and corrosion products littered the cells. These conditions, plus loss of negative grid material, clogged electrolyte channels, and positive plate surfaces choked with positive grid corrosion products all contributed to the low posttest capacities.

This effort is a subpart of a broader program to evaluate the accelerated aging methods used in qualifying Class 1E batteries (e.g., in IEEE Std 535-1979). By seismic-fragility testing naturally-aged battery cells, the actual failure modes and their thresholds can be determined. This determination serves to focus the evaluation and development of other aging methods on those specific failure modes, thresholds, and locations that have been observed.

Other activities that are in progress include: (1) "baseline" examination and seismic testing of new, same type, cells from the three manufacturers of Class 1E batteries; (2) accelerated aging of new, same type, cells and subsequent seismic testing; (3) accelerated-aging of naturally-aged cells to an 18-year age and subsequent seismic testing; (4) compiling of typical nuclear plant required response spectra for comparison with the fragility levels experienced in these and follow-on tests; and (5) additional lead-chemistry evaluations of battery internal components.

1.0 BACKGROUND

1.1 General

The seismic-fragility of naturally-aged nuclear station safety-related batteries is of interest for two reasons: (1) to determine actual failure modes and their thresholds and (2) to determine the validity of using the electrical capacity of individual cells as an indicator of the "end-of-life" of a battery if subjected to a seismic event.

1.2 Historical and Programmatic Perspective

The concern over the seismic susceptibility of nuclear station safety-related batteries was generated by the number of battery problems that periodically had been reported in Licensee Event Reports (LERs).^{1-8*} Following the problems reported at the Connecticut Yankee Station,⁸ the NRC conducted an investigation which concluded that aged batteries may be vulnerable to common-mode failures because of a seismic event.⁹ The NRC then issued Information Notice 83-11, Possible Seismic Vulnerability of Old Lead Storage Batteries on March 14, 1983, to make nuclear power plant personnel aware of the finding.¹⁰ Increasing concern over the possible adverse behavior of aged batteries in seismic events resulted in the NRC-sponsored Qualification Testing Evaluation (QTE) research program initiating an effort to evaluate the adequacy of batteries to survive seismic acceleration levels.¹¹ These series of reports are the initial efforts of that research program.

2.0 PROGRAM OBJECTIVES

2.1 Evaluation of Battery Aging Methodologies**

The overall research program¹ has seven main objectives:

* Reference 1 contains more detail on the historical and programmatic perspective.

** The overall program is discussed in greater detail in Reference 12.

1. To determine seismic failure modes and thresholds, primarily using naturally-aged cells.
2. To identify the dominant aging mechanism(s) through this testing experience, in conjunction with other test experience and expert evaluations.
3. To compare the response of naturally-aged cells to the response of new cells aged by the accelerated methods described in IEEE Std. 535-1979 and to compare dominant failure modes in both cases.
4. To identify appropriate accelerated aging methodologies for the dominant failure mode(s).
5. To demonstrate those accelerated aging methodologies through a specific demonstration test program.
6. To make final recommendations for appropriate accelerated-aging methodology(ies) for nuclear station batteries.
7. To develop in situ testing methods which can predict the remaining age and seismic "tolerance" of batteries.

2.2 Seismic-Fragility Testing of Batteries*

The seven objectives of the overall program can be grouped into four subprograms or goals. Objectives 1-3 relate to an effort to determine by test the actual failure modes and thresholds experienced in natural aging. Objectives 3-5 relate to an effort to compare/correlate current accelerated-aging methods and to recommend, develop, and prove modified aging methods based on the dominant failure modes observed. Objectives 5-6 lead to recommended aging method changes and incorporation into appropriate standards and guides. Objective 7 will lead to a predictive technique to determine "end-of-qualified" life of batteries.

This report covers the fourth in a test series to determine the seismic-fragility of naturally-aged battery cells; thus, it corresponds to the subgroup defined by objectives 1-3 above and continues the effort of the first test series.¹

3.0 APPROACH AND REPORT FORMAT

Naturally-aged, Class 1E, battery cells have been obtained from four nuclear power stations in the United States and sent to the

* The specifics of the seismic-fragility testing program are discussed in greater detail in Reference 13.

Ontario Hydro Research Center for cell conditioning and subsequent seismic testing and analyses. All three manufacturers of Class 1E batteries are represented among the four groups of cells obtained. The Test Series 1 report discussed the results of testing 12-year old Gould NCX-2250 battery cells. The Test Series 2 report discussed the results of testing 10-year old Exide FHC-19 cells. The Test Series 3 report discussed the results of testing 10-year old C&D LCU cells. This report discusses the results of testing 27-year old Exide EMP-13 cells obtained from the Shippingport Atomic Power Station. (No preference of treatment for testing or suspected failure should be implied from order of testing; the cells were tested in the order received.)

The details of the testing are summarized in the Appendices to this report. The generic approach followed this pattern: cell conditioning and pretest electrical capacity measurements were made; cells were exposed to simulated seismic (fragility) tests in both single and multicell configurations; posttest electrical capacity checks were made on cells which "survived"; selected cells were disassembled and evaluated; and the results were analyzed and reported.

3.1 Report Format

Ontario Hydro staff performed all testing and analyses; their results, presented in four stand-alone reports, are included as Appendices:

- A: Seismic Testing of Naturally Aged Exide EMP-13 Station Battery Cells
- B: Seismic Testing of Shippingport Nuclear Power Station Batteries-Cell Inspection and Capacity Tests
- C: Seismic Testing of Exide Aged Batteries
- D: Seismic Testing of Aged Shippingport Nuclear Power Plant Batteries

Appendix A is the collection and summary of the complete Ontario Hydro effort along with results and conclusions sections.

Appendix B describes the preseismic cell conditioning, pre- and postseismic electrical capacity tests, and the results of both the single and multicell configuration tests and cell disassembly. Addendum 1 to Appendix B provides cell specifications provided by the battery manufacturer; Addendum 2 provides discharge data obtained during the seismic tests; and Addendum 3 provides the calculations to convert discharge times at the 1-hour rate to the 3-hour rate.

Appendix C and D report on the single and multicell configuration testing, respectively. Both reports describe the test procedures followed, the test equipment used, and interpret the results of the tests. Figures show the response spectrum in each of the X, Y, and Z axes from accelerometers located both on a terminal post of the cell and on the base of the shake-table mounting jig.

In addition, Sections 4 and 5, which follow, draw from the Appendices the salient results and conclusions.

4.0 SEISMIC-FRAGILITY TESTS OF NATURALLY-AGED EXIDE, EMP-13, CELLS

4.1 Cell Selection and Condition

After the Shippingport Atomic Power Station was scheduled for decommissioning, Department of Energy staff released 20 randomly selected 27-year old EMP-13 cells for this test program. Because of shipping damage and low electrolyte levels, eight of the cells were discarded when received. The remaining 12 cells were placed on an equalizing and then a floating charge. Subsequent discharge capacity measurements showed that all cells had lost capacity while in service but that nine cells still had a rated electrical capacity of better than 80% as measured in a standard three-hour test. The other three cells were rejected for seismic testing but one was disassembled to observe internal damage. Thus the cells used for these seismic tests were not degraded to a beyond an "end-of-life" condition.

4.2 Results During Seismic-Fragility Tests

The Appendices describe the test methods, results, and analyses in detail. Only the results are highlighted here, as summarized in Tables 1 and 2. As noted previously, the cells in both cell configurations were exposed to a graduated series of increasing ZPA g-level steps until "failure" of the cells occurred or the limits of the shake table were reached. No electrical or mechanical failure modes were noted for either the single or multicell configuration at any of the acceleration levels attained.

The ZPA Response Levels are the zero period accelerations of a normalized spectrum fitted to the experimental data over the 4 to 33 Hz range. The ZPA is used to express the intensity of the seismic motion of a typical seismic environment. The ZPAs shown are for the spectra when the shake table limits were reached.

The single cells listed in Table 1 were rigidly mounted to the shake table in a jig designed to minimize relative motion between the table and the cell jar. This rigid mounting was

Table 1
Seismic-Fragility Test Results
Single-Cell Tests

Cell No.	Run Sequence*	ZPA Response Levels-g** (x/y/z)	Comments
1	1		
	2		
	3		
	4	1.83/1.56/1.47***	Shake table limit
5	1		
	2		Clamps came loose. Test stopped to tighten.
	3		
	4		
	5	1.65/1.5/1.5	Shake table limit
8	1		
	2		
	3		
	4	2.18/1.77/1.37	Shake table limit
11	1		
	2		
	3		
	4	2.16/1.59/1.63	Shake table limit

* The acceleration levels were generally increased for each run listed, so the runs imply cumulative severity.

** As measured on the shake table base mounting plate.

*** This run spectral data are plotted and available in the Appendices.

Table 2
Seismic-Fragility Test Results
Multicell Tests

Cell No. (x/y/z)	ZPA Response		Comments
	Run Sequence*	Levels-g**	
3,4,10,	1		
43,45	2		
	3		Cracks propagated along end of cell 43. Small separation at cover/jar interface on all cells.
	4	1.1/2.17/1.26***	Shake table limit

* The acceleration levels were generally increased for each run listed, so the runs imply cumulative severity.

** As measured on the shake table base mounting plate.

*** This run spectral data are plotted and available in the Appendices.

intended to investigate the failure modes (if any) of the internal components of the cells (e.g., lead plates, lead hangers, and the like).

The five cells listed in Table 2 (3,4,10,43,45) were mounted in a multicell battery rack configuration based on the design of a "typical" seismically-qualified station battery rack. The purpose for this configuration was to check for (1) the influences of the rack-to-cells and cell-to-cell interactions on the cell responses and (2) the effect of typical rigid cell-to-cell electrical couplers between cell terminal posts. Overall, there seemed to be no particular differences in cell response as a result of testing in the single or multicell configurations.

4.3 Postseismic Capacity Tests

Following the seismic testing, five of the seismically tested cells were measured for their electrical discharge capacities. The results of those measurements are shown in Table 3. In all

Table 3

Cell Capacities Before and After Seismic Testing
(Given in Percent of Rated Electrical Capacity)

Cell	Before Testing	After Testing
3	84	13
4	93	22
10	96	22
43	98	33
45	82	30

five cells the postseismic capacity was well below the accepted criterion of 80% even though all cells had a preseismic capacity of above 80%.

4.4 Posttest Disassembly and Evaluation

Two of the tested cells (43 and 45) and one of the untested, low-capacity cells (15) were disassembled and inspected for internal damage. All components were found to be in poor condition. Corrosion products dislodged from the positive plate grids were found throughout the cell; e.g., in the sediment spaces, on top of the plates, loosely attached to the positive busses and terminal posts, and, in the seismically tested cells, lodged between positive plates and adjacent separators.

While no cracks were observed in post or bus material when the cells were opened, moderate hammer blows to the positive post broke the bus away from the post and showed areas where chemical attack had taken place. The chemical attack was most severe on the underside of the bus and decreased as the cross section was traversed from bottom to top. The positive plates were solid and not warped, but the active lead buttons near the extremities of the plates were clogged with active lead oxides. Other buttons in the centers of the plates were not so densely packed with oxides.

The negative plates were weak and brittle at their tops with a considerable amount of loose negative plate material. In addition most negative plates were severely erupted on both sides. Nonerupted areas corresponded to the positions of the plastic spacers.

The extremely poor condition of both the negative and positive plates (e.g., loose active material, clogged lead buttons, and corroded bus bars) undoubtedly resulted in the very low post-seismic discharge capacities.

5.0 CONCLUSIONS

The tests and analyses can be summarized as follows (from Appendix A):

1. The twenty-seven year old Exide EMP-13 cells that were the subject of this study were in poor condition. They were all able to survive repeated strong shaking without sudden failures, but had all suffered from major losses in electrical capacity.
2. Internal components of the cells that were disassembled were in poor condition with extensive corrosion and embrittlement. The seismic testing caused corrosion products and active plate material to break away from the plates and lead to a loss in capacity.
3. There were no signs of damage to the jars during any of the tests. This includes tests with multi-cell racks.

Sandia staff concurs with the Ontario Hydro conclusions. Although these 27-year old cells were on-line as a part of a station battery to provide emergency power, the results of our testing indicate that the cells may not provide the minimum 80% discharge capacity after exposure to a seismic event.

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APPENDIX A

Executive Summary Seismic Testing of Naturally Aged Exide EMP-13 Station Battery Cells

J. D. Tulk
D. A. Black
W. J. Janis
B. M. Kukreti

Ontario Hydro Reaserach Division

**ontario hydro
research division**

EXECUTIVE SUMMARY

SEISMIC TESTING OF NATURALLY AGED EXIDE EMP-13
STATION BATTERY CELLS

J.D. Tulk, Mechanical Research Department
D.A. Black, Mechanical Research Department
W.J. Janis, Chemical Research Department
B.M. Kukreti, Electrical Design Department

A sample of 27 year old lead acid storage batteries from the Shippingport Nuclear Power Station (Shippingport, PA) were tested on a shaker table. The intensity of the shaker tests reached the full capacity of the table. There were no sudden changes in output voltage for any of the nine cells during the stimulated earthquakes. Following the tests, however, the capacity of the cells was found to be sharply reduced. A number of cells were disassembled and examined. Internal components were found to be in poor condition, with loss of negative plate material and generalized corrosion.

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ontario hydro research division

To Mr. B.A. Oliver
Manager
Electrical Design Department

SEISMIC TESTING OF NATURALLY AGED EXIDE EMP-13 STATION BATTERY CELLS

J.D. Tulk, Mechanical Research Department
D.A. Black, Mechanical Research Department
W.J. Janis, Chemical Research Department
B.M. Kukreti, Electrical Design Department

1.0 INTRODUCTION

The large lead-acid storage battery cells that are the subject of this report are used to provide dc power for nuclear power stations during and after an earthquake. It is well known that these cells deteriorate with age and it is normal practice to test them at regular intervals to ensure that they are capable of meeting a specified level of performance. What is not so well understood however, is the effect of age on the mechanical fragility of the cells and whether the cells would be capable of surviving seismic events at the operating basis earthquake (OBE) or safe shutdown earthquake (SSE) levels and to continue to meet the load profile required by the Class 1E system. Because of the importance of storage batteries to the Class 1E system, the US Nuclear Regulatory Commission has requested Sandia National Laboratories (SNL) to evaluate the impact of aging and seismic exposure on battery capacity. Ontario Hydro has been sub-contracted to carry out capacity and seismic shaker tests on naturally aged cells supplied by SNL from several US nuclear power stations (SNL contract 47-4077). The program addresses possible variations between designs produced by different manufacturers.

This report describes the results of a series of experiments carried out at the Ontario Hydro Research Laboratories on a set of twenty-seven year old Exide EMP-13 cells from the Shippingport Nuclear Power Station (Shippingport, PA). During the shaker tests, no sudden loss of output voltage was recorded, even when the intensity of the shaking reached the limit of the table. However, following the tests, it was found that the capacity (time to discharge) of all of the cells had been reduced sharply. To determine the nature of the damage that was

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caused by the shaking, several cells were disassembled for inspection and metallurgical examination. The results indicate that this batch of cells was in generally poor condition with widespread corrosion and damage to the plates.

This report summarizes the test and results for this batch of cells. A more detailed discussion of the tests and results is contained in reports C84-121-P (battery condition and performance)/1/, B84-44-P (seismic test results, single cells)/2/ and 84-428-P (seismic tests, rack mounted cells)/3/.

The tests described here were part of a larger program of testing of aged cells. Other cell types tested to date have included Gould FKR (Pickering NGS)/4,5,6/, Gould NCX2250 (Fitzpatrick NPS)/7/, C&D LCU-13 (North Anna NPS)/9/ and Exide FHC-19 (Calvert Cliffs NPS)/8/.

The Exide EMP-13 cells are of an obsolete type that is no longer being installed in nuclear power plants. They were however the oldest samples of station cells that could be obtained and it was for this reason that they were included in the program.

2.0 TEST METHODS AND RESULTS

2.1 Initial Inspection and Condition

Twelve Exide EMP-13 cells were received from the Shippingport plant. There was no superficial damage, but the cells showed signs of aging, including swollen and warped plates and black precipitate on the bottom of the jars. Our experience with aged station cells suggests that the condition of these cells was consistent with their type and age. The cells were conditioned (charged and discharged several times to stabilize their internal chemical state) and tested for capacity. The electrical state of the cells prior to the seismic tests is summarized in Table 1.

2.2 Seismic Testing - Single Cells

The shaker table and instrumentation used in these experiments is described in Reference 2. The table provides independent motion in three directions. The motion is based on a quasi-random signal, filtered to match the frequency content of a typical earthquake. The duration of each test was 30 seconds. The seismic test method is based on the recommendations of IEEE Std 344-1975 and IEEE Std 501-1978.

For the first phase of the seismic testing, the cells were mounted individually on the shaker table in a stiff frame, designed to minimize relative motion between the cell jar and

the table (see Figure 1). This series was intended to investigate possible failure modes of internal components. The rig was designed to minimize the danger of jar failure and acid spill. Accelerometers were mounted on the base of the frame and on the top of one of the posts of the cell.

Each cell was subjected to a series of tests at successively higher acceleration levels. The test sequence for each cell is shown in the test log given in Table 2. In this record, the acceleration level for each test is quoted in terms of the ZPA fitted IEEE 501 spectrum.

During the seismic tests, the cells were discharged against a resistive load at a one hour discharge rate. They were considered to have passed a seismic test if they remained above 1.75 V during and immediately after the test. The cells were shaken at progressively higher levels up to the machine limit. Each of the four cells that were tested in the single cell frame passed all of the tests. Table 2 provides a log of the test sequence, while Table 3 summarizes the results. Figures 3-14 show response spectra for the final test for each cell. There were no sudden drops in cell voltage during any of the shaker tests.

The seismic test results are presented in this report and in References 2 and 3 in terms of acceleration response spectra of the table motion. To provide a convenient means of comparing the acceleration levels encountered during various tests, each test spectrum is compared to a normalized spectrum defined in IEEE Std 501-1978 /10/. The shape of this spectrum is intended to reflect the frequency content of the "typical" seismic environment for electrical equipment. The intensity of the simulated seismic motion is expressed in terms of the ZPA (zero period acceleration).

2.3 Multi-Cell Rack Test

The single cell tests were designed to focus on failure modes of internal components. To examine the possible failure modes that would be encountered with normal in-plant mounting arrangements, a shaker test was carried out on a set of five cells mounted on a rack that resembled typical seismically qualified battery racks (see Figure 2). The test log and results are shown on Tables 2 and 3. Figures 15-17 show response spectra for the final test with the rack mounted cells. Again, no failures occurred.

For practical reasons, the rack that was used for these tests held only five cells. Full scale racks in power stations are typically much longer. The present tests could be non-conservative since long strings of cells could, under violent shaking, impose large impact loads on cells at the end of the string. These tests provide no positive indication that this is a potential source of trouble. Nevertheless, we suggest that in severe seismic environments, it would be beneficial to separate cells into groups of three or so, with rigid partitions on the rack and flexible electrical connections between groups.

2.4 Post Seismic Capacity Tests and Inspection

Following the shaker table tests the cells were re-tested for electrical capacity. The results of these tests are shown on Table 1. There was considerable loss of discharge capacity for all cells and none were able to meet the acceptance criterion of 80% rated capacity.

Following these tests, four of the cells were disassembled and inspected. It was found that the internal components were in poor condition. On the negative plates, the grid material was cracked and broken near the top of the plates, while a significant proportion of the active material (sponge lead) had apparently been shaken out of the grids by the seismic tests. Plate surfaces were severely pitted and erupted, apparently a result of excessive gassing during service. On the positive plates, there were signs of extensive corrosion. During the shaker tests, a considerable amount of corrosion product had been shaken loose from the plates and in some instances, caused short-circuits between positive and negative plates. Negative bus material was corroded and brittle. Photographs illustrating the post-test condition of the cells can be found in Reference 1.

3.0 CONCLUSIONS

1. The twenty-seven year old Exide EMP13 cells that were the subject of this study were in poor condition. They were all able to survive repeated strong shaking without sudden failures, but had all suffered from major losses in electrical capacity.

2. Internal components of the cells that were disassembled were in poor condition with extensive corrosion and embrittlement. The seismic testing caused corrosion products and active plate material to break away from the plates and lead to a loss in capacity.
3. There were no signs of damage to the jars during any of the tests. This includes tests with multi-cell racks.

4.0 ACKNOWLEDGEMENTS

Test cells for this project were provided by Sandia National Laboratories. This support is gratefully acknowledged. Lloyd Bonzon and Done Hente of SNL are thanked for their large contribution to the project. Within Ontario Hydro, contract co-ordination was handled by the Electrical Design Department. We are grateful to Colin Royce and Jerry Schendel for their efforts. Much of the testing and analysis was carried out by Brian Aucoin of the Chemical Research Department and Gordon Paulson of the Mechanical Research Department. Their able work was essential to the successful outcome of the project.

Approved by:

G.J. Clarke
Manager
Mechanical Research Department

Submitted by:

J.D. Tulk
Unit Head - Special Projects
Applied Structural and Solid
Mechanics Section

D.A. Black
Engineer
Lines, Materials & Seismology

O.A. Kupcis
Manager
Chemical Research Department

W.J. Janis
Chemist
Organic Section

B.A. Oliver
Manager
Electrical Design Department
Design and Development Division

B.M. Kukreti
Engineer
Electrical Design Dept

JDT/DAB/WJJ/BMK:LG

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TABLE 1

CELL CAPACITIES BEFORE AND AFTER SEISMIC TESTING

Cell	Time to 1.75 VPC at 3 h Rate (min)			Per Cent of Rated Capacity at 3 h Rate		
	Pre- Seismic	Post- Seismic*	Post- Seismic Plus Seismic**	Pre- Seismic	Post- Seismic*	Post- Seismic Plus Seismic**
3	151	10	24	84	4	13
4	167	25	39	93	14	22
10	172	25	39	96	14	22
43	177	45	59	98	25	33
45	147	40	54	82	22	30
Avg	163	29	43	91	16	24

* Cells not recharged following seismic testing.

** Capacity during seismic test at 1 h rate converted to 3 h capacity and added to post-seismic capacity, as discussed in Appendix 3.

TABLE 2

TEST LOG OF SEISMIC TESTS ON EXIDE CELLS

Test No	Run No	Cell No	Approx ZPA Level (g) IEEE 501	Comments
1	1	8	0.8	Shaker limit
	2	8	1.0	
	3	8	1.3	
	4	8	1.7	
2	1	1	0.8	Shaker limit
	2	1	1.0	
	3	1	1.3	
	4	1	1.7	
3	1	5	0.8	Jar clamps came loose. Test stopped. Shaker limit.
	2	5	1.0	
	3	5	1.0	
	4	5	1.3	
	5	5	1.7	
4	1	11	0.8	Shaker limit.
	2	11	1.0	
	3	11	1.3	
	4	11	1.7	
Multi-Cell Rack Test (July 26/84) Cells 43, 10, 4, 3, 45				
	1		0.8	No failures.
	2		1.0	
	3		1.3	
	4		1.5	

TABLE 3
MINIMUM ZPA VALUES (g)

Cell	Location	Direction	ZPA
8	base	X	2.18
	base	Y	1.77
	base	Z	1.37
	terminal	X	2.00
	terminal	Y	2.24
	terminal	Z	1.47
1	base	X	1.83
	base	Y	1.56
	base	Z	1.47
	terminal	X	1.84
	terminal	Y	2.00
	terminal	Z	1.63
5	base	X	1.65
	base	Y	1.50
	base	Z	1.50
	terminal	X	1.65
	terminal	Y	1.54
	terminal	Z	2.61
11	base	X	2.16
	base	Y	1.59
	base	Z	1.63
	terminal	X	1.85
	terminal	Y	2.00
	terminal	Z	1.56
43, 10, 4, 3, 45 (rack test)	base	X	1.1
	base	Y	2.17
	base	Z	1.26
	terminal	X	1.31
	terminal	Y	0.8*
	terminal	Z	1.22

* accelerometer malfunction

FIGURE 1

MOUNTING ARRANGEMENT FOR SINGLE CELL TESTS
 THE CELL IS CLAMPED IN PLACE BY THREADED RODS.
 ACCELEROMETERS ARE MOUNTED ON THE BASE AND ON A CELL
 TERMINAL POST. ACCELEROMETER DIRECTIONS ARE AS
 INDICATED.

FIGURE 2

MOUNTING ARRANGEMENT FOR BATTERY RACK TESTS
ACCELEROMETERS ARE MOUNTED ON THE BASE AND ON A CELL
TERMINAL POST. ACCELEROMETER DIRECTIONS ARE AS
INDICATED.

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4

FIGURE 3

TEST ITEM

Station cells, Exide, Model EMP 13, Serial 8.

PARTICULARS

March 14/84, Time 11:28, Temp(°C) 23, Humidity(%) 39,
Press (kPa) 100.2, Graph 5110

SPECIFICATIONS

Specs IEEE 501, Conditions span 6.8, voltage & current monitored

ANALYSIS

Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis X
Shaker tri-axial, ZPA=2.18g

ACCELEROMETER

Wilcoxon, Serial S757, Range dB58, Location base-mounting jig,
TT 702, Channel 1

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TEST ITEM

Station cells. Exida. Model EMP 13. Serial 8.

PARTICULARS

March 14/84. Time 11:28. Temp (°C) 23. Humidity (%) 39.
Press (kPa) 100.2. Graph 5111

SPECIFICATIONS

Specs IEEE 501. Conditions span 6.8. voltage & current monitored

ANALYSIS

Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis Y.
Shaker tri-axial. ZPA=1.77g

ACCELEROMETER

Wilcoxon. Serial S761. Range dB58. Location base-mounting jig.
TT 702. Channel 2

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W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4

FIGURE 5

TEST ITEM

Station cells, Exide, Model EMP 13, Serial 8.

PARTICULARS

March 14/84, Time 11:28, Temp(°C) 23, Humidity(%) 39,
Press (kPa) 100.2, Graph 5112

SPECIFICATIONS

Specs IEEE 501, Conditions span 6.8, voltage & current monitored

ANALYSIS

Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Z,
Shaker tri-axial, ZPA=1.37g

ACCELEROMETER

Wilcoxon, Serial S901, Range dB52, Location base-mounting jig,
TT 702, Channel 3

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800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4

RESPONSE SPECTRUM

FIGURE 6

TEST ITEM

Station cells. Exide. Model EMP 13. Serial 1

PARTICULARS

March 14/84. Time 1:45. Temp(°C) 23. Humidity(%) 39.
Press (kPa) 100.2. Graph 5116

SPECIFICATIONS

Specs IEEE 501. Conditions span 6.8. voltage & current monitored

ANALYSIS

Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis X.
Shaker tri-axial. ZPA=1.83g

ACCELEROMETER

Wilcoxon. Serial S757. Range dB58. Location base-mounting jig.
TT 710. Channel 1

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TEST ITEM

Station cells, Exida, Model EMP 13, Serial 1

PARTICULARS

March 14/84, Time 1:45, Temp(°C) 23, Humidity(%) 39,
Press (kPa) 100.2, Graph 5117

SPECIFICATIONS

Specs IEEE 501, Conditions span 6.8, voltage & current monitored

ANALYSIS

Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Y,
Shaker tri-axial, ZPA=1.56g

ACCELEROMETER

Wilcoxon, Serial S761, Range dB58, Location base-mounting jig,
TT 710, Channel 2

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TEST ITEM

Station cells, Exida, Model EMP 13, Serial 1

PARTICULARS

March 14/84, Time 1:45, Temp(°C) 23, Humidity(%) 39,
Press (kPa) 100.2, Graph 5118

SPECIFICATIONS

Specs IEEE 501, Conditions span 6.8, voltage & current monitored

ANALYSIS

Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Z,
Shaker tri-axial, ZPA=1.47g

ACCELEROMETER

Wilcoxon, Serial S901, Range dB58, Location base-mounting jig,
TT 710, Channel 3

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RESPONSE SPECTRUM

FIGURE 9

TEST ITEM

Station cells. Exide. Model EMP 13. Serial 5.

PARTICULARS

March 14/84. Time 2:35. Temp(°C) 23. Humidity(%) 39.
Press (kPa) 100.2. Graph 5122

SPECIFICATIONS

Specs IEEE 501. Conditions span 6.8. voltage & current monitored

ANALYSIS

Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis X.
Shaker tri-axial. ZPA=1.85g

ACCELEROMETER

Wilcoxon. Serial S757. Range dB58. Location base-mounting jig.
TT 720. Channel 1

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FIGURE 10

TEST ITEM

Station cells, Exide, Model EMP 13, Serial 5.

PARTICULARS

March 14/84, Time 2:35, Temp (°C) 23, Humidity (%) 39,
Press (kPa) 100.2, Graph 5123

SPECIFICATIONS

Specs IEEE 501, Conditions span 6.8, voltage & current monitored

ANALYSIS

Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Y,
Shaker tri-axial, ZPA=1.5g

ACCELEROMETER

Wilcoxon, Serial S761, Range dB58, Location base-mounting jig,
TT 720, Channel 2

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FIGURE 11

TEST ITEM

Station cells, Exide, Model EMP 13, Serial 5.

PARTICULARS

March 14/84, Time 2:35, Temp('C) 23, Humidity(%) 39,
Press (kPa) 100.2, Graph 5124

SPECIFICATIONS

Specs IEEE 501, Conditions span 3.8, voltage & current monitored

ANALYSIS

Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Z,
Shaker tri-axial, ZPA=1.5g

ACCELEROMETER

Wilcoxon, Serial S901, Range dB58, Location base-mounting jig,
TT 720, Channel 3

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FIGURE 12

TEST ITEM

Station cells. Exida. Model EMP 13. Serial 11.

PARTICULARS

March 14/84. Time 3:00. Temp(°C) 23. Humidity(%) 39.
Press (kPa) 100.2. Graph 5128

SPECIFICATIONS

Specs IEEE 501. Conditions span 6.8. voltage & current monitored

ANALYSIS

Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis X.
Shaker tri-axial. ZPA=2.16g

ACCELEROMETER

Wilcoxon. Serial S757. Range dB58. Location base-mounting jig.
TT 730. Channel 1

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FIGURE 13

TEST ITEM

Station cells. Exide. Model EMP 13. Serial 11.

PARTICULARS

March 14/84. Time 3:00. Temp('C) 23. Humidity(%) 39.
Press (kPa) 100.2. Graph 5129

SPECIFICATIONS

Specs IEEE 501. Conditions span 6.8. voltage & current monitored

ANALYSIS

Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis Y.
Shaker tri-axial. ZPA=1.59g

ACCELEROMETER

Wilcoxon. Serial 5761. Range dB58. Location base-mounting jig.
TT 730. Channel 2

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FIGURE 14

TEST ITEM

Station cells. Exide. Model EMP 13. Serial 11.

PARTICULARS

March 14/84. Time 3:00. Temp(°C) 23. Humidity(%) 35.
Press (kPa) 100.2. Graph 5130

SPECIFICATIONS

Specs IEEE 501. Conditions span 8.8. voltage & current monitored

ANALYSIS

Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis Z.
Shaker tri-axial. ZPA=1.63g

ACCELEROMETER

Wilcoxon. Serial S901. Range dB58. Location base-mounting jig.
T. 730. Channel 3

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800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4

FIGURE 15

TEST ITEM

Station Cells & Rack, Exida, Model EMP-13, Serial 43.10.4.3.45

PARTICULARS

July 26/84, Time 3:08, Temp(°C) 23, Humidity(%) 55, Press (kPa) 100, Graph 5260

SPECIFICATIONS

Specs IEEE 501, Conditions operating : 1 hour rate, span 7

ANALYSIS

Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis X, Shaker tri-axial, ZPA=1.1g

ACCELEROMETER

Wilcoxon, Serial S297, Range dB49, Location base-mounting plate, Channel 1

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W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4

FIGURE 16

TEST ITEM

Station Cells & Rack, Exide, Model EMP-13, Serial 43,10,4,3,45

PARTICULARS

July 26/84, Time 3:08, Temp('C) 23, Humidity(X) 55, Press (kPa) 100,
Graph 5261

SPECIFICATIONS

Specs IEEE 501, Conditions operating : 1 hour rate, span 7

ANALYSIS

Type Maximax, Damping (X) 5, B.W. = 1/12 Octaves, Axis Y,
Shaker tri-axial, ZPA=2.17g

ACCELEROMETER

Wilcoxon, Serial S761, Range dB49, Location base-mounting plate,
Channel 2

FIGURE 17

TEST ITEM

Station Cells & Rack, Exida, Model EMP-13, Serial 43,10,4,3,45

PARTICULARS

July 26/84, Time 3:08, Temp('C) 23, Humidity(%) 55, Press (kPa) 100, Graph 5262

SPECIFICATIONS

Specs IEEE 501, Conditions operating : 1 hour rate, span 7

ANALYSIS

Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Z, Shaker tri-axial, ZPA=1.26g

ACCELEROMETER

Wilcoxon, Serial S759, Range dB49, Location base-mounting plate, Channel 3

APPENDIX B

Seismic Testing of Shippingport Nuclear Power Station Batteries - Cell Inspection and Capacity Tests

W. J. Janis

Ontario Hydro Research Division

ontario hydro
research division

To Mr. B.A. Oliver
Manager
Electrical Design Dept

**SEISMIC TESTING OF SHIPPINGPORT NUCLEAR
POWER STATION BATTERIES -
CELL INSPECTION AND CAPACITY TESTS**

W.J. Janis

The performance and condition of 27-year-old, antimony alloy, lead-acid cells were monitored before, during and after seismic testing to determine cell resistance to damage by seismic stresses. Nine EMP-13 cells were tested and none failed electrically during seismic testing. However, none of five seismically tested cells chosen for post-seismic capacity tests could deliver more than 39% of rated capacity after seismic testing. Low post-seismic capacities were primarily due to an appreciable loss of negative grid material, weakened bus/grid connections, clogged electrolyte channels and, possibly, corrosion product bridging negative and positive plates. Chemical corrosion of bus material may have been a contributing factor. Dissected cell negative plate surfaces were severely erupted and pitted and positive plate surfaces were choked with positive grid corrosion products.

1.0 INTRODUCTION

Sandia National Laboratories (SNL) is currently under contract to the United States Nuclear Regulatory Commission (NRC) to conduct studies on the degradation and failure modes of safety related components used in nuclear power plants. Of particular interest to SNL and NRC, and also to Ontario Hydro, is the significance of aging on the seismic-accident survivability of stationary, Class 1E, emergency power batteries.

Because of mutual interest, experience in seismic testing of batteries and the availability of special test facilities, Ontario Hydro was sub-contracted by SNL to carry out seismic

job	file	date	report no.
740632-168-950	832.31 X836.74	January 31, 1985	C84-121-P

fragility tests of naturally aged, lead-acid cells from the Shippingport Nuclear Power Station, Shippingport, Pennsylvania. Following guidelines set out by SNL, a research program was developed by the Electrical Design Department (Design and Development Division), and the Mechanical and Chemical Research Departments (Research Division). In this program the performance and condition of aged cells were monitored before, during and after shaker table testing under simulated earthquake conditions.

This report presents cell condition and performance data obtained during the test program as applied to Shippingport EMP-13 type cells.

2.0 TEST CELLS

Twenty Exide EMP-13 cells were selected at random by Shippingport Station personnel from a large number of cells recently released after 27 years of service. All were delivered to the Battery Research Facility, Ontario Hydro Kipling Complex, in good condition although slight spillage of sulphuric acid electrolyte had occurred during transport because of loose fitting filling caps.

The test cells were of the Planté, lead-antimony alloy type. That is all grid materials were composed of lead-antimony alloy and the positive plate active material was chemically produced from special, pure lead buttons imbedded in the positive grids. Cell specifications supplied by the manufacturer are given in Appendix 1.

3.0 EXPERIMENTAL

3.1 Cell Inspection and Initial Conditioning

On delivery to Ontario Hydro Research Division (OHRD) the cells were inspected for leaks, excess sediment, broken posts, cracks, crazing and any damage which might have been induced by handling during transportation. No significant damage was observed for 16 of the cells and these cells were therefore put on equalizing, then floating charge at 2.25 and 2.15 Volts per cell (VPC), respectively. Four cells showed excessively low electrolyte levels and were discarded. Undamaged cells were placed on floating charge prior to, and between, capacity tests to minimize capacity loss through self-discharge.

During storage, the specific gravities of the cells were maintained between 1.200 and 1.220, corrected to 25°C per IEEE standard 450-1980/1/. Specific gravities, cell voltages, electrolyte levels and temperatures were monitored and adjusted as necessary to maintain the cells in serviceable condition.

3.2 Initial Capacity Tests

Following inspection, charge equalization, and a minimum of 24 h float charging, 12 serviceable cells selected at random from the set of 16 cells were discharged at the manufacturer's specified 3 h rate of 62 A to a final cell potential of 1.75 VPC. The discharge tests provided benchmark capacity data for cells selected for seismic test and were carried out per Reference 1 as follows:

1. Three or four cells and a resistance load were connected in series and the cells were discharged at a constant current following the procedure outlined in OHRD Report No E76-85-H/2/.
2. Cell potentials, discharge currents and temperatures were monitored during the discharge test. The data were recorded at 5 min intervals.
3. Discharged cells were recharged in series at a potential of 2.25 V for 35-70 h, followed by sustained float charging at 2.15 V.

3.3 Cell Discharge During Seismic Testing

Five of the 12 cells tested for capacity and four untested cells were submitted to seismic testing. To assess the immediate effect of a seismic event on cell performance, cells were kept on discharge during seismic tests and cell voltages and currents were monitored continuously during the tests. A 1.5 h discharge rate was used for the Shippingport cells to simulate a high load emergency service condition.

Discharge was initiated a few seconds prior to the first 30 s seismic event and was continued until the cell either failed during a seismic event or passed the scheduled sequence of seismic events. Failure was defined as the inability of a cell to maintain a potential greater than 1.75 V while under a constant current discharge at the 1.5 h rate.

3.4 Post Seismic Capacity Tests

After seismic testing, all cells which did not fail were discharged at the 3 h rate. The procedure was the same as for the initial capacity tests.

3.5 Cell Disassembly and Material Studies

Four test cells were disassembled following seismic and capacity testing to identify changes in internal components resulting

directly from seismic testing. A photographic record of cell components was obtained. Representative photographs are presented as part of section 4.5.

4.0 RESULTS AND DISCUSSION

4.1 Cell Inspection

Twenty cells from Shippingport NGS arrived at OHRD on March 2, 1984. None of the cells showed outward evidence of damage but four cells had abnormally low electrolyte levels due to spillage. All of the electrolyte levels were within the manufacturer's specified limits for the remaining 16 cells.

All 16 cells which passed visual inspection were put on equalizing charge on March 6, 1984. Specific gravities averaged 1.16 ± 0.01 when the cells were received and 1.21 ± 0.01 seven days later.

As expected for lead-antimony alloy cells, considerable sediment (5 - 10 mm) was observed during cell inspection.

4.2 Initial Capacity Tests

Capacity data and pre-test specific gravities and open circuit cell potentials are presented in Table I. Nine of twelve cells met the IEEE recommended acceptance criterion of 80% rated capacity.

After initial capacity tests, the cells were recharged at 2.15 VPC. After 6 days of float charging cell specific gravities averaged 1.207 and both open circuit voltages and charging current had stabilized. (Approximately 2.1 V and 3 A per cell, respectively.) Following Appendix B of IEEE Standard 450/1/, stabilization of the voltage-regulated charging current at the charging voltage of 2.15 VPC was taken as an indication that the cells in question were charged. Five cells selected at random were therefore allowed to proceed to seismic testing.

4.3 Cell Discharge During Seismic Testing

No sudden loss of cell potential was observed for any cells during seismic testing up to the capacity of the shaker table. The pass/fail results are summarized in Table II and presented in more detail in Appendix 2. Details of the seismic testing procedure and fragility level assessment are presented in OHRD reports B84-44-P/3/ and B84-428-P/4/.

TABLE I
CAPACITY TEST DATA*

Cell Number	25°C Gravity Prior to Discharge	Open Circuit Potential (Volts)	Time to 1.75 VPC at 3 h rate of 62 A (min)	Percent Rated Capacity at 3 h Rate
3	1.205	2.16	151	84
4	1.210	2.19	167	93
7	1.205	2.19	167	93
9	1.210	2.16	151	84
10	1.210	2.17	172	96
12	1.205	2.19	167	93
13	1.210	2.19	173	96
15	1.200	2.08	143	46
18	1.210	2.09	132	73
43	1.200	2.17	177	98
44	1.215	2.10	142	79
45	1.210	2.10	147	82

* Cells equalized at 2.25 VPC for 7 days, then float charged at 2.15 VPC for 26 days prior to discharge.

TABLE II
DISCHARGE DATA SUMMARY - SEISMIC EVENT TESTS

Cell Number	Pass/Fail at 1.5 h Discharge Rate*	Cell Potential (V) While Under Load		Total Time on Discharge (s)
		Before Testing	After Testing	
1	Pass	1.99	1.93	240
3**	Pass	1.88	1.84	435
4**	Pass	1.88	1.84	435
5	Pass	1.97	1.93	180
8	Pass	1.96	1.92	180
10**	Pass	1.88	1.84	435
11	Pass	1.94	1.91	218
43**	Pass	1.88	1.84	435
45**	Pass	1.88	1.84	435

* 96 Amperes

** Multi-cell test (5 cells connected in series)

The data in Table II indicate that all Shippingport test cells survived seismic stress up to the capacity of the shaker table test equipment.

4.4 Post Seismic Capacity Tests

Post test discharge capacities were determined for five of the cells which survived seismic testing. The data are compared to pre-seismic values in Table III. Also in Table III is the cumulative capacity for the cells, as measured from the start of the seismic test, expressed as a percentage of the 3 h rated capacity. The required calculations to convert discharge times at the 1.5 h rate to discharge times at the 3 h rate is provided in Appendix 3.

TABLE III
CELL CAPACITIES BEFORE AND AFTER SEISMIC TESTING

Cell	Time to 1.75 VPC at 3 h Rate (min)			Per Cent of Rated Capacity at 3 h Rate		
	Pre- Seismic	Post- Seismic*	Post- Seismic Plus Seismic**	Pre- Seismic	Post- Seismic*	Post-Seismic Plus Seismic**
3	151	10	24	84	4	13
4	167	25	39	93	14	22
10	172	25	39	96	14	22
43	177	45	59	98	25	33
45	147	40	54	82	22	30
AVG	163	29	43	91	16	24

* Cells not recharged following seismic testing.

** Capacity during seismic test at 1.5 h rate converted to 3 h capacity and added to post-seismic capacity, as discussed in Appendix 3.

The Table III data indicate a significant loss of discharge capacity for all cells as a result of seismic testing.

4.5 Cell Disassembly and Material Study

Seismically tested cells 43 and 45 and non-seismically tested, low capacity cell 15 were disassembled and inspected for internal damage. Common features identified during the inspection are documented in Photographs 1-5 and summarized below.

Photograph 1 shows cell posts and buses of a typical EMP-13 cell (cell 15) as they appear when the cell jar top is removed and the cell drained of electrolyte. The dark flakes in the photograph are corrosion products dislodged from the positive plate grids. White flakes are case shavings produced when the cell top was removed. All EMP-13 cells examined contained large amounts of the flakes in the sediment spaces, on top of the plate packs, and loosely attached to the positive buses and terminal posts. The horizontal plates at the extreme left and right of photograph 1 are the negative and positive buses, respectively. The cell plates are attached to the buses from plate hangers directly beneath the buses. No cracks were observed in post or bus materials when the cells were opened.

Photograph 2 shows the result of two moderate hammer blows to the negative post of cell 15. The first blow broke all top grid edges while the second easily bent the bus/plate hanger assembly away from the plate pack. In all dissected cells the negative plate grids were very weak and brittle at their tops. In cells 43 and 45 considerable negative plate material, particularly at the tops of the plates near the plate hangers, was loose, presumably as a result of seismic testing.

Photograph 3 shows the result of several moderate hammer blows to the positive post of cell 15. The bus material was relatively brittle and the bus fractured as the post was hammered. The dark portions in the bus cross-section of photograph 3 identify areas where some chemical attack has taken place. The attack is most severe on the underside of the bus and decreases as the cross-section is traversed from bottom to top.

Most negative plates of the three dissected cells were severely erupted on both sides, as shown in photograph 4 (cell 43). Non-erupted, vertical areas of photograph 4 correspond to the positions of plastic spacers. The spacers appear to have restricted chemical activity where they contacted the negative plates and therefore enhanced chemical activity in the erupted areas and plate extremities.

Photograph 5 shows a typical positive plate from cell 43. The positive plates were quite solid and were not warped. Lead buttons, the circular structures of photograph 5, near the extremities of the plates were usually clogged with active lead oxides. The buttons in the centers of most plates were not so densely packed with oxides, indicating less frequent participation of these buttons in cell reactions.

All positive grids showed evidence of flaking (the loose background material of photographs 1, 4 and 5) and in seismically tested cells the flaked material was distributed on the tops of the plate packs, deposited in the sediment space and lodged between positive plates and adjacent separators.

DOCUMENTATION PHOTOGRAPHS

SHIPPINGPORT LEAD-ANTIMONY CELLS (EMP-13)

(1)

(2)

B-8-

C84-121

DOCUMENTATION PHOTOGRAPHS

SHIPPINGPORT LEAD-ANTIMONY CELLS (EMP-13)

(3)

(4)

B-9-

C84-121

DOCUMENTATION PHOTOGRAPHS

SHIPPINGPORT LEAD-ANTIMONY CELLS (EMP-13)

(5)

CONCLUSION

1. All nine EMP-13 cells selected for seismic testing provided uninterrupted power at required electrical potential under load during repeated and violent shaking.
2. All five EMP-13 cells tested for discharge capacity following seismic testing failed to meet the acceptance criterion of 80% of rated capacity due to internal damage suffered during shaking.
3. Internally, the 27-year old EMP-13 cells were in poor condition prior to seismic testing. Negative plates in the vicinity of bus connections were extremely weak, positive buses were corroded and brittle, negative and positive active material utilization was extremely uneven and corrosion products, mostly from the positive grids, littered the cells. Seismic testing dislodged active negative material, weakened plate attachments and clogged electrolyte channels with dislodged corrosion products.

Approved by:

R.W. Glass
Section Head
Chemical Research Dept

Prepared by:

W.J. Janis
Chemist
Organic Section

WJJ:lg

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APPENDIX 1

TEST CELL SPECIFICATIONS - EMP-13 CELLS

(a) Capacity

Discharge Rate to 1.75 V Per Cell at 25°C (Amperes)				
For 8 h	For 5 h	For 3 h	For 1.5 h	For 1 h
30	44	62	96	120

(b) Dimensions

	Height (cm)	Width (cm)	Length (cm)	Thickness (cm)
Overall	45.5	25.7	17.5	--
Positive Plate	19.7	19.7	--	1.12
Negative Plate	19.7	19.7	--	0.46

(c) Materials

Container	Transparent Polystyrene Case Opaque Styrene-butadiene Cover
Separators	microporous rubber
Positive Plate active material retainers	fiberglass mat
Electrodes	lead-antimony grid (6 positive, 7 negative)
Posts and Buses ¹	1 positive post, 1 negative post, 2.5 cm x 2.5 cm each, attached to to lead bus.
Electrolyte	1.215 specific gravity sulphuric acid (25°C)

¹ Note: Buses are sometimes referred to as straps.

APPENDIX 2

DISCHARGE DATA - SEISMIC EVENT TESTS

Cell Number	Seismic Event Data			Cell Potential Data		
	Event Number	Intensity Setting	Relative Start Time (S)	At Start of Seismic Event (V)	At End of Seismic Event (V)	Difference (End-Start) (mV)
3*, 4, 10, 43 and 45	1	4	0	1.882	1.839	-43
	2	5	84	1.832	1.834	2
	3	6	182**	1.837	1.838	1
	4	6.8	245	1.844	1.839	-5
1	1	4	0	1.991	1.937	-54
	2	5	63	1.915	1.917	2
	3	6	126	1.922	1.927	5
	4	6.8	175	1.931	1.934	3
5	1	4	0	1.967	1.936	-31
	2	5	42**	1.956	1.930	-26
	3	6	84	1.923	1.924	1
	4	6.8	133	1.926	1.929	3
8	1	4	0	1.957	1.928	-29
	2	5	35	1.920	1.915	-5
	3	6	77	1.917	1.921	3
	4	6.8	119	1.924	1.925	1
11	1	4	0	1.930	1.905	-25
	2	5	42	1.899	1.895	-4
	3	6	84	1.897	1.904	7
	4	6.8	126	1.907	1.909	-2

* Multi-Cell Test (cell potential data are averages).

** Does not include a 10-15 minute stoppage to tighten loose connections. The stoppage caused a first attempt at setting 5 to be abandoned in the test of cell 5.

APPENDIX 2 (cont'd)

Notes

1. Seismic test event duration = 30 s in all cases.
2. The relative start time zero is coincident with the initiation of the first 30s seismic event.
3. The cell failure criterion is a sharp cell potential drop to <1.75 VPC.
4. The maximum accelerations for the intensity settings are approximately as follows:

<u>Intensity Setting</u>	<u>Maximum Acceleration (g)</u>
2	2
3	3
4	4
5	5
6	6
6.8 (machine limit)	6.5

APPENDIX 3

DISCHARGE TIME/RATE CALCULATIONS

Discharge Time at Nominal 1.5 h Rate-Converted to Discharge Time at Nominal 3 h Rate

The most widely used and accepted equation relating discharge current and time is Peukert's equation/5/:

$$I^n t = C \quad [A3.1]$$

where I and t are the discharge current and time, respectively, and n and C are temperature dependent constants. The constants n and C may be evaluated by tests made on any cell or battery at at least two different rates of discharge at constant temperature.

Results of a linear regression analysis of $\log_e(t)$ versus $\log_e(I)$, using the I and t data of Appendix 1, are summarized in Table A3.1. An approximate empirical relation for the discharge rate, in amperes, as a function of the discharge time, in hours, is as follows:

$$I = (7.0392 \times 10^{-4} t)^{-0.6644} \quad [A3.2]$$

TABLE A3.1

LINEAR REGRESSION FIT - $\log_e(t)$ VERSUS $\log_e(I)$

t (h)	$\log_e(t)$	I (amperes)	$\log_e(I)$	Curve Fitting Parameters
8	2.079	30	3.401	Slope(-n)=-1.5052 y-intercept ($\log_e(c)$)=7.259 correlation coefficient = -0.998
5	1.609	44	3.784	
3	1.099	62	4.127	
1.5	0.405	96	4.564	
1	0.000	120	4.787	

From relation [A3.1], discharge currents at different discharge times are related by:

$$t_2 = \left(\frac{I_1}{I_2}\right)^n \cdot t_1 \quad [A3.3]$$

where the subscripts refer to different (I,t) pairs.

Equation [A3.3], with $n = 1.5052$, was used to calculate 3 h rate data using 1.5 h rate data, and the results are shown in Table A3.2.

TABLE A3.2

DISCHARGE TIME CONVERSION (1.5 h RATE TO 3 h RATE)

Cell Number	1.5 h Rate Discharge		3 Rate Discharge	
	Time (s)	Current (A) (nominal)	Time (s) (calculated)	Current (A) (nominal)
3, 4 10, 43 and 45 in series	435	96	840	62

APPENDIX C

Seismic Testing of
Exide Aged Batteries

D. A. Black
G. D. Paulsen

Ontario Hydro Research Division

**ontario hydro
research division**

To Mr. B.A. Oliver
Manager
Electrical Design
Design & Development

**SEISMIC TESTING OF
EXIDE AGED BATTERIES**

D.A. Black and G.D. Paulsen

Four naturally aged Exide cells were seismically tested to IEEE specifications. The testing was part of a program to determine the effects of aging on the ability of station cells to withstand seismic events. This report describes the test equipment used, the test procedure followed and gives the results of the tests.

1.0 INTRODUCTION

Four Exide cells were seismically tested to IEEE 344/1/ and IEEE 501/2/ specifications. Date of test, specimen description, test facility name and location, test data and test temperature, humidity and pressure are recorded on each of the response spectrum curves. These curves also show the conditions of the test, the type of analysis, the accelerometers used, the direction of the test, and the axis analysed. All tests were analysed using 5% damping and the maximax shock spectrum. The tests performed were tri-axial tests as defined in IEEE 344. The shaker inputs were pseudo-random with a duration of 30 s. All technical terms used in this report are defined by Harris/3/.

2.0 SAMPLE

The samples tested were described as follows:

Exide, Model EMP13, Serial Numbers 8, 1, 5 and 11, used cells approximately 27 years old.

job	file	date	report no.
740624-268-450	824.46	June 28, 1984	B84-44-P

3.0 TEST EQUIPMENT

3.1 Equipment Used

3.1.1 Shaker Control Equipment

1. MTS 436 control units
2. MTS 406.11 controllers
3. MTS hydraulic pumps
4. Ontario Hydro noise generators and filters
5. Ontario Hydro tri-axial shaker table.

3.1.2 Analysis

1. Columbia Model 9000 amplifiers and matching Wilcoxon M-408 accelerometers.

<u>Amplifier Serial No</u>	<u>Accelerometer Serial No</u>
368 1632	S893
368 1633	S297
368 1634	S901
368 1635	S369
368 1636	S753
368 1637	S754
369 1638	S756
369 1639	S757
369 1640	S759
369 1641	S760
369 1642	S761
369 1643	S771

2. SE tape recorder Model 7000A, Serial No 547.
3. Tektronix 5113 dual beam storage oscilloscope, KS3681.
4. Spectral Dynamics 13231 Shock Spectrum Analyser, Serial No 27.
5. Spectral Dynamics 13191 Transient Memory, Serial No 29.
6. Ontario Hydro transmissibility circuit.
7. Watanabe WX4400 X-Y Recorder, Serial No 83010070.
8. Hewlett-Packard 7046A X-Y1-Y2 Recorder, Serial No 1914A05842.
9. Spectral Dynamics 50121L Tracking Filter, Serial No 171.

10. Spectral Dynamics SD122L Tracking Filter, Serial No 370.
11. Honeywell 1858 oscillograph, Serial No 2649JF78.
12. Nicolet Scientific Corp, Model 660A Dual Channel FFT Analyzer, Serial No 9866226.
13. Hewlett-Packard Model 7470A Plotter, Serial No 2210A-12990.

3.1.3 Calibration Equipment

1. Bruel and Kjaer Type 3506, Serial No 877022 Accelerometer Calibration Set which includes Type 2626, Serial No 842947 and Type 83055, Serial No 858627, traceable to NBS.
2. General Radio 1557-A vibration calibrator, Serial No 2379.
3. Data Precision 2440 digital voltmeter, Serial No 8583, traceable to NBS.
4. Data Precision 248 digital voltmeter, Serial No 8583, traceable to NBS.

4.0 TESTS AND PROCEDURES

4.1 Calibration Procedure

Accelerometers and amplifiers are calibrated using the back-to-back calibration procedure. The reference accelerometer was mounted on the vibration calibrator with the Wilcoxon accelerometer. Using 100 Hz sine wave vibration of approximately 1 g, the sensitivity of the Columbia amplifiers was set to give 500 mV/g output. The outputs were measured using the digital voltmeter. By using the same voltmeter for both the reference and the Columbia amplifiers, slight differences in voltmeters need not be considered. Since the voltmeter measures true RMS voltages, the waveshapes of the 100 Hz signals were compared on the oscilloscope. This ensures that the signals are equivalent.

4.2 Test Setup and Procedures

Each cell was mounted in the fixture as shown in Figure 1. Accelerometers were placed at the base and on one terminal post. Electrical connections were made and the cell loaded to the 3-hour rating by Chemical Research. The cells were then subjected to increasing levels of vibration.

4.3 Vibration Tests

The shaker consists of random generators and hydraulic actuators which are capable of driving the shaker in three directions simultaneously. The shaker has the following limitation in each axis:

Displacement limit	152 mm
Velocity limit	820 m/s
Acceleration limit	4 g (no load)
Acceleration limit	1.6 g (fully loaded)
Maximum load	2000 kg

Simultaneous random inputs were applied in three axes and the coherence between axes was negligible. The vibration levels in the two horizontal and vertical directions were individually controlled to nominally give similar levels. These levels were set by adjusting a "span" potentiometer. The span setting used is of no significance in itself except equivalent span settings nominally indicate equivalent vibration levels. The vibration is never the same from one test to the next since a different random signal is used for each test.

5.0 RESULTS

A test log (Table I) shows the sequence of testing for each cell. The cells did not show any signs of failure. The test response spectrums are given in Figures 2 through 25. No electrical failures were observed.

6.0 CONCLUSIONS

The Exide cells have minimum ZPA values, as described in IEEE 501 and as shown in Table 2. These cells were well constructed and showed no signs of failure.

Approved:

Submitted:

D.B. Craig
Section Head
Mechanical Testing and
Development Section
Mechanical Research Dept

G.D. Paulsen
Technologist
Mechanical Testing and
Development Section

D.A. Black
Engineer
Mechanical Testing and
Development Section

GDP:DAB:sf

B84-44

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2. The Institute of Electrical and Electronic Engineers Inc.
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3. Harris, Cyril M., and Charles E. Crede. "Shock and Vibration
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Toronto. 1976.

TABLE I

TEST LOG OF SEISMIC TESTS ON EXIDE CELLS

Test No	Run No	Battery Number	Span Level	Comments
1	1	8	4	
	2	8	5	
	3	8	6	
	4	8	6.8	Shaker limit.
2	1	1	4	
	2	1	5	
	3	1	6	
	4	1	6.8	Shaker limit.
3	1	5	4	
	2	5	5	Jar clamps came loose. Test stopped
	3	5	5	
	4	5	6	
	5	5	6.8	Shaker limit.
4	1	11	4	
	2	11	5	
	3	11	6	
	4	11	6.8	Shaker limit.

TABLE II
MINIMUM ZPA VALUES (g)

Cell	Location	Direction	ZPA
8	base	X	2.18
	base	Y	1.77
	base	Z	1.37
	terminal	X	2.00
	terminal	Y	2.24
	terminal	Z	1.47
1	base	X	1.83
	base	Y	1.56
	base	Z	1.47
	terminal	X	1.84
	terminal	Y	2.00
	terminal	Z	1.63
5	base	X	1.65
	base	Y	1.50
	base	Z	1.50
	terminal	X	1.65
	terminal	Y	1.54
	terminal	Z	2.61
11	base	X	2.16
	base	Y	1.59
	base	Z	1.63
	terminal	X	1.85
	terminal	Y	2.00
	terminal	Z	1.56

FIGURE 1

TYPICAL MOUNTING OF EXIDE CELL IN SINGLE CELL RIGID FRAME. WOOD SPACERS WERE REQUIRED FOR THIS CELL. THE CELL IS CLAMPED AT THE FOUR CORNERS USING THREADED RODS. ACCELEROMETERS WERE MOUNTED AT THE BASE AND ONE OF THE TERMINAL POSTS. THE AXES OF VIBRATION ARE INDICATED.

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4

RESPONSE SPECTRUM

FIGURE 2

TEST ITEM

Station cells, Exide, Model EMP 13, Serial 8,

PARTICULARS

March 14/84, Time 11:28, Temp(°C) 23, Humidity(%) 39,
Press (kPa) 100.2, Graph 5110

SPECIFICATIONS

Specs IEEE 501, Conditions span 6.8, voltage & current monitored

ANALYSIS

Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis **X**
Shaker tri-axial, ZPA=2.18g

ACCELEROMETER

Wilcoxon, Serial S757, Range dB58, Location base-mounting jig,
TT 702, Channel 1

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4

RESPONSE SPECTRUM

FIGURE 3

TEST ITEM

Station cells. Exide. Model EMP 13. Serial 8.

PARTICULARS

March 14/84. Time 11:28. Temp('C) 23. Humidity(%) 39.
Press (kPa) 100.2. Graph 5111

SPECIFICATIONS

Specs IEEE 501. Conditions span 6.8. voltage & current monitored

ANALYSIS

Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis Y.
Shaker tri-axial. ZPA=1.77g

ACCELEROMETER

Wilcoxon. Serial S761. Range dB58. Location base-mounting jig.
TT 702. Channel 2

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4

FIGURE 4

TEST ITEM

Station cells, Exide, Model EMP 13, Serial 8.

PARTICULARS

March 14/84, Time 11:28, Temp(°C) 23, Humidity(%) 39,
Press (kPa) 100.2, Graph 5112

SPECIFICATIONS

Specs IEEE 501, Conditions span 6.8, voltage & current monitored

ANALYSIS

Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Z,
Shaker tri-axial, ZPA=1.37g

ACCELEROMETER

Wilcoxon, Serial S901, Range dB58, Location base-mounting jig,
TT 702, Channel 3

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4

RESPONSE SPECTRUM

FIGURE 5

TEST ITEM

Station cells, Exide, Model EMP 13, Serial 8.

PARTICULARS

March 14/84, Time 11:28, Temp(°C) 23, Humidity(%) 39,
Press (kPa) 100.2, Graph 5113

SPECIFICATIONS

Specs IEEE 501, Conditions span 6.8, voltage & current monitored

ANALYSIS

Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis X,
Shaker tri-axial, ZPA=2g

ACCELEROMETER

Wilcoxon, Serial S771, Range dB58, Location top-cell terminal,
TT 702, Channel 4

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4

RESPONSE SPECTRUM

FIGURE 6

TEST ITEM

Station cells. Exida. Model EMP 13. Serial 8.

PARTICULARS

March 14/84. Time 11:28. Temp(°C) 23. Humidity(%) 39.
Press (kPa) 100.2. Graph 5114

SPECIFICATIONS

Specs IEEE 501. Conditions span 6.8. voltage & current monitored

ANALYSIS

Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis Y.
Shaker tri-axial. ZPA=2.24g

ACCELEROMETER

Wilcoxon. Serial S297. Range dB58. Location top-cell terminal.
TT 702. Channel 5

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4

FIGURE 7

TEST ITEM

Station cells, Exide, Model EMP 13, Serial 8

PARTICULARS

March 14/84, Time 11:28, Temp(°C) 23, Humidity(%) 39,
Press (kPa) 100.2, Graph 5115

SPECIFICATIONS

Specs IEEE 501, Conditions span 6.8, voltage & current monitored

ANALYSIS

Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Z,
Shaker tri-axial, ZPA=1.47g

ACCELEROMETER

Wilcoxon, Serial S754, Range dB58, Location top-cell terminal,
TT 702, Channel 6

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FIGURE 8

TEST ITEM

Station cells, Exida, Model EMP 13, Serial 1

PARTICULARS

March 14/84, Time 1:45, Temp(°C) 23, Humidity(%) 39,
Press (kPa) 100.2, Graph 5116

SPECIFICATIONS

Specs IEEE 501, Conditions span 6.8, voltage & current monitored

ANALYSIS

Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis X,
Shaker tri-axial, ZPA=1.83g

ACCELEROMETER

Wilcoxon, Serial S757, Range dB58, Location base-mounting jig,
TT 710, Channel 1

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W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4

TEST ITEM

Station cells, Exide, Model EMP 13, Serial 1

PARTICULARS

March 14/84, Time 1:45, Temp(°C) 23, Humidity(%) 39,
Press (kPa) 100.2, Graph 5117

SPECIFICATIONS

Specs IEEE 501, Conditions span 6.8, voltage & current monitored

ANALYSIS

Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Y,
Shaker tri-axial, ZPA=1.56g

ACCELEROMETER

Wilcoxon, Serial S761, Range dB58, Location base-mounting jig,
TT 710, Channel 2

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TEST ITEM

Station cells, Exida, Model EMP 13, Serial 1

PARTICULARS

March 14/84, Time 1:45, Temp('C) 23, Humidity(%) 39,
Press (kPa) 100.2, Graph 5118

SPECIFICATIONS

Specs IEEE 501, Conditions span 6.8, voltage & current monitored

ANALYSIS

Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Z,
Shaker tri-axial, ZPA=1.47g

ACCELEROMETER

Wilcoxon, Serial S901, Range dB58, Location base-mounting jig,
TT 710, Channel 3

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W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4

RESPONSE SPECTRUM

FIGURE //

TEST ITEM

Station cells, Exide. Model EMP 13, Serial 1

PARTICULARS

March 14/84, Time 1:45, Temp('C) 23, Humidity(%) 39,
Press (kPa) 100.2, Graph 5119

SPECIFICATIONS

Specs IEEE 501, Conditions span 6.8, voltage & current monitored

ANALYSIS

Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis X
Shaker tri-axial, ZPA=1.84g

ACCELEROMETER

Wilcoxon, Serial S771, Range dB58, Location top-cell terminal,
TT 710, Channel 4

ONTARIO HYDRO
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RESPONSE SPECTRUM

FIGURE 12

TEST ITEM

Station cells, Exide, Model EMP 13, Serial 1

PARTICULARS

March 14/84, Time 1:45, Temp(°C) 23, Humidity(%) 39,
Press (kPa) 100.2, Graph 5120

SPECIFICATIONS

Specs IEEE 501, Conditions span 6.8, voltage & current monitored

ANALYSIS

Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Y,
Shaker tri-axial, ZPA=2g

ACCELEROMETER

Wilcoxon, Serial S297, Range dB58, Location top-cell terminal,
TT 710, Channel 5

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
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FIGURE /3

TEST ITEM

Station cells, Exide, Model EMP 13, Serial 1

PARTICULARS

March 14/84, Time 1:45, Temp('C) 23, Humidity(%) 39,
Press (kPa) 100.2, Graph 5121

SPECIFICATIONS

Specs IEEE 501, Conditions span 6.8, voltage & current monitored

ANALYSIS

Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Z,
Shaker tri-axial, ZPA=1.63g

ACCELEROMETER

Wilcoxon, Serial S754, Range dB58, Location top-cell terminal,
TT 710, Channel 6

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RESPONSE SPECTRUM

FIGURE 14

TEST ITEM

Station cells, Exida. Model EMP 13, Serial 5.

PARTICULARS

March 14/84, Time 2:35, Temp(°C) 23, Humidity(%) 39,
Press (kPa) 100.2, Graph 5122

SPECIFICATIONS

Specs IEEE 501, Conditions span 6.8, voltage & current monitored

ANALYSIS

Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis X,
Shaker tri-axial, ZPA=1.65g

ACCELEROMETER

Wilcoxon, Serial S757, Range dB58, Location base-mounting jig,
TT 720, Channel 1

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RESPONSE SPECTRUM

FIGURE 15

TEST ITEM

Station cells. Exide. Model EMP 13. Serial 5.

PARTICULARS

March 14/84. Time 2:35. Temp (°C) 23. Humidity (%) 39.
Press (kPa) 100.2. Graph 5123

SPECIFICATIONS

Specs IEEE 501. Conditions span 6.8. voltage & current monitored

ANALYSIS

Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis Y.
Shaker tri-axial. ZPA=1.5g

ACCELEROMETER

Wilcoxon. Serial S761. Range dB58. Location base-mounting jig.
TT 720. Channel 2

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RESPONSE SPECTRUM

FIGURE 16

TEST ITEM

Station cells, Exide, Model EMP 13, Serial 5.

PARTICULARS

March 14/84, Time 2:35, Temp('C) 23, Humidity(%) 39,
Press (kPa) 100.2, Graph 5124

SPECIFICATIONS

Specs IEEE 501, Conditions span 8.8, voltage & current monitored

ANALYSIS

Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Z,
Shaker tri-axial, ZPA=1.5g

ACCELEROMETER

Wilcoxon, Serial S901, Range dB58, Location base-mounting jig,
TT 720, Channel 3

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TEST ITEM

Station cells. Exide. Model EMP 13. Serial 5.

PARTICULARS

March 14/84. Time 2:35. Temp('C) 23. Humidity(%) 39.
Press (kPa) 100.2. Graph 5125

SPECIFICATIONS

Specs IEEE 501. Conditions span 6.8. voltage & current monitored

ANALYSIS

Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis X.
Shaker tri-axial. ZPA=1.65g

ACCELEROMETER

Wilcoxon. Serial S771. Range dB58. Location top-cell terminal.
TT 720. Channel 4

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RESPONSE SPECTRUM

FIGURE 8

TEST ITEM

Station cells, Exide, Model EMP 13, Serial 5.

PARTICULARS

March 14/84, Time 2:35, Temp(°C) 23, Humidity(%) 39,
Press (kPa) 100.2, Graph 5125

SPECIFICATIONS

Specs IEEE 501, Conditions span 6.8, voltage & current monitored

ANALYSIS

Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Y,
Shaker tri-axial, ZPA=1.54g

ACCELEROMETER

Wilcoxon, Serial S297, Range dB58, Location top-cell terminal,
TT 720, Channel 5

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TEST ITEM

Station cells, Exide, Model EMP 13, Serial 5.

PARTICULARS

March 14/84, Time 2:35, Temp('C) 23, Humidity(%) 39.
Press (kPa) 100.2, Graph 5127

SPECIFICATIONS

Specs IEEE 501, Conditions span 6.8, voltage & current monitored

ANALYSIS

Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Z.
Shaker tri-axial, ZPA=2.61g

ACCELEROMETER

Wilcoxon, Serial S754, Range dB58, Location top-cell terminal,
TT 720, Channel 6

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FIGURE 20

TEST ITEM

Station cells, Exida, Model EMP 13, Serial 11.

PARTICULARS

March 14/84, Time 3:00, Temp('C) 23, Humidity(%) 39,
Press (kPa) 100.2, Graph 5128

SPECIFICATIONS

Specs IEEE 501, Conditions span 6.8, voltage & current monitored

ANALYSIS

Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis X,
Shaker tri-axial, ZPA=2.16g

ACCELEROMETER

Wilcoxon, Serial S757, Range dB58, Location base-mounting jig,
TT 730, Channel 1

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TEST ITEM

Station cells. Exida. Model EMP 13. Serial 11.

PARTICULARS

March 14/84. Time 3:00. Temp (°C) 23. Humidity (%) 39.
Press (kPa) 100.2. Graph 5129

SPECIFICATIONS

Specs IEEE 501. Conditions span 6.8. voltage & current monitored

ANALYSIS

Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis Y.
Shaker tri-axial. ZPA=1.59g

ACCELEROMETER

Wilcoxon. Serial S761. Range dB58. Location base-mounting jig.
TT 730. Channel 2

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FIGURE 22

TEST ITEM

Station cells, Exida, Model EMP 13, Serial 11.

PARTICULARS

March 14/84, Time 3:00, Temp (°C) 23, Humidity (%) 39,
Press (kPa) 100.2, Graph 5130

SPECIFICATIONS

Specs IEEE 501, Conditions span 6.8, voltage & current monitored

ANALYSIS

Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis **Z**,
Shaker tri-axial, ZPA=1.63g

ACCELEROMETER

Wilcoxon, Serial S901, Range dB50, Location base-mounting jig,
TT 730, Channel 3

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4

FIGURE 23

TEST ITEM

Station cells, Exida, Model EMP 13, Serial 11.

PARTICULARS

March 14/84, Time 3:00, Temp(°C) 23, Humidity(%) 39.
Press (kPa) 100.2, Graph 5131

SPECIFICATIONS

Specs IEEE 501, Conditions span 6.8, voltage & current monitored

ANALYSIS

Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis X.
Shaker tri-axial, ZPA=1.85g

ACCELEROMETER

Wilcoxon, Serial S771, Range dB58, Location top-cell terminal.
TT 730, Channel 4

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FIGURE 24

TEST ITEM

Station cells, Exide, Model EMP 13, Serial 11.

PARTICULARS

March 14/84, Time 3:00, Temp('C) 23, Humidity(%) 39.
Press (kPa) 100.2, Graph 5132

SPECIFICATIONS

Specs IEEE 501, Conditions span 6.8, voltage & current monitored

ANALYSIS

Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Y,
Shaker tri-axial, ZPA=2g

ACCELEROMETER

Wilcoxon, Serial S297, Range dB58, Location top-cell terminal,
TT 730, Channel 5

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FIGURE 25

TEST ITEM

Station cells. Exida. Model EMP 13. Serial 11.

PARTICULARS

March 14/84. Time 3:00. Temp(°C) 23. Humidity(%) 39.
Press (kPa) 100.2. Graph 5133

SPECIFICATIONS

Specs IEEE 501. Conditions span 6.8. voltage & current monitored

ANALYSIS

Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis Z.
Shaker tri-axial. ZPA=1.56g

ACCELEROMETER

Wilcoxon. Serial S754. Range dB58. Location top-cell terminal.
TT 730. Channel 6

APPENDIX D

Seismic Testing of Aged Shippingport Nuclear Power Plant Batteries

D. A. Black
G. D. Paulsen

Ontario Hydro Research Division

**ontario hydro
research division**

To Mr. B.A. Oliver
Manager
Electrical Design
Design & Development

SEISMIC TESTING OF AGED
SHIPPINGPORT NUCLEAR POWER PLANT BATTERIES

D.A. Black and G.D. Paulsen

Five exide batteries removed from the Shippingport Nuclear Power Plant were seismically tested to IEEE Specifications. This report describes the test equipment used, the test procedure followed and gives the results of the tests.

1.0 INTRODUCTION

The five cells were tested together in a simulated rack. The assembly was tested to IEEE 344/1/ and IEEE 501/2/ Specifications. Date of test, specimen description, test facility name and location, test data and test temperature, humidity and pressure are recorded on each of the response spectrum curves. These curves also show the conditions of the test, the type of analysis, the accelerometers used, the direction of the test, and the axis analysed. All tests were analysed using 5% damping and the maximum shock spectrum. The tests performed were tri-axial tests as defined in IEEE 344. The shaker inputs were pseudo-random with a duration of 30 s. All technical terms used in this report are defined by Harris/3/.

2.0 SAMPLES

The station cells supplied for testing were naturally aged for a period of 27 years. They were identified as follows:

Exide; Model EMP-13; Serial No 43, 10, 4, 3, 45

job	file	date	report no.
740624-268-450	824.46	December 11, 1984	84-428-P

3.0 TEST EQUIPMENT

3.1 Equipment Used

3.1.1 Shaker Control Equipment

1. MTS 436 control units
2. MTS 406.11 controllers
3. MTS hydraulic pumps
4. Ontario Hydro noise generators and filters
5. Ontario Hydro tri-axial shaker table.

3.1.2 Analysis

1. Columbia Model 9000 amplifiers and matching Wilcoxon M-408 accelerometers.

<u>Amplifier Serial No</u>	<u>Accelerometer Serial No</u>
368 1632	S893
368 1633	S297
368 1634	S901
368 1635	S369
368 1636	S753
368 1637	S754
369 1638	S756
369 1639	S757
369 1640	S759
369 1641	S760
369 1642	S761
369 1643	S771

2. SE tape recorder Model 7000A, Serial No 547.
3. Tektronix 5113 dual beam storage oscilloscope, KS3681.
4. Spectral Dynamics 13231 Shock Spectrum Analyser, Serial No 27.
5. Spectral Dynamics 13191 Transient Memory, Serial No 29.
6. Ontario Hydro transmissibility circuit.
7. Watanabe WX4400 X-Y Recorder, Serial No 83010070.
8. Hewlett-Packard 7046A X-Y1-Y2 Recorder, Serial No 1914A05842.
9. Spectral Dynamics 50121L Tracking Filter, Serial No 171.

10. Spectral Dynamics SD122L Tracking Filter, Serial No 370.
11. Honeywell 1858 oscillograph, Serial No 2649JF78.
12. Nicolet Scientific Corp, Model 660A Dual Channel FFT Analyzer, Serial No 9866226.
13. Hewlett-Packard Model 7470A Plotter, Serial No 2210A-12990.

3.1.3 Calibration Equipment

1. Bruel and Kjaer Type 3506, Serial No 877022 Accelerometer Calibration Set which includes Type 2626, Serial No 842947 and Type 83055, Serial No 858627, traceable to NBS.
2. General Radio 1557-A vibration calibrator, Serial No 2379.
3. Data Precision 2440 digital voltmeter, Serial No 5733, traceable to NBS.
4. Data Precision 248 digital voltmeter, Serial No 8583, traceable to NBS.

4.0 TESTS AND PROCEDURES

4.1 Calibration Procedure

Accelerometers and amplifiers are calibrated using the back-to-back calibration procedure. The reference accelerometer was mounted on the vibration calibrator with the Wilcoxon accelerometer. Using 100 Hz sine wave vibration of approximately 1 g, the sensitivity of the Columbia amplifiers was set to give 500 mV/g output. The outputs were measured using the digital voltmeter. By using the same voltmeter for both the reference and the Columbia amplifiers, slight differences in voltmeters need not be considered. Since the voltmeter measures true RMS voltages, the waveshapes of the 100 Hz signals were compared on the oscilloscope. This ensures that the signals are equivalent.

4.2 Test Setup and Procedures

The cells were mounted in a rack similar in design to the ones used in the Fitzpatrick NPP. All five cells were loaded and the current and voltage monitored by the Chemical Department/4/. The mounting arrangement is shown in Figure 01A. A test history is given in Table II.

4.3 Vibration Tests

The shaker consists of random generators and hydraulic actuators which are capable of driving the shaker in three directions simultaneously. The shaker has the following limitation in each axis:

Displacement limit	152 mm
Velocity limit	820 m/s
Acceleration limit	4 g (no load)
Acceleration limit	1.6 g (fully loaded)
Maximum load	2000 kg

Simultaneous random inputs were applied in three axes and the coherence between axes was negligible. The vibration levels in the two horizontal and vertical directions were individually controlled to nominally give similar levels. These levels were set by adjusting a "span" potentiometer. The span setting used is of no significance in itself except equivalent span settings nominally indicate equivalent vibration levels. The vibration is never the same from one test to the next since a different random signal is used for each test.

5.0 RESULTS

The test results are given in Figures 01B through 06. The batteries had a minimum standard ZPA for each direction as shown in Table I. A table of ZPA's and equivalent span levels is given in Table III.

CONCLUSIONS

The five batteries tested experienced no structural or electrical damage as a result of the tests.

Approved:

Submitted:

G.J. Clarke *inc*
Manager
Mechanical Research Dept

G.D. Paulsen *AAE*
Technologist
Mechanical Testing and
Development Section

D.A. Black
Engineer
Mechanical Testing and
Development Section

GDP:DAB:sf

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TABLE I
TEST RESULTS

<u>Cell</u>	<u>Direction</u>	<u>ZPA</u>
43, 10, 4, 3, 45	X - Base	1.1
	Y - Base	2.17
	Z - Base	1.26
	X - Top	1.31
	Y - Top	0.8
	Z - Top	1.22

TABLE II
TEST HISTORY

<u>Date</u>	<u>Time</u>	<u>Run</u>	<u>Span</u>	<u>Comments</u>
July 26/84	3:03	1	4	
	3:04	2	5	
	3:06	3	6	
	3:08	4	7	No failure

TABLE III
SPAN VS ZPA

<u>Direction</u>	<u>Span</u>	<u>Average ZPA</u>
X	7	1.31
	6	1.11
	5	0.86
	4	0.75
	3	0.63
Y	7	1.91
	6	1.46
	5	0.90
	4	0.72
	3	0.55
Z	7	1.47
	6	1.31
	5	1.02
	4	0.86
	3	0.62

FIGURE 01A

THE FIVE EXIDE, MODEL EMP-13 BATTERIES WERE MOUNTED TO THE TRI-AXIAL SHAKER TABLE AS SHOWN. ACCELEROMETERS WERE MOUNTED ON THE MOUNTING PLATES AND ON THE CELL TERMINAL FOR THE TEST. THE ACCELEROMETER DIRECTIONS ARE AS SHOWN.

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4

TEST ITEM

Station Cells & Rack, Exide, Model EMP-13, Serial 43,10,4,3,45

PARTICULARS

July 26/84, Time 3:08, Temp('C) 23, Humidity(%) 55, Press (kPa) 100,
Graph 5260

SPECIFICATIONS

Specs IEEE 501, Conditions operating : 1 hour rate, span 7

ANALYSIS

Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis X,
Shaker tri-axial, ZPA=1.1g

ACCELEROMETER

Wilcoxon, Serial S297, Range dB49, Location base-mounting plate,
Channel 1

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TEST ITEM

Station Cells & Rack, Exide, Model EMP-13, Serial 43,10,4,3,45

PARTICULARS

July 26/84, Time 3:08, Temp('C) 23, Humidity(%) 55, Press (kPa)100,
Graph 5261

SPECIFICATIONS

Specs IEEE 501, Conditions operating : 1 hour rate, span 7

ANALYSIS

Type Maximax, Damping (%)5, B.W. = 1/12 Octaves, Axis Y,
Shaker tri-axial, ZPA=2.17g

ACCELEROMETER

Wilcoxon, Serial S761, Range dB49, Location base-mounting plate,
Channel 2

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TEST ITEM

Station Cells & Rack, Exide, Model EMP-13, Serial 43.10.4.3.45

PARTICULARS

July 26/84, Time 3:08, Temp('C) 23, Humidity(%) 55, Press (kPa) 100,
Graph 5262

SPECIFICATIONS

Specs IEEE 501, Conditions operating ; 1 hour rate, span 7

ANALYSIS

Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Z,
Shaker tri-axial, ZPA=1.26g

ACCELEROMETER

Wilcoxon, Serial S759, Range dB49, Location base-mounting plate,
Channel 3

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RESPONSE SPECTRUM

FIGURE 04

TEST ITEM

Station Cells & Rack, Exide, Model EMP-13, Serial 43,10,4,3,45

PARTICULARS

July 26/84, Time 3:08, Temp('C) 23, Humidity(%) 55, Press (kPa)100,
Graph 5263

SPECIFICATIONS

Specs IEEE 501, Conditions operating : 1 hour rate, span 7

ANALYSIS

Type Maximax, Damping (%)5, B.W. = 1/12 Octaves, Axis X,
Shaker tri-axial, ZPA=1.31g

ACCELEROMETER

Wilcoxon, Serial S901, Range dB49, Location top-cell terminal,
Channel 4

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TEST ITEM

Station Cells & Rack, Exide, Model EMP-13, Serial 43,10,4,3,45

PARTICULARS

July 26/84, Time 3:08, Temp('C) 23, Humidity(%) 55, Press (kPa)100,
Graph 5264

SPECIFICATIONS

Specs IEEE 501, Conditions operating : 1 hour rate, span 7

ANALYSIS

Type Maximax, Damping (%)5, B.W. = 1/12 Octaves, Axis Y,
Shaker tri-axial, ZPA=.8g

ACCELEROMETER

Wilcoxon, Serial S757, Range dB49, Location top-cell terminal,
Channel 5

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RESPONSE SPECTRUM

FIGURE 06

TEST ITEM

Station Cells & Rack, Exide, Model EMP-13, Serial 43,10,4,3,45

PARTICULARS

July 26/84, Time 3:08, Temp(°C) 23, Humidity(%) 55, Press (kPa) 100, Graph 5263

SPECIFICATIONS

Specs IEEE 501, Conditions operating: 1 hour rate, span 7

ANALYSIS

Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Z, Shaker tri-axial, ZPA=1.22g

ACCELEROMETER

Wilcoxon, Serial S369, Range dB49, Location top-cell terminal, Channel 6

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CANADA
Attn: G. F. Lynch

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Montreal, Quebec H3H 1P9
CANADA
Attn: S. Nish

Atomic Energy Research Establishment
Building 47, Division M.D.D.
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WEST GERMANY
Attn: R. Schemmel

Bundesanstalt fur Materialprufung
Unter den Eichen 87
D-1000 Berlin 45
WEST GERMANY
Attn: K. Wundrich

CEA/CEN-FAR
Departement de Surete Nucleaire
Service d'Analyse Fonctionnelle
B.P. 6
92260 Fontenay-aux-Roses
FRANCE
Attn: M. Le Meur
J. Henry

CERN
Laboratoire 1
CH-1211 Geneve 23
SWITZERLAND
Attn: H. Schonbacher

Canada Wire and Cable Limited
Power & Control Products Division
22 Commercial Road
Toronto, Ontario
CANADA M4G 1Z4
Attn: Z. S. Paniri

Centro Elettrotecnico
Sperimentale Italiano
Research and Development
Via Rubattino 54
20134 Milan,
ITALY
Attn: Carlo Masetti

Commissariat a l'Energie Atomique
ORIS/LABRA
BP N° 21
91190 Gif-Sur-Yvette
FRANCE
Attn: G. Gaussens
J. Chenion
F. Carlin

Commissariat a l'Energie Atomique
CEN Cadarache DRE/STRE
BP N° 1
13115 Saint Paul Lez Durance
FRANCE
Attn: J. Campan

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MEXICO
Attn: P. G. Murga

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Paris, FRANCE
Attn: H. Herouard
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Attn: J. Roubault
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FRANCE
Attn: G. Chauvin
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Hiratsuka Wire Works
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Health & Safety Executive
Thames House North
Milbank
London SW1P 4QJ
ENGLAND
Attn: W. W. Ascroft-Hutton

ITT Cannon Electric Canada
Four Cannon Court
Whitby, Ontario L1N 5V8
CANADA
Attn: B. D. Vallillee

Imatran Voima Oy
Electrotechn. Department
P.O. Box 138
SF-00101 Helsinki 10
FINLAND
Attn: B. Regnell
K. Koskinen

Institute of Radiation Protection
Department of Reactor Safety
P.O. Box 268
00101 Helsinki 10
FINLAND
Attn: L. Reiman

Instituto de Desarrollo y Diseno
Ingar - Santa Fe
Avellaneda 3657
C.C. 34B
3000 Santa Fe
REPUBLICA ARGENTINA
Attn: N. Labath

Japan Atomic Energy Research Institute
Takasaki Radiation Chemistry
Research Establishment
Watanuki-machi
Takasaki, Gunma-ken
JAPAN
Attn: N. Tamura
K. Yoshida
T. Seguchi

Japan Atomic Energy Research Institute
Tokai-Mura
Naka-Gun
Ibaraki-Ken
319-11
JAPAN
Attn: Y. Koizumi

Japan Atomic Energy Research Institute
Osaka Laboratory for Radiation Chemistry
25-1 Mii-Minami machi,
Neyagawa-shi
Osaka 572
JAPAN
Attn: Y. Nakase

Kalle Niederlassung der Hoechst AG
Postfach 3540
6200 Wiesbaden 1,
WEST GERMANY
Biebrich
Attn: Dr. H. Wilski

Kraftwerk Union AG
Department R361
Hammerbacherstrasse 12 + 14
D-8524 Erlangen
WEST GERMANY
Attn: I. Terry

Kraftwerk Union AG
Section R541
Postfach: 1240
D-8757 Karlstein
WEST GERMANY
Attn: W. Siegler

Kraftwerk Union AG
Hammerbacherstrasse 12 + 14
Postfach: 3220
D-8520 Erlangen
WEST GERMANY
Attn: W. Morell

Motor Columbus
Parkstrasse 27
CH-5401
Baden
SWITZERLAND
Attn: H. Fuchs

National Nuclear Corporation
Cambridge Road
Whetstone
Leicester LE8 3LH
ENGLAND
Attn: A. D. Hayward
J. V. Tindale

NOK AG Baden
Beznau Nuclear Power Plant
CH-5312 Doettingen
SWITZERLAND
Attn: O. Tatti

Norsk Kabelfabrik
3000 Drammen
NORWAY
Attn: C. T. Jacobsen

Nuclear Power Engineering Test Center
6-2, Toranomon, 3-Chome
Minato-ku
No. 2 Akiyana Building
Tokyo 105
JAPAN
Attn: K. Takumi

Ontario Hydro
700 University Avenue
Toronto, Ontario M5G 1X6
CANADA
Attn: R. Wong
B. Kukreti

Oy Stromberg Ab
Helsinki Works
Box 118
FI-00101 Helsinki 10
FINLAND
Attn: P. Paloniemi

Radiation Center of
Osaka Prefecture
Radiation Application-
Physics Division
Shinke-Cho, Sakai
Osaka, 593, JAPAN
Attn: S. Okamoto

Rappinl
ENEA-PEC
Via Arcoveggio 56/23
Bologna
ITALY
Attn: Ing. Ruggero

Rheinisch-Westfallscher
Technischer Überwachungs-Verein e.V.
Postfach 10 32 61
D-4300 Essen 1
WEST GERMANY
Attn: R. Sartori

Sydkraft
Southern Sweden Power Supply
21701 Malmo
SWEDEN
Attn: O. Grondalen

Technical University Munich
Institut für Radiochemie
D-8046 Garching
WEST GERMANY
Attn: Dr. H. Heusinger

UKAEA
Materials Development Division
Building 47
AERE Harwell
OXON OX11 0RA
ENGLAND
Attn: D. C. Phillips

United Kingdom Atomic Energy Authority
Safety & Reliability Directorate
Wigshaw Lane
Culcheth
Warrington WA3 4NE
ENGLAND
Attn: M. A. H. G. Alderson

Waseda University
Department of Electrical Engineering
4-1 Ohkubo-3, Shinjuku-ku
Tokyo
JAPAN
Attn: K. Yahagi

1800	R. L. Schwoebel
1810	R. G. Kepler
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8024	M. A. Pound
3141	C. M. Ostrander (5)
3151	W. L. Garner

NRC FORM 335 (2-84) NRCM 1102 3201, 3202		U.S. NUCLEAR REGULATORY COMMISSION		1 REPORT NUMBER (Assigned by TIDC add Vol No if any) NUREG/CR-4097 SAND84-2630	
BIBLIOGRAPHIC DATA SHEET					
SEE INSTRUCTIONS ON THE REVERSE					
2 TITLE AND SUBTITLE Test Series 4: Seismic-Fragility Tests of Naturally-Aged Exide EMP-13 Battery Cells			3 LEAVE BLANK		
5 AUTHOR(S) Lloyd L. Bonzon Donald B. Hente			4 DATE REPORT COMPLETED MONTH: April YEAR: 1985		
			6 DATE REPORT ISSUED MONTH: April YEAR: 1985		
			8 PROJECT TASK WORK UNIT NUMBER		
			9 FIN OR GRANT NUMBER A-1051		
7 PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code) Qualification Methodology Assessment Division 6446 Sandia National Laboratories P.O. Box 5800 Albuquerque, NM 87185			11a TYPE OF REPORT b PERIOD COVERED (Inclusive dates)		
10 SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code) Division of Engineering Technology Office of Nuclear Regulatory Research U.S. Nuclear Regulatory Commission Washington, DC 20555			12 SUPPLEMENTARY NOTES		
13 ABSTRACT (200 words or less) <p>This report, the fourth in a test series of an extensive seismic research program, covers the testing of 27-year old lead-antimony Exide EMP-13 cells from the recently decommissioned Shippingport Atomic Power Station. The Exide cells were tested in two configurations using a triaxial shake table: single-cell tests, rigidly mounted; and multicell (five-cell) tests, mounted in a typical battery rack.</p> <p>A total of nine electrically active cells was used in the two different cell configurations. None of the nine cells failed during the actual seismic tests when a range of ZPAs up to 1.5 g was imposed. Subsequent discharge capacity tests of five of the cells showed, however, that none of the cells could deliver the accepted standard of 80% of their rated electrical capacity for 3 hours. In fact, none of the 5 cells could deliver more than a 33% capacity. Two of the seismically tested cells and one untested, low capacity cell were disassembled for examination and metallurgical analyses. The inspection showed the cells to be in poor condition. The negative plates in the vicinity of the bus connections were extremely weak, the positive buses were corroded and brittle, negative and positive active material utilization was extremely uneven, and corrosion products littered the cells.</p>					
14 DOCUMENT ANALYSIS -- KEYWORDS/DESCRIPTORS b IDENTIFIERS/OPEN ENDED TERMS				15 AVAILABILITY STATEMENT Unlimited	
				16 SECURITY CLASSIFICATION (This page) Unclassified (This report) Unclassified	
				17 NUMBER OF PAGES	
				18 PRICE	