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Seismic-Fragility Tests of New and Accelerated-Aged Class 1E Battery Cells

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U. S. NUCLEAR REGULATORY COMMISSION

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SEISMIC-FRAGILITY TESTS OF NEW AND ACCELERATED-AGED
CLASS 1E BATTERY CELLS

January 1987

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Operated by
Sandia Corporation
for the
U.S. Department of Energy

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Work Performed Under Sandia Contract No. 96-9358

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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.
- "Program to Analyze the Failure Mode of Lead-Acid Batteries," D. Zuckerbrod, Westinghouse R&D Center. Prepared for Sandia National Laboratories under contract No. 25-0448, SAND86-7080, NUREG/CR-4533, March 1986.
- "Age-Related Degradation of Naturally-Aged Class 1E Battery Cells," SAND84-2632, NUREG/CR-4099, Sandia National Laboratories, Albuquerque, New Mexico, April 1986.
- "Comparison of Naturally-Aged and Accelerated-Aged Class 1E Battery Cells: An Evaluation of the Aging Method", Sandia National Laboratories, Albuquerque, New Mexico. (To be published.)

ABSTRACT

The seismic-fragility response of naturally-aged nuclear station safety-related batteries is of interest for two reasons: (1) to determine actual failure modes and thresholds and (2) to determine the validity of using the electrical capacity of individual cells as an indicator of the potential survivability of a battery given a seismic event. Prior reports in this series discussed the seismic-fragility tests and results for three specific naturally-aged cell types: 12-year old NCX-2250, 10-year old LCU-13, and 10-year old FHC-19.

This report focuses on the complementary approach, namely, the seismic-fragility response of accelerated-aged batteries. Of particular interest is the degree to which such approaches accurately reproduce the actual failure modes and thresholds. In these tests the significant aging effects observed, in terms of seismic survivability, were: embrittlement of cell cases, positive bus material and positive plate grids; and excessive sulphation of positive plate active material causing hardening and expansion of positive plates. The IEEE Standard 535 accelerated aging method successfully reproduced seismically significant aging effects in new cells but accelerated grid embrittlement an estimated five years beyond the conditional age of other components.

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FOREWORD AND ACKNOWLEDGMENTS

This work was performed at the Ontario Hydro Research Center, Toronto, Ontario, Canada, under Sandia National Laboratories (SNL) contract 96-9358. It covers the period from October 1, 1983, through June 30, 1986. The SNL technical project monitor is Lloyd L. Bonzon.

The overall development and execution of this program was carried out by Mr. J. S. Schendel of the Electrical Design Department. Dr. James W. Tulk of the Applied Structural and Solid Mechanics Section, Mechanical Research Department, coordinated the research activities. Mr. W. John Janis, Chemical Research Department, performed the battery testing and the chemical analyses of the components of the battery cells.

Messrs. D. A. Black and G. D. Paulsen of the Mechanical Testing and Development Section, Mechanical Research Department, provided expertise in seismic testing.

EXECUTIVE SUMMARY

Sandia National Laboratories is currently under contract to the United States Nuclear Regulatory Commission to study the degradation and failure modes of Class 1E, safety-related, equipment used in nuclear power stations. One aspect of the effort is the interest in the significance of aging and the subsequent survivability of stationary emergency power batteries when exposed to a simulated seismic event.

The list of "Related Publications in This Series" (page ii) is indicative of the overall program goals:

- To determine seismic failure modes and thresholds, primarily using naturally-aged cells.
- To select the dominant aging mechanism(s) through this testing experience, other test experience, and expert evaluations.
- 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 compare dominant failure modes in both cases.
- To identify appropriate accelerated aging methodologies for the dominant failure mode(s).
- To demonstrate those accelerated aging methodologies through a specific demonstration test program.
- To make final recommendations for appropriate accelerated-aging methodology(ies) for nuclear station batteries.
- To develop in situ testing methods which can predict the remaining age and seismic "tolerance" of batteries.

Prior reports in this series discussed the seismic-fragility tests and results for three specific naturally-aged lead-calcium cell types: 12-year old NCX-2250, 10-year old LCU-13, and 10-year old FHC-19. Because of Canadian interests, and their sponsorship, results for 13-year old Gould FKR-25 cells (lead-antimony) are also included. Finally, 23-year old Exide EMP-13 cells (lead-antimony) made available from the Shippingport Nuclear Station were also tested and evaluated under this program. The result is a broad range of battery coverage: age, type and manufacturer.

This report focuses on the complementary approach, namely the seismic-fragility response of accelerated-aged

batteries. Of particular interest is the degree to which such approaches accurately reproduce the actual failure modes and thresholds. In these tests the significant aging effects observed, in terms of seismic survivability, were: embrittlement of cell cases, positive bus material and positive plate grids; and excessive sulphation of positive plate active material causing hardening and expansion of positive plates. The IEEE Standard 535 accelerated aging method successfully reproduced seismically significant aging effects in new cells but accelerated grid embrittlement an estimated five years beyond the conditional age of other components.

The specifics of the tests must be assessed on an individual basis to determine their relevance to any other application.

1. 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 potential survivability of a battery if subjected to a seismic event.

The complement is the seismic-fragility response of accelerated-aged batteries. Of particular interest is the degree to which such approaches accurately reproduce the actual failure modes and thresholds that would be experienced in normal service.

1.2 Historical and Programmatic Perspective*

The concern over the seismic susceptibility of nuclear station safety-related batteries originated with a number of battery problems that had been reported in Licensee Event Reports (LERs).^{2-8*} Although these were not solely or specifically related to seismic concerns, following the problems reported at the Connecticut Yankee Station⁸ 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

2. 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 with naturally-aged test results 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 may lead to a predictive technique to determine "end-of-qualified" life of batteries.

Prior reports in this series (see "Related Publications in this Series") discussed the seismic-fragility tests and results for three specific (lead-calcium) naturally-aged cell types: 12-year old NCX-2250, 10-year old LCU-13, and 10-year old FHC-19. Because of Canadian interests, and their sponsorship, results for 13-year old Gould FKR-25

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

cells (lead-antimony) are also included. Finally, 23-year old Exide EMP-13 cells (lead-antimony) made available from the Shippingport Nuclear Station were also tested and evaluated under this program. The result is a broad range of battery coverage: age, type and manufacturer.

This report focuses on the complementary approach, namely, the seismic-fragility response of accelerated-aged batteries. Of particular interest is the degree to which such approaches accurately reproduce the actual failure modes and thresholds. In these tests the significant aging effects observed, in terms of seismic survivability, were: embrittlement of cell cases, positive bus material and positive plate grids; and excessive sulphation of positive plate active material causing hardening and expansion of positive plates. The IEEE Standard 535 accelerated aging method successfully reproduced seismically significant aging effects in new cells but accelerated grid embrittlement an estimated five years beyond the conditional age of other components.

3. REPORT FORMAT

Ontario Hydro staff performed all testing and analyses; their results and conclusions are attached as Appendices to this report.

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

4. SUMMARY OF TESTS PERFORMED AND RESULTS

4.1 Cells Included in Test Series

All cells obtained for the artificial aging program were new and of lead-calcium type. That is, all grid materials contained a small amount of calcium, less than 0.1%, alloyed with lead. Twelve C&D LC-13, twelve Exide FHC-19 and eight Gould NCS-2250 cells were obtained for test.

4.2 Accelerated Aging Procedure

After initial capacity tests, eight LC-13, eight FHC-19 and four NCX-2250 cells were placed on float charge at 2.22 volts per cell in a constant temperature enclosure and maintained at $71^{\circ} \pm 1^{\circ}\text{C}$ for 100, 100 and 120 days, respectively. Based on accelerated thermal aging factors for the conditions of test as outlined in IEEE Standard 535-1979 (Reference 14) this procedure effectively aged LC-13 and FHC-19 cells 10 years and NCX-2250 cells 12 years.

To guard against case sagging due to the relatively high cell temperatures, the test cells were grouped in sets of four and supported on all sides by wooden spacers held in place by metal bands. As a precaution against spills, the cell sides and bottoms were wrapped in plastic sheeting.

Thermocouples in silicone fluid filled tubes inserted in the vent caps of the test cells were used to monitor the internal temperatures of all cells. At least once a week the cell temperatures were recorded for a period of 1 h using a 24-point chart recorder. The enclosure air temperature was monitored continuously on a seven-day, circular chart.

4.3 Postaging Observations

Eight FHC-19 cells (serial numbers 55001, 55002, 55005, 55010, 55007 and 56502 to 56504), eight LC-13 cells (serial numbers 3871CA6, 3871CA1 to 3871CA3, 3868CA6, 4056CA16, 4056CA1, 4056CA25), and four NCX-2250 cells (serial numbers 17102, 17093, 17099, 17091) were artificially aged at 71°C for the equivalent of 10-12 years, depending upon cell type, without incident. The only outward signs of the aging process were cell cover sagging (with consequent distortion of post and filler cap holes), discoloration of cell covers as a result of acid mist escaping around poorly fitting filler caps, and positive bus darkening as a result of acid attack.

Four of each of the FHC-19 and LC-13 cells were set aside on flat charge after accelerated aging pending further aging at a later date. For the remaining artificially aged cells, it was noted that the discharge capacities of FHC-19 and NCX-2250 cells increased an average of 17 and 26 percent over their respective preaged values while the average capacity of the LC-13 cells dropped approximately 10 percent. In terms of 3-hour discharge capacity, all of these aged cells exceeded the 80 percent requirement for acceptance, (the minimum capacity being 98 percent) and were therefore judged suitable for seismic testing.

4.4 Seismic Test Results

No sudden loss of cell potential was observed for any of the new cells during seismic testing up to the capacity of the shaker table and at no time did the cell potential under load fall below 1.75 VPC. However, the potential for NCX-2250 cell 17096 gradually dropped 0.06 V while under test (initial 1.81 V, final 1.75 V) indicating that minor damage to cell internals had occurred.

For the artificially-aged cells, various responses were obtained. FHC-19 cells 55010 and 55001, and NCX-2250 cell 17091 failed to maintain adequate cell potentials during seismic testing while LC-13 cells 3871CA6 and 3871CA3 survived seismic stresses up to the capacity of the shaker table. The case failure of NCX-2250 cell 17091 indicated that the accelerated aging process had made the NCX cases too brittle to withstand seismic testing. Therefore further seismic testing of aged NCX cells was suspended. Remaining NCX cells were fitted with new cases and maintained on float charge pending further testing or disposal.

4.5 Postseismic Tests

Each type of new cell showed a loss of reserve capacity at the 3 h rate due to the effects of seismic testing. The average losses were 5%, 11%, and 17% for FHC-19, LC-13 and NCX-2250 cells, respectively, with two of the three NCX-2250 cells failing to meet the acceptance criterion of 80% capacity immediately after seismic testing.

Both of the accelerated-aged LC-13 cells which survived seismic testing showed acceptable discharge capacity after the tests (93% average), while the only other cell capable of being discharged following seismic testing (FHC-19 cell 55010) showed an extremely poor capacity (16%).

4.6 Cell Inspection (Positive Internals)

The positive internals of all new seismically tested cells were in relatively good condition, discounting minor hardening (FHC-19), pitting (LC-13) and cracking (NCX-2250) of positive plate active material. Most of the plate damage during seismic testing of these cells occurred at the bottoms of the outer-most positive plates, presumably because the outer plates are not held as rigidly as inner ones.

Artificially-aged LC-13 cell positive plates were in good condition and exhibited minor cracking. Aged NCX-2250 positive plates showed the same delamination of active material seen in seismically tested, unaged cells, but more plates were affected. In addition, positive NCX plates were warped and hardened due to expansion of active material. FHC positive plates suffered more damage from accelerated aging than did the other cell types. The grids became brittle and active material was hardened, cracked and disconnected from the grids.

As expected, seismically tested, artificially aged cells were more damaged than their "seismically tested only" or

"artificially aged only" counterparts. Most FHC-19 positive plates failed catastrophically, suffered grid breakages, material fallout and plate bridging. NCX 2250 cells showed high fallout of hardened material, especially in outer-most positive plates, and LC-13 cells, while not as damaged as the other cell types, showed cracked active material and high fallout from outer-most positive plates.

4.7 Cell Inspection (Negative Internals)

Overall, negative plates and grids from seismically tested cells were in good condition, although negative active material in the outer-most negative plates of FHC-19 cells was contracted and cracked, and a few small blisters were observed on some LC-13 negative plates. Accelerated aging did not affect negative plates significantly and the plates obtained from aged-only and seismically tested, artificially aged cells resembled those obtained from unaged cells.

4.8 Cell Inspection (bus, hangers, and posts)

Positive buses, hangers and posts of new cells seismically tested only were in good condition. All were ductile, resisted hammering and were not corroded.

In contrast, artificially aged FHC-19 and NCX-2250 cells contained relatively brittle, easily sheared positive bus material. Similar LC-13 bus material was firm but moderately brittle, with some parts breaking rather than bending when hit with a hammer.

Positive bus material was definitely the weakest link in the post/bus/hanger assembly. All posts and most hangers were relatively ductile and not easily fractured.

Corrosion penetration into positive buses, as indicated by discoloration, was observed for all cell types, but varied from 10-90% of the cross-sectional area of the bus, depending on cell type; the cross-sections were measured at the line of fracture due to hammering.

Material from the negative bus, hanger and post was in better condition than the corresponding positive material presumably because chemical attack on the negative electrodes was minimal.

5. CONCLUSIONS

In tests to date, loss of capacity of artificially aged cells during or after seismic testing has been due to: (1) fracture of embrittled cases; (2) fracture of embrittled and

corroded positive bus and grid material and; (3) significant loss of sulfate-hardened positive plate active material. In addition, weakening of case/cover bonds due to high temperature aging indirectly contributed to all failure mechanisms by allowing easy separation of cover, and therefore relatively unrestricted motion between cases and internal components.

Based on previous data for naturally-aged cells (see the list of Related Publications in this series), cells which underwent accelerated aging exhibited more seismically significant damage than cells which were aged naturally. In addition to the positive bus embrittlement and sulphation of positive plates observed in naturally aged cells, the artificially aged cells exhibited brittle positive grids, significant active material fallout and case fragility.

The aging test procedure used in this study (Reference 14) is in wide use in North America and is generally viewed as an acceptable method to accelerate age related effects in lead-acid cells. In regard to seismically significant aging effects, this view is largely supported by the present work, except in the areas of case and positive grid embrittlement, where simulated aging results in more damage than natural aging.

For most seismic testing purposes, case embrittlement during accelerated aging is not a concern as cell internals can be easily housed in new cases. However, grid embrittlement is more serious as it is an internal effect which appears to age the cell more than anticipated on the basis of the standard aging factors of Reference 14.

In summary:

1. Formation of brittle positive bus and grid material in artificially aged cells is a significant aging effect which can lead to abrupt failure during a seismic event or reduced capacity after the event.
2. Excessive sulphation leading to plate hardening and expansion is also an aging effect of significance, but of less importance than the formation of brittle materials. Sulphation reduces postseismic discharge capacity, increases self discharge and aids active material fallout by decreasing active material flexibility and therefore resistance to seismic stresses.
3. Case embrittlement can occur during accelerated aging at 71°C and can lead to catastrophic failure during seismic testing. Cells aged for studies of internal component

aging should be fitted with new cases prior to seismic testing to avoid case effects.

4. Embrittlement and/or cracking of positive buses and grids was aided by corrosion along large grain boundaries in all cell types tested.
5. The accelerated aging method of Reference 14 provides an acceptable procedure for reproducing seismically significant, age related effects in lead-acid, emergency power battery cells. However, accelerated grid embrittlement results in faster than anticipated aging of the cell during to aging procedure at 71°C.
6. On the basis of qualitative cell postmortem observations for naturally and artificially aged cells tested in the SNL/Ontario Hydro program, it is estimated that the grid embrittlement during accelerated aging added the equivalent of five years to the conditional age of the test cells as given by the aging factors of Reference 14.

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APPENDIX A

SEISMIC TESTING OF ARTIFICIALLY-AGED
NUCLEAR POWER STATION BATTERIES

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SEISMIC TESTING OF ARTIFICIALLY AGED NUCLEAR POWER STATION BATTERIES

W.J. Janis

ABSTRACT

Cell inspection data for Gould NCX-2250, C&D LC-13 and Exide FHC-19 cells, artificially aged at 71°C for the equivalent of 10-12 years and subjected to seismic fragility testing, is summarized and reviewed. The significant aging effects observed, in terms of seismic survivability, were: embrittlement of cell cases, positive bus material and positive plate grids; and excessive sulphation of positive plate active material causing hardening and expansion of positive plates. The IEEE Standard 535 accelerated aging method successfully reproduced seismically significant aging effects in new cells but accelerated grid embrittlement an estimated five years beyond the conditional age of other components.

1. 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 fragility tests of naturally and artificially aged, lead-acid cells.

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740632-150-950	832.31x	May 23, 1986	86-97-CON

Following guidelines set out by SNL, a research program was developed by the Electrical Design Department (Design and Development Division - Generation), and the Mechanical and Chemical Research Departments (Research Division). In this program the performance and condition of new, aged and artificially aged cells were monitored before, during and after shaker table testing under simulated earthquake conditions.

This report presents a summary of cell condition data for three types of cell tested under the SNL program and examines potential degradation mechanisms for cells subjected to artificial aging and/or seismic stresses. Similar work with naturally aged cells is summarized in Ontario Hydro Research Division Report C85-88 (Reference 1).

2. TEST CELLS

All cells obtained for the artificial aging program were new and of lead-calcium type. That is, all grid materials contained a small amount of calcium, less than 0.1%, alloyed with lead. Twelve C&D LC-13, twelve Exide FHC-19 and eight Gould NCX-2250 cells were obtained for test; cell specifications supplied by the manufacturers are given in Appendix I.

3. EXPERIMENTAL

3.1 Cell Inspection and Conditioning

On delivery to Ontario Hydro Research Division (OHRD) the new lead-acid cells were inspected for any damage which might have been induced by handling during transportation. They were then given a conditioning charge, followed by a pre-seismic discharge capacity check at the 3 h (hour) discharge rate.

The conditioning charge was carried out at a nominal float voltage of 2.25 volts per cell (VPC) and was continued for at least 24 h prior to the capacity check. When not required for capacity, seismic or 71°C aging tests, the cells were kept on charge to maintain a specific gravity average of 1.220. The 1.220 average gravity, although lower than the 1.250 recommended by manufacturers, was adopted as a standard to conform with that used in previous tests of naturally aged cells of similar type/2-5/.

3.2 Initial Capacity Tests

Following inspection, charge equalization, and a minimum of 24-h float charging, all cells were discharged to a final cell potential of 1.75 VPC at the manufacturers' specified 3 h rates of 246 A, 354 A and 585 A, for LC-13, FHC-19 and NCX-2250 cells,

Figure 1. Cells Set Up for Accelerated Aging Tests

Figure 2. Thermocouple Placement in LC-13 Cells

respectively. These discharge tests provided benchmark capacity data for cells selected for accelerated aging and/or seismic testing and were carried out per Reference 6 as follows:

1. Three or four cells and a resistance load were connected in series and the cells discharged at a constant current following the procedure outlined in OHRD Report No E76-85-H/7/.
2. Cell potentials, discharge currents and temperatures were monitored during the discharge test. The data were recorded at 5-minute intervals.
3. Discharged cells were recharged in series at a potential of 2.30 V for approximately 70 h, followed by sustained float charging at 2.25 V.

3.3 Accelerated Aging

After initial capacity tests, eight LC-13, eight FHC-19 and four NCX-2250 cells were placed on float charge at 2.22 VPC in a 1.8 m x 3.7 m x 2.4 m high constant temperature enclosure and maintained at $71^{\circ} \pm 1^{\circ}\text{C}$ for 100, 100 and 120 days, respectively. Based on accelerated thermal aging factors for the conditions of test as outlined in IEEE Standard 535-1979 (Reference 8) this procedure effectively aged LC-13 and FHC-19 cells 10 years and NCX-2250 cells 12 years.

To guard against case sagging due to the relatively high cell temperatures, the test cells were grouped in sets of four and supported on all sides by wooden spacers held in place by metal bands. As a precaution against spills, the cell sides and bottoms were wrapped in plastic sheeting. Cells being prepared for aging are shown in Figure 1. The cardboard at the top of the Figure is an air deflector which helped to maintain uniform cell temperatures by deflecting hot air from the heater fans down toward the cells.

Thermocouples in silicone fluid filled tubes inserted in the vent caps of the test cells were used to monitor the internal temperatures of all cells. At least once a week the cell temperatures were recorded for a period of 1 h using a 24-point chart recorder. The enclosure air temperature was monitored continuously on a seven-day, circular chart. A close-up view of thermocouple placement is given in Figure 2.

3.4 Cell Discharge During Seismic Testing

Three new cells of each type (LC-13, FHC-19, NCX-2250), two artificially aged LC-13 and FHC-19 cells and one artificially

aged NCX-2250 cell 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 (989 A) was used for the NCX-2250 cell and a 1 h discharge rate (480 A and 679 A for LC-13 and FHC-19, respectively) was used for the other 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 or 1.0 h rate, depending on cell type.

3.5 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 that used for the initial capacity tests of Section 3.2.

3.6 Cell Disassembly and Material Studies

Three LC-13, three NCX-2250 and four FHC-19 cells were disassembled following seismic (and/or aging) and capacity testing to identify changes in internal components resulting from accelerated aging, seismic testing or both. A photographic record of cell components was obtained and representative photographs are discussed in Section 4.5.

4. RESULTS AND DISCUSSION

4.1 Cell Inspection and Conditioning

All new LC-13, FHC-19 and NCX-2250 cells were received at OHRD in good condition. All electrolyte levels were within the manufacturers' specified limits and no sediments were observed. Specific gravities averaged 1.21 for both NCX-2250 and FHC-19 cells and 1.22 for LC-13 cells. The specific gravities of all cells were up to the required 1.220 average in less than 70 h of conditioning at 2.25-2.30 VPC at 25°C.

4.2 Initial Capacity Tests

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

TABLE I

INITIAL CAPACITY TEST DATA FOR LC-13 CELLS

CELL NUMBER	25°C GRAVITY PRIOR TO DISCHARGE	OPEN CIRCUIT POTENTIAL (VOLTS)	TIME TO 1.75 VPC AT 3 h RATE OF 246 A (min)	PERCENT RATED CAPACITY AT 3 h RATE
3871CA6	1.216	2.05	200	111
3871CA1	1.216	2.05	200	111
3871CA2	1.216	2.05	194	108
3871CA3	1.216	2.05	194	108
3869CA4	1.221	2.06	200	111
3871CA4	1.219	2.05	194	108
3869CA2	1.223	2.05	200	111
3869CA6	1.219	2.05	200	111
3869CA3	1.221	2.06	194	108
4056CA16	1.220	2.06	220	122
4056CA1	1.220	2.05	214	119
4056CA25	1.220	2.06	205	114

TABLE II

INITIAL CAPACITY TEST DATA FOR FHC-19 CELLS

CELL NUMBER	25°C GRAVITY PRIOR TO DISCHARGE	OPEN CIRCUIT POTENTIAL (VOLTS)	TIME TO 1.75 VPC AT 3 h RATE OF 354 A (min)	PERCENT RATED CAPACITY AT 3 h RATE
55001	1.218	2.05	153	85
55002	1.225	2.10	166	92
55003	1.215	2.05	171	95
55005	1.215	2.05	166	92
55006	1.221	2.10	153	85
55007	1.220	2.06	148	82
55010	1.220	2.05	153	85
55011	1.215	2.05	149	83
55012	1.219	2.06	144	80
56502	1.222	2.05	176	98
56503	1.222	2.04	166	92
56504	1.222	2.05	176	98

TABLE III

INITIAL CAPACITY TEST DATA FOR NCX-2250 CELLS

CELL NUMBER	25°C GRAVITY PRIOR TO DISCHARGE	OPEN CIRCUIT POTENTIAL (VOLTS)	TIME TO 1.75 VPC AT 3 h RATE OF 585 A (min)	PERCENT RATED CAPACITY AT 3 h RATE
17102	1.212	2.09	164	91
17093	1.212	2.09	164	91
17099	1.212	2.10	153	85
17091	1.212	2.09	146	81
17103	1.213	2.08	175	97
17098	1.212	2.07	175	97
17089	1.213	2.07	164	91
17096	1.211	2.07	158	88

4.3 Accelerated Aging

Eight FHC-19 cells (serial numbers 55001, 55002, 55005, 55010, 55007 and 56502 to 56504), eight LC-13 cells (serial numbers 3871CA6, 3871CA1 to 3871CA3, 3868CA6, 4056CA16, 4056CA1, 4056CA25), and four NCX-2250 cells (serial numbers 17102, 17093, 17099, 17091) were artificially aged at 71°C for the equivalent of 10-12 years, depending upon cell type, without incident. The only outward signs of the aging process were cell cover sagging (with consequent distortion of post and filler cap holes), discolouration of cell covers as a result of acid mist escaping around poorly fitting filler caps, and positive bus darkening as a result of acid attack.

Four of each of the FHC-19 and LC-13 cells were set aside on float charge after accelerated aging pending further aging at a later date. Cell condition data for the remaining artificially aged cells is presented in the columns labeled: "Condition After Aging" (Columns 5-7) in Data Summary Tables IV-VI. It is noted that the discharge capacities of FHC-19 and NCX-2250 cells increased an average of 17 and 26 percent over their respective pre-aged values while the average capacity of the LC-13 cells dropped approximately 10 percent.

In terms of 3-hour discharge capacity, all the aged cells of Tables IV-VI exceeded the 80 percent requirement for acceptance. (the minimum capacity being 98 percent) and were therefore judged suitable for seismic testing.

TABLE VI
DATA SUMMARY - NCX--2250 CELLS

CELL CATEGORY AND NUMBER	CONDITION AS RECEIVED			CONDITION AFTER AGING			CONDITION DURING/AFTER SEISMIC TESTING					
	25°C GRAVITY PRIOR TO DISCHARGE	OPEN CIRCUIT POTENTIAL (VOLTS)	PERCENT RATED 3 h CAPACITY	25°C GRAVITY PRIOR TO DISCHARGE	OPEN CIRCUIT POTENTIAL (VOLTS)	PERCENT RATED 3 h CAPACITY*	25°C GRAV- ITY PRIOR TO SEISMIC TEST	OPEN CIRCUIT POTENTIAL (VOLTS)	CELL POTENTIAL UNDER LOAD		PASS/FALL AT 1 h DISCHARGE RATE	PERCENT RATED 3 h CAPACITY AFTER TEST
									BEFORE TESTING (VOLTS)	AFTER TESTING (VOLTS)		
Seismically Tested Only												
17103	1.213	2.08	97	-	-	- (a)	1.209	2.09	1.88	1.89	Pass	-
17096	1.211	2.07	88	-	-	- (b)	1.203	2.05	1.80	1.83	Pass	71
17089	1.213	2.07	91	-	-	-	1.203	2.06	1.81	1.75	Pass	81
							1.210	2.07	1.83	1.83	Pass	72
Artificially Aged 12 Yrs Only												
17102	1.212	2.09	91	1.225	2.07	113	-	-	-	-	-	-
17093	1.212	2.09	91	1.220	2.06	113	-	-	-	-	-	-
17099	1.212	2.10	85	1.225	2.07	113	-	-	-	-	-	-
Artificially Aged 12 Yrs and Seismic- ally Tested												
17091	1.212	2.09	80	1.220	2.07	113	1.215	2.02	1.81	0.0 (Open Circuit)	Fail	N/A** (Case Broken)

** NA = Not Available
 * (a) = Single cell test
 (b) = Multi-cell test

TABLE V
DATA SUMMARY - LC-13 CELLS

CELL CATEGORY AND NUMBER	CONDITION AS RECEIVED			CONDITION AFTER AGING			CONDITION DURING/AFTER SEISMIC TESTING					
	25°C GRAVITY PRIOR TO DISCHARGE	OPEN CIRCUIT POTENTIAL (VOLTS)	PERCENT RATED 3 h CAPACITY	25°C GRAVITY PRIOR TO DISCHARGE	OPEN CIRCUIT POTENTIAL (VOLTS)	PERCENT RATED 3 h CAPACITY*	25°C GRAV- ITY PRIOR TO SEISMIC TEST	OPEN CIRCUIT POTENTIAL (VOLTS)	CELL POTENTIAL UNDER LOAD		PASS/FAIL AT 1 h DISCHARGE RATE	PERCENT RATED 3 h CAPACITY AFTER TEST
									BEFORE TESTING (VOLTS)	AFTER TESTING (VOLTS)		
Seismically Tested Only												
3871 CA4	1.219	2.05	108	-	-	-	1.208	2.06	1.86	1.86	Pass	101
3869 CA6	1.219	2.05	111	-	-	- (a)	1.206	2.08	1.84	1.85	Pass	-
				-	-	- (b)	1.205	2.07	1.84	1.85	Pass	95
3869 CA3	1.221	2.06	108	-	-	- (a)	1.209	2.08	1.84	1.86	Pass	-
				-	-	- (b)	1.208	2.06	1.85	1.82**	Pass	92
Artificially Aged 10 Yrs Only												
3869 CA2	1.223	2.05	111	1.215	2.09	104	-	-	-	-	-	-
3871 CA1	1.216	2.05	111	1.210	2.09	101	-	-	-	-	-	-
Artificially Aged 10 Yrs and Seismic- ally Tested												
3871 CA6	1.216	2.05	111	1.210	2.09	98	1.215	2.04	1.83	1.86	Pass	89
3871 CA3	1.216	2.05	108	1.215	2.09	98	1.210	2.04	1.85	1.85	Pass	97

* (a) = Single cell test

(b) = Multi-cell test

** Potential prior to an external connection failure during span 7 test

TABLE IV
DATA SUMMARY - FHC-19 CELLS

CELL CATEGORY AND NUMBER	CONDITION AS RECEIVED			CONDITION AFTER AGING			CONDITION DURING/AFTER SEISMIC TESTING					
	25°C GRAVITY PRIOR TO DISCHARGE	OPEN CIRCUIT POTENTIAL (VOLTS)	PERCENT RATED 3 h CAPACITY	25°C GRAVITY PRIOR TO DISCHARGE	OPEN CIRCUIT POTENTIAL (VOLTS)	PERCENT RATED 3 h CAPACITY*	25°C GRAV- ITY PRIOR TO SEISMIC TEST	OPEN CIRCUIT POTENTIAL (VOLTS)	CELL POTENTIAL UNDER LOAD		PASS/FAIL AT 1 h DISCHARGE RATE	PERCENT RATED 3 h CAPACITY AFTER TEST
Seismically Tested Only												
55003	1.215	2.05	95	-	-	- (a)	1.213	2.07	1.80	1.81	Pass	-
55006	1.221	2.10	85	-	-	- (b)	1.208	2.05	1.82	1.80	Pass	80
55011	1.215	2.05	83	-	-	- (a)	1.215	2.05	1.80	1.82	Pass	90
				-	-	- (b)	1.215	2.08	1.81	1.82	Pass	-
							1.210	2.06	1.83	1.82	Pass	80
Artificially Aged 10 Yrs Only												
55002	1.225	2.10	92	1.225	2.06	104	-	-	-	-	-	-
55005	1.215	2.05	92	1.210	2.06	108	-	-	-	-	-	-
Artificially Aged 10 Yrs and Seismic- ally Tested												
55001	1.218	2.05	85	1.215	2.06	102	1.210	2.06	1.80	1.47	Fail	-
55010	1.220	2.05	85	1.215	2.06	99	1.215	2.06	1.75	1.65	Fail	16

* (a) = Single cell test
 (b) = Multi-cell test

4.4 Seismic Testing

Discharge capacity data for cells during and after seismic testing is summarized in columns 8 to 13 of Tables IV-VI, and presented in more detail in Appendix II. Details of the seismic testing procedure and fragility level assessment are presented in OHRD reports 85-67, 85-68 and 85-69 (References 9-11).

The data for new and artificially aged cells are discussed below.

4.4.1 New Cells

No sudden loss of cell potential was observed for any of the new cells during seismic testing up to the capacity of the shaker table and at no time did the cell potential under load fall below 1.75 VPC. However, the potential for NCX-2250 cell 17096 gradually dropped 0.06 V while under test (initial 1.81 V, final 1.75 V) indicating that minor damage to cell internals had occurred.

As indicated in Tables IV-VI, all new cells tested passed seismic testing.

4.4.2 Artificially Aged Cells

FHC-19 cells 55010 and 55001, and NCX-2250 cell 17091 failed to maintain adequate cell potentials during seismic testing while LC-13 cells 3871CA6 and 3871CA3 survived seismic stresses up to the capacity of the shaker table. Observations made during the three cell failures are listed in Table VII.

The case failure of NCX-2250 cell 17091 indicated that the accelerated aging process had made the NCX cases too brittle to withstand seismic testing. Therefore further seismic testing of aged NCX cells was suspended. Remaining NCX cells were fitted with new cases and maintained on float charge pending further testing or disposal.

4.5 Post Seismic Capacity Tests

Post-test discharge capacities were determined for eleven cells which survived seismic testing and one cell which failed. The data are compared to pre-seismic values in Tables IV-VI, columns 2, 7 and 13, and discussed below.

TABLE VII

TEST OBSERVATIONS FOR SEISMICALLY FAILED CELLS

CELL	SEISMIC INTENSITY LEVEL*	OBSERVATIONS
FHC-19 55010	7	One top corner of case cracked and one 3cmx3cm chip broken from another top case corner.
	10	The cell failed electrically- potential dropped to 1.65 V. Positive plate grids cracked-active material lost from the grids. Plate stack shorted due to fallout.
FHC-19 55001	5	One top case corner cracked.
	7	All four top case corners cracked.
	10	Cell failed electrically- potential dropped to 1.60 V. Case cracks propagated and widened. All positive plates were broken horizontally in the lower third plate area. All positive plate connectors fractured at bus. Positive active material lost from grids
NCX-2250 17091	5	Case lid lifted.
	10	Case destroyed prior to electrical failure. Positive bus severely cracked. Severe fallout and loss of electrolyte.

* Maximum level corresponds to a per-axis acceleration maximum of 1.6 to 4 g, depending on table load. See references 9-11 for details.

4.5.1 New Cells

Each type of cell showed a loss of reserve capacity at the 3 h rate due to the effects of seismic testing. The average losses were 5%, 11%, and 17% for FHC-19, LC-13 and NCX-2250 cells, respectively, with two of the three NCX-2250 cells failing to meet the acceptance criterion of 80% capacity immediately after seismic testing.

The high capacity losses of NCX cells relative to those of FHC and LC cells may indicate that the rather large NCX-2250 cell is more sensitive to seismic damage than are the other cells of approximately one-half the size.

4.5.2 Artificially Aged Cells

Both of the LC-13 cells which survived seismic testing showed acceptable discharge capacity after the tests (93% average), while the only other cell capable of being discharged following seismic testing (FHC-19 cell 55010) showed an extremely poor capacity (16%).

Although the sample size is small, the data indicate that the artificially aged 10-year old LC-13 cells are more robust than the equivalently aged FHC-19 cells. Comparisons between NCX-2250 and other cell types are not appropriate as the NCX cells were artificially aged 12 years, and the one cell tested sustained non-representative shock loading after case failure because the failure released the cell from its mounting jig.

4.6 Cell Disassembly and Inspection

The 13 cells listed in Table VIII were disassembled and inspected for internal damage. Detailed inspection data is presented in Appendix III, summarized in Tables IX to XIII, and discussed below.

4.6.1 Positive Plates and Grids

As shown in Table IX, the positive internals of all new seismically tested cells were in relatively good condition, discounting minor hardening (FHC-19), pitting (LC-13) and cracking (NCX-2250) of positive plate active material. Most of the plate damage during seismic testing of these cells occurred at the bottoms of the outer-most positive plates, presumably because the outer plates are not held as rigidly as inner ones.

TABLE VIII
CELLS DISASSEMBLED AFTER ACCELERATED
AGING AND/OR SEISMIC FRAGILITY TESTS

CELL TYPE	CELL NUMBER	TEST TYPE*		
		AGING ONLY	SEISMIC ONLY	AGING AND SEISMIC
LC-13	3871CA4	-	X	-
LC-13	3869CA6	-	X	-
LC-13	3871CA1	X	-	-
LC-13	3871CA6	-	-	X
FHC-19	55006	-	X	-
FHC-19	55011	-	X	-
FHC-19	55002	X	-	-
FHC-19	55001	-	-	X
FHC-19	55010	-	-	X
NCX-2250	17103	-	X	-
NCX-2250	17096	-	X	-
NCX-2250	17102	X	-	-
NCX-2250	17091	-	-	X

* X = Tested, - = Not Tested.

Photographs of typical positive plates and grids are shown as Figures 3 to 5 of Appendix III for FHC-19, LC-13 and NCX-2250 cells, respectively. Outer-most positive plate damage observed for NCX cell 17103 (loss of thin sheets of active material) is shown in Figure 6 of Appendix III.

Artificially aged LC-13 cell positive plates were in good condition and exhibited minor cracking. Aged NCX-2250 positive plates showed the same delamination of active material seen in seismically tested, unaged cells, but more plates were affected. In addition, positive NCX plates were warped and hardened due to expansion of active material.

FHC positive plates suffered more damage from accelerated aging than did the other cell types. The grids became brittle and active material was hardened, cracked and disconnected from the grids. Figure 7 of Appendix III shows a brittle outer positive plate which broke apart when the cell casing was removed.

TABLE IX

POSITIVE PLATE CONDITION SUMMARY
SEISMIC FRAGILITY TESTING PROGRAM*

Characteristic		FHC-19 CELLS			LC-13 CELLS			NCX-2250 CELLS		
		A	S	A+S	A	S	A+S	A	S	A+S
Detrimental Active Material Conditions	(1) Brittle	X	-	X	-	-	-	X	-	X
	(2) Hard	X	X ¹	X	-	-	-	-	-	X
	(3) Pitted	-	-	-	X	X ¹	-	-	-	-
	(4) Cracked	X	-	X	X	-	X ¹	-	X ¹	X
	(5) Obstructed	-	-	-	-	-	-	-	-	-
	(6) Disconnected	X	-	X ³	-	-	X	X ²	X ²	X
Detrimental Grid Conditions	(1) Warped	-	-	-	-	-	-	X ⁴	-	X
	(2) Corroded	-	-	-	-	-	-	-	-	-
	(3) Flaking	-	-	-	-	-	-	-	-	-
	(4) Brittle/Broken	X	-	X	-	-	X ⁵	-	-	-
Active Material Shore Hardness ⁶		65	60	65	50	50	50	55	55	60
Plate Growth Or (Shrinkage) Per Plate	(1) Thickness (mm)	(1)	0.0	(1)	(1)	0.0	0.0	0.0	0.0	(0.1)
	(2) Width (cm)	0.4	0.0	0.4	0.3	0.0	0.3	0.6	0.0	1.0
	(3) Height (cm)	0.4	0.0	0.4	0.0	0.0	0.1	0.4	0.0	0.7

- ¹ Minor Damage.
² Thin Sheets.
³ Chunks.
⁴ Maximum deflection = 6.3 mm.
⁵ Physical damage resulted from cell internals moving relative to cell case.
⁶ Type A-2 Hardness Meter as used for ASTM D2240-81.

LEGEND*

X = Condition is Present
A = Artificially Aged Only
S = Seismically Tested Only
A+S = Artificially Aged and
Seismically Tested

TABLE X
 NEGATIVE PLATE CONDITION SUMMARY
SEISMIC FRAGILITY TESTING PROGRAM

Characteristic		FHC-19 CELLS			LC-13 CELLS			NCX-2250 CELLS		
		A	S	A+S	A	S	A+S	A	S	A+S
Detrimental Active Material Conditions	(1) Erupted	-	-	-	-	-	-	-	-	-
	(2) Blistered	X	-	-	X	X	-	-	-	-
	(3) Contracted/ Cracked	-	X	X ¹	-	X	-	-	-	-
	(4) Obstructed	-	-	-	-	-	-	-	-	-
	(5) Disconnected	X ²	X	X ¹	-	-	-	-	-	-
Detrimental Grid Conditions	(1) Fractured	-	-	-	-	-	-	-	-	-
	(2) Warped	-	-	-	-	-	X ¹	-	-	-
	(3) Corroded	-	-	-	-	-	-	-	-	-
	(4) Brittle	-	-	-	-	-	-	-	-	-
Plate Growth Or (Shrinkage)	(1) Thickness (mm)	(1)	(1)	(1)	0.0	0.0	0.0	0.0	0.0	0.0
	(2) Width (cm)	(0.2)	(0.0)	(0.2)	(0.5)	(0.5)	(0.5)	(0.1)	(0.1)	(0.1)
	(3) Height (cm)	(0.3)	(0.4)	(0.3)	(0.1)	0.0	(0.1)	0.0	0.0	0.0

¹ Minor Damage.

² Material may have been dislodged during cell disassembly.

LEGEND*

X = Condition is Present
 A = Artificially Aged Only
 S = Seismically Tested Only
 A+S = Artificially Aged and
 Seismically Tested

TABLE XI

POSITIVE BUS, HANGERS AND POSTS-CONDITION SUMMARY
SEISMIC FRAGILITY TESTING PROGRAM

Characteristic		FHC-19 CELLS			LC-13 CELLS			NCX-2250 CELLS		
		A	S	A+S	A	S	A+S	A	S	A+S
Detrimental Conditions	(1) Fractured	X ¹	-	X ²	-	-	-	-	-	X ⁴
	(3) Brittle ¹	X	-	X	X ³	-	X ³	X	-	X
	(4) Corroded ^{1, 2}	X	-	-	X	-	X	X	-	X
	(5) Flaking ²	-	-	-	-	-	-	-	-	-
Corrosion penetration through bus cross-section (% of conduction area discoloured)		90	<10	90	30	<10	30	80	<10	>90

- ¹ Bus Material.
² Bus and hanger material.
³ Minor Damage.
⁴ Cell abused during transport.

LEGEND*

X = Condition is Present
 A = Artificially Aged Only
 S = Seismically Tested Only
 A+S = Artificially Aged and Seismically Tested

TABLE XII
 NEGATIVE BUS, HANGERS AND POSTS-CONDITION SUMMARY
 SEISMIC FRAGILITY TESTING PROGRAM

Characteristic	FHC-19 CELLS			LC-13 CELLS			NCX-2250 CELLS		
	A	S	A+S	A	S	A+S	A	S	A+S
Detrimental Conditions	(1) Fractured	- ¹	-	-	-	-	-	-	-
	(3) Brittle	- ¹	-	-	-	-	-	-	- ²
	(4) Corroded	-	-	-	-	-	-	-	-
	(5) Flaking	-	-	-	-	-	-	-	-
Corrosion penetration through bus cross-section (% of conduction area discoloured)		<5	<5	<5	<5	<5	<5	<5	<5

- ¹ One negative post de-laminated when hammered.
² Bus sheared when hammered.

LEGEND*

X = Condition is Present
 A = Artificially Aged Only
 S = Seismically Tested Only
 A+S = Artificially Aged and Seismically Tested

TABLE XIII

MISCELLANEOUS CONDITIONS SUMMARY
SEISMIC FRAGILITY TESTING PROGRAM

Characteristic	FHC-19 CELLS			LC-13 CELLS			NCX-2250 CELLS		
	A	S	A+S	A	S	A+S	A	S	A+S
Age (years)	10	0	10	10	0	10	12	0	12
Sediment (mm)	<3	<3	>25	<3	<3	5	5	5	5
Nature of sediment (Footnote number)	-	-	- ¹	-	- ¹	- ²	-	- ³	- ³
Case Embrittlement	X	X ⁴	X	-	-	-	X	X ⁴	X
Possible Bridging ¹	-	-	-	-	-	-	-	-	-
(1) Top	-	-	-	-	-	-	-	-	-
(2) Bottom	-	-	X	-	-	-	-	-	X
Spacers or end stops dislodged	-	-	-	-	-	X	-	-	-

- ¹ Dark brown powder with some chunks.
² Dark brown powder with some flakes.
³ Dark brown chunks with some powder.
⁴ Un-aged cell cases brittle relative to LC-13 cases.

LEGEND*

X = Condition is Present
A = Artificially Aged Only
S = Seismically Tested Only
A+S = Artificially Aged and
Seismically Tested

As expected, seismically tested, artificially aged cells were more damaged than their "seismically tested only" or "artificially aged only" counterparts. Most FHC-19 positive plates failed catastrophically, suffered grid breakages, material fallout and plate bridging. NCX-2250 cells showed high fallout of hardened material, especially in outer-most positive plates, and LC-13 cells, while not as damaged as the other cell types, showed cracked active material and high fallout from outer-most positive plates. Figures 8-13 of Appendix III show, respectively: (1) a typical FHC-19 plate remnant, (2) FHC-19 sediment attached to the bottom of a cracked plate, (3) an NCX-2250 outer-most positive plate almost devoid of active material, (4) an intact inner positive NCX plate, (5) a damaged outer LC-13 positive plate, and (6) an intact inner LC-13 positive plate exhibiting some damage at the bottom due to motion of the plate stack relative to the case.

4.6.2 Negative Plates and Grids

Overall, negative plates and grids from seismically tested cells were in good condition, although negative active material in the outer-most negative plates of FHC-19 cells was contracted and cracked, and a few small blisters were observed on some LC-13 negative plates.

Typical* LC-13, FHC-19 and NCX-2250 negative plates are shown in Figures 14-16 of Appendix III, and LC-13 plate blisters and FHC-19 active material cracking are shown in Figures 17 and 18 of Appendix III.

Accelerated aging did not affect negative plates significantly and the plates obtained from aged-only and seismically tested, artificially aged cells resembled those obtained from unaged cells.

One LC-13 cell showed evidence of negative plate warping (Figure 19 of Appendix III) but the warping was considered to be the result of the plate manufacturing procedure, as these plates were otherwise without defect.

4.6.3 Positive Bus, Hangers and Posts

Positive buses, hangers and posts of new cells seismically tested only were in good condition. All were ductile, resisted hammering

* Negative plate discolouration, evident at the top of Figure 15, is due to partial loss of electrolyte and is not typical of filled cells.

and were not corroded. Post/bus assemblies for NCX, FHC and LC cells after hammering are shown in Figures 20-22, respectively, of Appendix III.

Artificially aged FHC-19 and NCX-2250 cells contained relatively brittle, easily sheared bus material. Similar LC-13 bus material was firm but moderately brittle, with some parts breaking rather than bending when hit with a hammer. Typical fractures induced in the buses of FHC-19, NCX-2250 and LC-13 cells are shown in Figures 23-25, respectively, of Appendix III.

As expected, seismically tested, artificially aged cell positive buses, hangers and posts resembled those of the artificially aged only cells and the brittleness of the buses decreased in the order: FHC-19, NCX-2250 and LC-13.

Figures 26-28 of Appendix III show the results of hammering positive buses of FHC-19, NCX-2250 and LC-13 cells, respectively. It is noted that very little non-corroded (metal coloured) bus is visible in the fracture areas of FHC-19 or NCX-2250 cells, while the fracture area of the LC-13 bus shows relatively less corrosion.

Corrosion penetration into buses, as indicated by discoloration, was observed for all cell types, but varied from 10-90% of the cross-section area of the bus, depending on cell type. The cross-sections were measured at the line of fracture due to hammering, as indicated schematically in Figure 29.

Bus material was definitely the weakest link in the post/bus/hanger assembly. All posts and most hangers were relatively ductile and not fractured easily.

4.6.4 Negative Bus, Hangers and Posts

Negative bus, hanger and post material was in better condition than the corresponding positive material in terms of the characteristics listed in Tables XI and XII. While some brittle material was detected it was not easily fractured, presumably because chemical attack on the negative electrodes was minimal.

The ductility of negative buses is documented in Figures 30 and 31 of Appendix III, which show artificially aged and seismically tested FHC-19 and LC-13 buses, respectively, after severe hammering.

4.6.5 Miscellaneous

In most cases, the sediment levels for the cells listed in Table XIII are relatively low, even for artificially aged test cells.

SIDE
VIEW

TOP
VIEW

FIGURE 29
SCHEMATIC POST, BUS AND HANGER
ASSEMBLY SHOWING FRACTURE INDUCED BY
HAMMERING POSTS

However, after seismic testing the sediments often contained large chunks of hardened positive plate active material.

New LC-13 cases were more flexible than those of either FHC-19 or NCX-2250 cells. In a flexibility test, 40 cm x 30 cm coupons of LC-13 case material could be bent through 90 degrees without breaking, when a torque was applied at one end of the long axis of the coupon and the other end was held fixed. Similar coupons for both NCX and FHC cells shattered when bent through 40-45 degrees under similar conditions.

An increase in case brittleness due to accelerated aging at 71°C was observed for all cell types, and the covers of all artificially aged cells were warped by the heating process.

A metallurgical examination of bus materials from new and artificially aged cells indicated that brittle areas were formed of large grain boundary material which had been corroded by the electrolyte. As previously observed with naturally aged cells, large grain positive bus material is particularly susceptible to corrosion.

4.7 Cell Degradation Due to Accelerated Aging

In tests to date, loss of capacity of artificially aged cells during or after seismic testing has been due to: (1) fracture of embrittled cases; (2) fracture of embrittled and corroded positive bus and grid material and; (3) significant loss of sulfate-hardened positive plate active material. In addition, weakening of case/cover bonds due to high temperature aging indirectly contributed to all failure mechanisms by allowing easy separation of covers, and therefore relatively unrestricted motion between cases and internal components.

Based on previous data for naturally aged cells (Reference 1), cells which underwent accelerated aging exhibited more seismically significant damage than cells which were aged naturally. In addition to the positive bus embrittlement and sulphation of positive plates observed in naturally aged cells, the artificially aged cells exhibited brittle positive grids, significant active material fallout and case fragility.

The aging test procedure used in this study (Reference 8) is in wide use in North America and is generally viewed as an acceptable method to accelerate age related effects in lead-acid cells. In regard to seismically significant aging effects, this view is largely supported by the present work, except in the areas of case and positive grid embrittlement, where simulated aging results in more damage than natural aging.

For most seismic testing purposes, case embrittlement during accelerated aging is not a concern as cell internals can be easily housed in new cases. However, grid embrittlement is more serious as it is an internal effect which appears to age the cell more than anticipated on the basis of the standard aging factors of Reference 8.

5. CONCLUSIONS

1. Formation of brittle positive bus and grid material in artificially aged cells is a significant aging effect which can lead to abrupt failure during a seismic event or reduced capacity after the event.
2. Excessive sulphation leading to plate hardening and expansion is also an aging effect of significance, but of less importance than the formation of brittle materials. Sulphation reduces post-seismic discharge capacity, increases self discharge and aids active material fallout by decreasing active material flexibility and therefore resistance to seismic stresses.
3. Case embrittlement can occur during accelerated aging at 71°C and can lead to catastrophic failure during seismic testing. Cells aged for studies of internal component aging should be fitted with new cases prior to seismic testing to avoid case effects.
4. Embrittlement and/or cracking of positive buses and grids was aided by corrosion along large grain boundaries in all cell types tested.
5. The accelerated aging method of Reference 8 provides an acceptable procedure for reproducing seismically significant, age related effects in lead-acid, emergency power battery cells. However, accelerated grid embrittlement results in faster than anticipated aging of the cell during the aging procedure at 71°C.
6. On the basis of qualitative cell post-mortem observations for naturally and artificially aged cells tested in the SNL/Ontario Hydro program, it is estimated that the grid embrittlement during accelerated aging added the equivalent of five years to the conditional age of the test cells as given by the aging factors of Reference 8.

6. RECOMMENDATIONS

1. As the presence of large grain material in positive buses may be related to industry-wide casting procedures, Manufacturers' quality assurance programs should include grain-size monitoring of bus structures, particularly post/bus and lug/bus connectors.
2. Further work is recommended on the propagation of corrosion along grain boundaries, with a view to developing better inhibitors or protective coatings for buses.
3. Manufacturers should consider case flexibility as a prime requirement of cell design, especially for cells to be used in earthquake sensitive areas. Consideration should also be given to plate spacing and cell geometry to take into account potential losses or obstruction of active material during seismic events.

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APPENDIX 1

TEST CELL SPECIFICATIONS - NCX-2250 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*
281	405	585	989	1336

* Calculated from manufacturer's data.

(b) Dimensions

	Height (cm)	Width (cm)	Length (cm)	Thickness (cm)
Overall	57.2	36.9	37.0	--
Positive Plate	38.1	31.8	--	0.81
Negative Plate	38.1	31.8	--	0.55

APPENDIX I (cont'd)

(c) Materials

Container	styrene-acrylonitrile copolymer (jar) styrene-acrylonitrile-butadiene terpolymer (cover)
Separators	unspecified microporous material
Positive Plate active material retainers	fiberglass mat
Electrodes	lead-calcium grid (31 positive, 32 negative)
Posts and Buses ¹	2 positive posts, 2 negative posts, 3.8 cm x 3.8 cm each, attached to lead bus.
Electrolyte	1.215 specific gravity sulphuric acid (25°C)

¹ Note: Buses are sometimes referred to as straps.

APPENDIX 1 (Continued)

TEST CELL SPECIFICATIONS - LC-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
112	161	246	374	480

* Calculated from manufacturer's data.

(b) Dimensions

	Height (cm)	Width (cm)	Length (cm)	Thickness (cm)
Overall	57.5	35.9	19.4	--
Positive Plate	38.1	30.5	--	0.79
Negative Plate	38.1	30.5	--	0.53* 0.33**

* Inside negative

** Outside negative

(c) Materials

Container	Transparent Polycarbonate Case Opaque Thermoplastic Cover
Separators	unspecified microporous material
Positive Plate active material retainers	fiberglass mat
Electrodes	lead-calcium grid (6 positive, 7 negative)
Posts and Buses ¹	2 positive posts, 2 negative posts, 2.5 cm x 2.5 cm each, attached to to lead bus.
Electrolyte	1.210 specific gravity sulphuric acid (25°C)

¹ Note: Buses are sometimes referred to as straps.

APPENDIX 1 (Continued)

TEST CELL SPECIFICATIONS - FHC-19 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
168	244	354	551	679

(b) Dimensions

	Height (cm)	Width (cm)	Length (cm)	Thickness (cm)
Overall	57.7	36.8	22.9	--
Positive Plate	36.6	30.7	--	0.81
Negative Plate	36.6	30.7	--	0.61

APPENDIX I (cont'd)

(c) Materials

Container	styrene-acrylonitrile copolymer (jar) styrene butadiene copolymer (cover)
Separators	microporous rubber
Positive Plate active material retainers	fiberglass mat
Electrodes	lead-calcium grid (9 positive, 10 negative,)
Posts and buses ¹	2 positive posts, 2 negative posts, 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 II

(A) SEISMIC EVENT DISCHARGE DATA FOR FHC-19 CELLS

CELL NUMBER	SEISMIC EVENT DATA			CELL POTENTIAL DATA		
	EVENT	INTENSITY SETTING	RELATIVE START TIME (s)	AT START OF SEISMIC EVENT (V)	AT END OF SEISMIC EVENT (V)	DIFFERENCE (END-START) (mV)
55003 (single cell test) (multi- cell test)	1	3	0	1.80	1.81	10
	2	4	91	1.80	1.80	0
	3	5	147	1.81	1.81	0
	4	6	210	1.81	1.81	0
	5	7	280	1.81	1.81	0
	6	3	0	1.82	1.82	0
	7	4	85	1.81	1.81	0
	8	5	170	1.81	1.81	0
55006 (multi- cell test)	1	3	0	1.80	1.81	10
	2	4	85	1.81	1.81	0
	3	5	170	1.81	1.82	10
55011 (single cell test) (multi- cell test)	1	3	0	1.81	1.81	0
	2	4	110	1.82	1.82	0
	3	5	180	1.82	1.82	10
	4	6	310*	1.83	1.84	10
	5	7	405	1.82	1.82	0
	6	3	0	1.83	1.83	0
	7	4	85	1.83	1.82	-10
	8	5	170	1.81	1.82	10
55001 (single cell test)	1	3	0	1.80	1.79	-10
	2	5	35	1.81	1.80	-10
	3	7	80	1.75	1.78	30
	4	10	125	1.72	1.66	-60
55010 (single cell test)	1	3	0	1.75	1.75	0
	2	5	45	1.76	1.77	10
	3	7	95	1.76	1.75	-10
	4	10	135	1.73	1.65	-80

APPENDIX II (cont'd)

(B) SEISMIC EVENT DISCHARGE DATA FOR LC-13 CELLS

CELL NUMBER	SEISMIC EVENT DATA			CELL POTENTIAL DATA		
	EVENT	INTENSITY SETTING	RELATIVE START TIME (s)	AT START OF SEISMIC EVENT (V)	AT END OF SEISMIC EVENT (V)	DIFFERENCE (END-START) (mV)
3871CA4 (single cell test- split over two days)	1	3	0	1.84	1.87	30
	2	4	185	1.84	1.84	0
	3	5	270	1.84	1.77	-70
	4	6	355	1.85	1.98	130
	5	7	400	1.86	1.87	10
	6	7	0	1.85	1.83	-20
	7	10	60	1.82	1.84	20
3869CA6 (single cell test) (multi- cell test)	1	3	0	1.87	1.88	10
	2	3	120	1.84	1.85	10
	3	4	220	1.85	1.85	0
	4	5	260	1.85	1.85	0
	5	6	315	1.85	1.85	0
	6	7	395	1.85	1.85	0
	7	3	0	1.85	1.88	30
	8	4	185	1.86	1.85	-10
	9	5	270	1.85	1.85	0
	10	6	355	1.84	1.84	0
	11	7	400	1.84	1.82	0
3869CA3 (single cell test) (multi- cell test)	1	3	0	1.83	1.85	20
	2	4	60	1.86	1.86	0
	3	5	120	1.86	1.86	0
	4	6	165	1.86	1.86	0
	5	7	210	1.86	1.86	0
	6	3	0	1.86	1.89	30
	7	4	185	1.86	1.86	0
	8	5	270	1.86	1.86	0
	9	6	355	1.86	1.86	0
	10	7	400	1.86	1.85	-10

APPENDIX II (cont'd)

(B) SEISMIC EVENT DISCHARGE DATA FOR LC-13 CELLS (CONTINUED)

CELL NUMBER	SEISMIC EVENT DATA			CELL POTENTIAL DATA		
	EVENT	INTENSITY SETTING	RELATIVE START TIME (s)	AT START OF SEISMIC EVENT (V)	AT END OF SEISMIC EVENT (V)	DIFFERENCE (END-START) (mV)
3871CA6 (single cell test)	1	5	0	1.90	1.90	0
	2	7	50	1.87	1.86	-10
	3	10	110	1.87	1.86	-10
3871CA3 (single cell test)	1	3	0	1.85	1.85	0
	2	5	55	1.86	1.87	10
	3	7	105	1.87	1.87	0
	4	10	150	1.85	1.85	0

(C) SEISMIC EVENT DISCHARGE DATA FOR NCX-2250 CELLS

CELL NUMBER	SEISMIC EVENT DATA			CELL POTENTIAL DATA		
	EVENT	INTENSITY SETTING	RELATIVE START TIME (s)	AT START OF SEISMIC EVENT (V)	AT END OF SEISMIC EVENT (V)	DIFFERENCE (END-START) (mV)
17103 (single cell test)	1	3	0	1.88	1.88	0
	2	4	105	1.88	1.89	10
	3	5	200	1.89	1.89	0
	4	6	305	1.89	1.89	0
	5	7	410	1.89	1.89	0
	6	7	560	1.89	1.89	0
(multi- cell test)	7	3	0	1.81	1.82	10
	8	4	45	1.81	1.83	20
	9	5	115	1.82	1.81	-10
	10	6	180	1.81	1.80	-10
	11	7	290	1.79	1.83	40

APPENDIX II (cont'd)

(C) SEISMIC EVENT DISCHARGE DATA FOR NCX-2250 CELLS (CONTINUED)

CELL NUMBER	SEISMIC EVENT DATA			CELL POTENTIAL DATA		
	EVENT	INTENSITY SETTING	RELATIVE START TIME (s)	AT START OF SEISMIC EVENT (V)	AT END OF SEISMIC EVENT (V)	DIFFERENCE (END-START) (mV)
17096 (single cell test)	1	3	0	1.81	1.82	10
	2	4	40	1.82	1.82	0
	3	5	105	1.82	1.83	10
	4	6	150	1.83	1.83	0
	5	7	295	1.83	1.83	0
	6	3	0	1.83	1.84	10
	7	4	45	1.84	1.85	10
	8	5	115	1.85	1.84	-10
	9	6	180	1.84	1.84	0
	10	7	290	1.84	1.84	0
17089 (multi- cell test)	1	3	0	1.80	1.82	20
	2	4	45	1.82	1.83	10
	3	5	115	1.83	1.84	10
	4	6	180	1.83	1.84	10
	5	7	290	1.83	1.83	0
17091 (single cell test)	1	3	0	1.81	1.8	-10
	2	5	35	1.82	1.81	-10
	3	7	70	1.84	1.80	-40
	4	10	110	1.82	<1.71	>-110

APPENDIX III

DOCUMENTATION PHOTOGRAPHS

(TEXT FIGURES 3-28, 30 AND 31)

Figure 3

Figure 4

Figure 5

Figure 6

Figure 7

Figure 8

Figure 9

Figure 10

Figure 11

Figure 12

Figure 13

Figure 14

Figure 15

Figure 16

Figure 17

Figure 18

Figure 19

Figure 20

Figure 21

Figure 22

Figure 23

Figure 24

Figure 25

Figure 26

Figure 27

Figure 28

Figure 30

Figure 31

APPENDIX B

SEISMIC TESTING OF UNAGED
EXIDE STATION CELL

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**SEISMIC TESTING OF
UNAGED EXIDE STATION CELL**

D.A. Black and G.D. Paulsen

One unaged Exide station cell was seismically tested to IEEE Specifications. The purpose of these tests was to determine the cell's ability to withstand a seismic event. This report describes the test procedure followed, the test equipment used, and gives the results of the tests. This cell is a part of an ongoing program to determine the effects of a seismic event on new and aged cells.

1.0 INTRODUCTION

The Exide cell 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 analyzed using 5% damping and the maximax shock spectrum. The tests performed were tri-axial tests as defined in IEEE 344. All technical terms used in this report are defined by Harris/3/.

2.0 SAMPLE

The cell submitted for testing was identified as follows:

- 1) Station cell; Exide; Model FHC; Serial 55006; unaged.

job	file	date	report no.
740624-153-40150	824.46	June 9, 1986	86-120-CON

3.0 TEST EQUIPMENT

3.1 Equipment Used

All or part of the following equipment was used in the tests.

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 cell was mounted as shown in Figure 01A. The cell was held in the test jig by four corner clamps consisting of 1-1/2" rubber padded angle iron and 1/2" threaded rods. This setup insures minimum movement of the cell in the jig. Since the jig was originally designed for a larger cell, wood blocks were installed to insure a snug fit. Accelerometers were mounted on the base of the test jig as well as on one cell terminal. During the seismic tests the cells were loaded and each cell was monitored for voltage drop by Chemical Research/4/.

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 response spectra are given in Figures 01B through 03. The cell was tested once at span 7 and once at span 10. At span 7 some electrolyte spilled from the air vents. At span 10 the top corners cracked off and the top cover of the cell began to separate from the cell jar.

6.0 CONCLUSIONS

The cell was structurally damaged by the tests and some loss of electrolyte occurred.

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2. The Institute of Electrical and Electronic Engineers, Inc. IEEE 501. IEEE Recommended Practices for Seismic Qualification of Relays.
3. Harris, Cyril M., and Charles E. Crede. "Shock and Vibration Handbook." Second Edition. McGraw Hill Book Company. Toronto, 1976.
4. Janis, W.J. (Report to follow).

Figure 01A

The Cell was Typically Mounted to the Tri-Axial Table as Shown. Wood blocks were installed to ensure a snug fit. Accelerometer directions were as indicated.

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RESPONSE SPECTRUM

FIGURE 013

TEST ITEM

Station Cell, Exide, Model FHC, Serial 55006.

PARTICULARS

Sept 12/85, Time 1:51, Temp('C) 23, Humidity(X) 55, Press (kPa) 99.9,
Graph 5681

SPECIFICATIONS

Specs IEEE 501, Conditions 1.5 amp hour, span 10

ANALYSIS

Type Maximax, Damping (X) 5, B.W. = 1/12 Octaves, Axis X,
Shaker tri-axial, ZPA=2.41g

ACCELEROMETER

Wilcoxon, Serial 1213, Range dB48, Location mounting beams, TT 0143,
Channel 1

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TEST ITEM

Station Cell, Exida, Model FHC, Serial 55006,

PARTICULARS

Sept 12/85, Time 1:51, Temp('C) 23, Humidity(%) 55, Press (kPa) 99.9,
Graph 5682

SPECIFICATIONS

Specs IEEE 501, Conditions 1.5 amp hour, span 10

ANALYSIS

Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Y,
Shaker tri-axial, ZPA=1.94g

ACCELEROMETER

Wilcoxon, Serial 1214, Range dB48, Location mounting beams, TT 0143,
Channel 2

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RESPONSE SPECTRUM

FIGURE 03

TEST ITEM

Station Cell, Exide, Model FHC, Serial 55008.

PARTICULARS

Sept 12/85, Time 1:51, Temp('C) 23, Humidity(X) 55, Press (kPa) 99.9,
Graph 5883

SPECIFICATIONS

Specs IEEE 501, Conditions 1.5 amp hour, span 10

ANALYSIS

Type Maximax, Damping (X) 5, B.W. = 1/12 Octaves, Axis Z,
Shaker tri-axial, ZPA=1.94g

ACCELEROMETER

Wilcoxon, Serial S893, Range dB48, Location mounting beams, TT 0143,
Channel 3

APPENDIX C
SEISMIC TESTING OF UNAGED
C&D STATION CELL

D. A. Black
G. D. Paulsen
Ontario Hydro Research Center

**ontario hydro
research division**

TO: Mr. W.R. Collard
Manager
Electrical Design
Design & Dev - Generation

**SEISMIC TESTING OF
UNAGED C&D STATION CELL**

D.A. Black and G.D. Paulsen

One unaged C&D station cell was seismically tested to IEEE Specifications. The purpose of this test was to determine the cell's ability to withstand a seismic event. This report describes the test procedure followed, the test equipment used, and gives the results of the test. This cell is a part of an ongoing program to determine the effects of a seismic event on new and aged cells.

1.0 INTRODUCTION

The C&D cell 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 analyzed using 5% damping and the maximax shock spectrum. The tests performed were tri-axial tests as defined in IEEE 344. All technical terms used in this report are defined by Harris/3/.

2.0 SAMPLE

The sample submitted for testing was identified as follows:

Station cell; C&D; Model LC-13; Serial 3871 CA4; unaged.

job	file	date	report no.
740624-153-40150	824.46	June 9, 1986	86-118-CON

3.0 TEST EQUIPMENT

3.1 Equipment Used

All or part of the following equipment was used in the tests.

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 cell was mounted as shown in Figure 01A. The cell was held in the test jig by four corner clamps consisting of 1-1/2" rubber padded angle iron and 1/2" threaded rods. This setup insures minimum movement of the cells in the test jig. Since the jig was originally designed for a larger cell, wood blocks were installed to insure a snug fit. The accelerometers were mounted on the base of the test jig as well as on one cell terminal. During the seismic tests the cell was loaded and monitored for voltage drop by Chemical Research/4/.

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 03. The cell was shaken once at span 7 and once at span 10. The cell sustained no visible structural damage as a result of either of the tests.

6.0 CONCLUSIONS

The C&D cell survived the seismic testing with no visible structural damage.

Approved:

G.D. Clarke
Manager
Mechanical Research Dept

Submitted:

G.D. Paulsen
Technologist
Mechanical Testing and
Development Section

D.A. Black
Engineer
Mechanical Testing and
Development Section

GDP:DAB:sf

REFERENCES

1. The Institute of Electrical and Electronic Engineers Inc. IEEE 344. IEEE Recommended Practices for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations. New York. 1975.
2. The Institute of Electrical and Electronic Engineers, Inc. IEEE 501. IEEE Recommended Practices for Seismic Qualification of Relays.
3. Harris, Cyril M., and Charles E. Crede. "Shock and Vibration Handbook." Second Edition. McGraw Hill Book Company. Toronto, 1976.
4. Janis, W.J. (Report to follow).

Figure 01A

The Cell was Typically Mounted to the Tri-Axial Table as Shown. Wood blocks were installed to ensure a snug fit. Accelerometer directions were as indicated.

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

TEST ITEM

Station Cell. C & D. Model LC-13. Serial 3871 CA4.

PARTICULARS

Sept 12/85. Time 3:00. Temp(°C) 23. Humidity(%) 55. Press (kPa) 99.9.
Graph 5884

SPECIFICATIONS

Specs IEEE 501. Conditions 1.5 amp hour. span 10

ANALYSIS

Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis X.
Shaker tri-axial. ZPA=1.95g

ACCELEROMETER

Wilcoxon. Serial 1213. Range dB48. Location mounting beams. TT 0149.
Channel 1

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

RESPONSE SPECTRUM

FIGURE 02

TEST ITEM

Station Cell. C & D. Model LC-13. Serial 3871 CA4.

PARTICULARS

Sept 12/85. Time 3:00. Temp('C) 23. Humidity(%) 55. Press (kPa) 99.9.
Graph 5685

SPECIFICATIONS

Specs IEEE 501. Conditions 1.5 amp hour. span 10

ANALYSIS

Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis Y.
Shaker tri-axial. ZPA=1.98g

ACCELEROMETER

Wilcoxon. Serial 1214. Range dB48. Location mounting beams. TT 0149.
Channel 2

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

RESPONSE SPECTRUM

FIGURE 03

TEST ITEM

Station Cell, C & D, Model LC-13, Serial 3871 CA4.

PARTICULARS

Sept 12/85, Time 3:00, Temp('C) 23, Humidity(%) 55, Press (kPa) 99.9,
Graph 5686

SPECIFICATIONS

Specs IEEE 501, Conditions 1.5 amp hour, span 10

ANALYSIS

Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Z,
Shaker tri-axial, ZPA=1.94g

ACCELEROMETER

Wilcoxon, Serial S893, Range dB48, Location mounting beams, TT 0149,
Channel 3

APPENDIX D
SEISMIC TESTING OF ARTIFICIALLY-AGED
EXIDE STATION CELLS

D. A. Black
G. D. Paulsen
Ontario Hydro Research Center

**ontario hydro
research division**

Mr. W.R. Collard
Manager
Electrical Design
Design & Dev - Generation

SEISMIC TESTING OF
ARTIFICIALLY AGED EXIDE STATION CELLS

D.A. Black and G.D. Paulsen

Two Exide station cells were seismically tested to IEEE Specifications. These cells were artificially aged to 10 years to simulate ones now in use in generating stations in the United States. The purpose of these tests was to determine the cells' ability to withstand a seismic event. This report describes the test procedure followed, the test equipment used, and gives the results of the tests. These cells are a part of an on-going program to determine the effects of a seismic event on new and aged cells.

1.0 INTRODUCTION

The two Exide cells were 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 analyzed using 5% damping and the maximax shock spectrum. The tests performed were tri-axial tests as defined in IEEE 344. All technical terms used in this report are defined by Harris/3/.

2.0 SAMPLES

The two cells submitted for testing were identified as follows:

- 1) Station cell; Exide; Model FHC; Serial 55010.
- 2) Station Cell; Exide, Model FHC; Serial 55001.

Both cells were artificially aged by Chemical Research/4/.

job	file	date	report no.
740624-153-40150	824.46	June 9, 1986	86-116-CON

3.0 TEST EQUIPMENT

3.1 Equipment Used

All or part of the following equipment was used in the tests.

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 two cells were tested individually and mounted as shown in Figure 01A. The cells were held in the test jig by four corner clamps consisting of 1-1/2" rubber padded angle iron and 1/2" threaded rods. This setup insures minimum movement of the cells in the jig. Since the jig was initially designed for a larger cell, wood blocks were installed to insure a snug fit. Accelerometers were mounted on the base of the test jig as well as on one cell terminal. During the seismic tests the cells were loaded and each cell was monitored for voltage drop by Chemical Research.

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. In many cases, the accelerometer signals from the accelerometers located on the cell terminals were lost due to acid on the connectors. A complete test log is given in Table 1.

6.0 CONCLUSIONS

The Exide cells tested were damaged as indicated in Table 1.

Approved:

G.J. Clarke
Manager
Mechanical Research Dept

Submitted:

G.D. Paulsen
Technologist
Mechanical Testing and
Development Section

D.A. Black
Engineer
Mechanical Testing and
Development Section

GDP:DAB:sf

TABLE 1
EXIDE FHC CELLS

Date	Time	Cell	Span	Comments
Sept 11	1:20	55010	3	No movement
	1:26	55010	5	Some acid spilled
	1:30	55010	7	- Much acid spilled - Cracks on top corners of case
	1:35	55010	10	- Excessive acid spilled - Voltage drop
Sept 12	10:45	55001	3	- Some spillage from a lid corner
	10:51	55001	5	- Acid spilled from most edges - Cracks on one corner
	10:53	55001	7	- Cracks and splits on all 4 corners - One vertical split - One diagonal split
	10:57	55001	10	- Cracks open - Some loss in capacity

REFERENCES

1. The Institute of Electrical and Electronic Engineers Inc. IEEE 344. IEEE Recommended Practices for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations. New York. 1975.
2. The Institute of Electrical and Electronic Engineers, Inc. IEEE 501. IEEE Recommended Practices for Seismic Qualification of Relays.
3. Harris, Cyril M., and Charles E. Crede. "Shock and Vibration Handbook." Second Edition. McGraw Hill Book Company. Toronto, 1976.
4. Janis, W.J. (Report to follow).

Figure 01A

The Cells Were Typically Mounted to the Tri-Axial Table as Shown, Wood Blocks Were Installed to Ensure a Snug Fit. Accelerometer Directions Were as Indicated.

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

TEST ITEM

Station Cell, Exide, Model FHC, Serial 55010.

PARTICULARS

Sept 11/85, Time 1:35, Temp(°C) 23, Humidity(%) 55, Press (kPa) 99.9,
Graph 5698

SPECIFICATIONS

Specs IEEE 501, Conditions 1.5 amp hour, span 10

ANALYSIS

Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis X,
Shaker tri-axial, ZPA=2.5g

ACCELEROMETER

Wilcoxon, Serial 1213, Range dB48, Location mounting beams, TT 0112,
Channel 1

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

RESPONSE SPECTRUM

FIGURE 02

TEST ITEM

Station Cell. Exide. Model FHC. Serial 55010.

PARTICULARS

Sept 11/85. Time 1:35. Temp('C) 23. Humidity(%) 55. Press (kPa) 99.9.
Graph 5699

SPECIFICATIONS

Specs IEEE 501. Conditions 1.5 amp hour. span 10

ANALYSIS

Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis Y.
Shaker tri-axial. ZPA=1.45g

ACCELEROMETER

Wilcoxon. Serial 1214. Range dB48. Location mounting beams. TT 0112.
Channel 2

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

FIGURE 03

TEST ITEM

Station Cell, Exide, Model FHC, Serial 55010.

PARTICULARS

Sept 11/85, Time 1:35, Temp('C) 23, Humidity(%) 55, Press (kPa) 99.9,
Graph 5670

SPECIFICATIONS

Specs IEEE 501, Conditions 1.5 amp hour, span 10

ANALYSIS

Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Z,
Shaker tri-axial, ZPA=2.08g

ACCELEROMETER

Wilcoxon, Serial S893, Range dB48, Location mounting beams, TT 0112,
Channel 3

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

TEST ITEM

Station Cell, Exide, Model FHC, Serial 55001.

PARTICULARS

Sept 12/85, Time 10:55, Temp('C) 23, Humidity(%) 55, Press (kPa) 99.9,
Graph 5678

SPECIFICATIONS

Specs IEEE 501, Conditions 1.5 amp hour, span 10

ANALYSIS

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

ACCELEROMETER

Wilcoxon, Serial 1213, Range dB48, Location mounting beams, TT 0140,
Channel 1

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

RESPONSE SPECTRUM

FIGURE 05

TEST ITEM

Station Cell. Exida. Model FHC. Serial 55001.

PARTICULARS

Sept 12/85. Time 10:55. Temp('C) 23. Humidity(%) 55. Press (kPa) 99.9.
Graph 5679

SPECIFICATIONS

Specs IEEE 501. Conditions 1.5 amp hour. span 10

ANALYSIS

Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis Y.
Shaker tri-axial. ZPA=1.45g

ACCELEROMETER

Wilcoxon. Serial 1214. Range dB48. Location mounting beams. TT 0140.
Channel 2

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

TEST ITEM

Station Cell. Exide. Model FHC, Serial 55001.

PARTICULARS

Sept 12/85. Time 10:55. Temp(°C) 23. Humidity(%) 55. Press (kPa) 99.9.
Graph 5680

SPECIFICATIONS

Specs IEEE 501. Conditions 1.5 amp hour. span 10

ANALYSIS

Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis Z.
Shaker tri-axial. ZPA=1.98g

ACCELEROMETER

Wilcoxon. Serial S893. Range dB48. Location mounting beams. TT 0140.
Channel 3

APPENDIX E

SEISMIC TESTING OF ARTIFICIALLY-AGED
C&D STATION CELLS

D. A. Black
G. D. Paulsen
Ontario Hydro Research Center

ontario hydro research division

TO: Mr. W.R. Collard
Manager
Electrical Design
Design & Dev - Generation

SEISMIC TESTING OF ARTIFICIALLY AGED C&D STATION CELLS

D.A. Black and G.D. Paulsen

Two C&D station cells were seismically tested to IEEE Specifications. These cells were artificially aged to 10 years to simulate ones now in use in generating stations in the United States. The purpose of this test was to determine the cells' ability to withstand a seismic event. This report describes the test procedure followed, the test equipment used, and gives the results of the test. These cells are a part of an ongoing program to determine the effects of a seismic event on new and aged cells.

1.0 INTRODUCTION

The two C&D cells were 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 analyzed using 5% damping and the maximax shock spectrum. The tests performed were tri-axial tests as defined in IEEE 344. All technical terms used in this report are defined by Harris/3/.

2.0 SAMPLES

The samples submitted for testing were identified as follows:

Station cell; C&D; Model LC-13; Serial 3871 CA3.

Station cell; C&D; Model LC-13; Serial 3871 CA6.

job	file	date	report no.
740624-153-40150	824.46	June 9, 1986	86-119-CON

3.0 TEST EQUIPMENT

3.1 Equipment Used

All or part of the following equipment was used in the tests.

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 two cells were tested individually and mounted as shown in Figure 01A. The cells were held in the test jig by four corner clamps consisting of 1-1/2" rubber padded angle iron and 1/2" threaded rods. This setup insures minimum movement of the cells in the test jig. Since the jig was initially designed for a larger cell, wood blocks were installed to insure a snug fit. Accelerometers were mounted on the base of the test jig as well as on one cell terminal. During the seismic tests the cells were loaded and monitored for voltage drop by Chemical Research/4/.

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 response spectra are given in Figures 01B through 06. The connections to the accelerometers mounted on the cell terminals were damaged by acid from the cell. As a result, these spectra were not plotted. A complete test log with the damage noted after each test is found in Table 1.

6.0 CONCLUSIONS

The C&D cells tested sustained no visible structural damage as a result of the tests.

Approved:

G.J. Clarke
Manager
Mechanical Research Dept

Submitted:

G.D. Paulsen
Technologist
Mechanical Testing and
Development Section

D.A. Black
Engineer
Mechanical Testing and
Development Section

GDP:DAB:sf

TABLE 1
C&D CELLS TEST LOG

Date	Time	Cell	Span	Comments
Sept 11	3:12	CA3	3	No major effect
	3:14	CA3	5	No major effect
	3:17	CA3	7	No major effect
	3:25	CA3	10	No major effect
Sept 11	4:00	CA6	3	No effect
	4:15	CA6	5	No effect
	4:25	CA6	7	No effect
	4:29	CA6	10	No effect

REFERENCES

1. The Institute of Electrical and Electronic Engineers Inc. IEEE 344. IEEE Recommended Practices for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations. New York. 1975.
2. The Institute of Electrical and Electronic Engineers, Inc. IEEE 501. IEEE Recommended Practices for Seismic Qualification of Relays.
3. Harris, Cyril M., and Charles E. Crede. "Shock and Vibration Handbook." Second Edition. McGraw Hill Book Company. Toronto, 1976.
4. Janis, W.J. (Report to follow).

Figure 01A

The Cells Were Typically Mounted to the Tri-Axial Table as Shown. Wood blocks were installed to ensure a snug fit. Accelerometer directions were as shown.

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
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RESPONSE SPECTRUM

FIGURE C1B

TEST ITEM

Station Cell, C & D, Model LC-13, Serial 3871 CA3.

PARTICULARS

Sept 11/85, Time 3:25, Temp(°C) 23, Humidity(%) 55, Press (kPa) 99.9,
Graph 5672

SPECIFICATIONS

Specs IEEE 501, Conditions 1.5 amp hour, span 10

ANALYSIS

Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis X,
Shaker tri-axial, ZPA=2.05g

ACCELEROMETER

Wilcoxon, Serial 1213, Range dB48, Location mounting beams, TT 0119,
Channel 1

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RESPONSE SPECTRUM

FIGURE C2

TEST ITEM

Station Cell, C & D, Model LC-13, Serial 3871 CA3.

PARTICULARS

Sept 11/85, Time 3:25, Temp('C) 23, Humidity(%) 55, Press (kPa) 99.9,
Graph 5673

SPECIFICATIONS

Specs IEEE 501, Conditions 1.5 amp hour, span 10

ANALYSIS

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

ACCELEROMETER

Wilcoxon, Serial 1214, Range dB48, Location mounting beams, TT 0119,
Channel 2

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RESPONSE SPECTRUM

FIGURE C3

TEST ITEM

Station Cell, C & D, Model LC-13, Serial 3871 CA3,

PARTICULARS

Sept 11/85, Time 3:25, Temp(°C) 23, Humidity(%) 55, Press (kPa) 99.9,
Graph 5874

SPECIFICATIONS

Specs IEEE 501, Conditions 1.5 amp hour, span 10

ANALYSIS

Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Z,
Shaker tri-axial, ZPA=2.08g

ACCELEROMETER

Wilcoxon, Serial S893, Range dB48, Location mounting beams, TT 0119,
Channel 3

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RESPONSE SPECTRUM

FIGURE C4

TEST ITEM

Station Cell, C & D, Model LC-13, Serial 3871 CA6.

PARTICULARS

Sept 11/85, Time 4:29, Temp (°C) 23, Humidity (%) 55, Press (kPa) 99.9,
Graph 5875

SPECIFICATIONS

Spec IEEE 501, Conditions 1.5 amp hour, span 10

ANALYSIS

Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis X,
Shaker tri-axial, ZPA=2.36g

ACCELEROMETER

Wilcoxon, Serial 1213, Range dB48, Location mounting beams, TT 0130,
Channel 1

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TEST ITEM

Station Cell, C & D, Model LC-13, Serial 3871 CA6,

PARTICULARS

Sept 11/85, Time 4:29, Temp(°C) 23, Humidity(%) 55, Press (kPa) 99.9,
Graph 5678

SPECIFICATIONS

Specs IEEE 501, Conditions 1.5 amp hour, span 10

ANALYSIS

Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Y,
Shaker tri-axial, ZPA=2.2g

ACCELEROMETER

Wilcoxon, Serial 1214, Range dB48, Location mounting beams, TT 0130,
Channel 2

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RESPONSE SPECTRUM

FIGURE C6

TEST ITEM

Station Cell, C & D, Model LC-13, Serial 3871 CA6.

PARTICULARS

Sept 11/85, Time 4:29, Temp('C) 23, Humidity(%) 55, Press (kPa) 99.9,
Graph 5677

SPECIFICATIONS

Spec IEEE 501, Conditions 1.5 amp hour, span 10

ANALYSIS

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

ACCELEROMETER

Wilcoxon, Serial S893, Range dB48, Location mounting beams, TT 0130,
Channel 3

APPENDIX F

SEISMIC TESTING OF ARTIFICIALLY-AGED
GOULD STATION CELL

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research division**

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Manager
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**SEISMIC TESTING OF
ARTIFICIALLY AGED GOULD STATION CELL**

D.A. Black and G.D. Paulsen

One Gould station cell was seismically tested to IEEE Specifications. This cell was artificially aged to 12 years to simulate ones now in use in generating stations. The purpose of this test was to determine the cell's ability to withstand a seismic event. This report describes the test procedure followed, the test equipment used, and gives the results of the tests. This cell was a part of an ongoing program to determine the effects of a seismic event on new and aged cells.

1.0 INTRODUCTION

The Gould cell 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 analyzed using 5% damping and the maximax shock spectrum. The tests performed were tri-axial tests as defined in IEEE 344. All technical terms used in this report are defined by Harris/3/.

2.0 SAMPLE

The sample submitted for testing was identified as follows:

Station cell; Gould; Model NCX-2250; Serial 17091; Cell #4.

This cell was artificially aged to 12 years by Chemical Research/4/.

job	file	date	report no.
740624-153-40150	824.46	June 11, 1986	86-117-CON

3.0 TEST EQUIPMENT

3.1 Equipment Used

All or part of the following equipment was used in the tests.

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 cell was mounted as shown in Figure 01A. The cell was held in the test jig by four corner clamps consisting of 1-1/2" rubber padded angle iron and 1/2" threaded rods. This setup insures minimum movement of the cells in the test jig. Accelerometers were mounted on the base of the test jig as well as on one cell terminal. During the seismic tests the cell was loaded and monitored for voltage drop by Chemical Research (as noted in Reference 4).

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 03. A complete test log is given in Table 1, as well as all observations.

6.0 CONCLUSIONS

The cell tested sustained increasing damage as the span levels increased until total destruction occurred at span level 10.

Approved:

G.J. Clarke
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Mechanical Research Dept

Submitted:

G.D. Paulsen ^{FAE}
Technologist
Mechanical Testing and
Development Section

D.A. Black
Engineer
Mechanical Testing and
Development Section

GDP:DAB:sf

TABLE 1

GOULD STATION CELL TEST LOG

Date	Time	Cell	Span	Comments
Sept 9	14:24	17091	3	
	14:26	17091	5	- Acid spilled, apparently due to lid/jar separation
	14:29	17091	7	- More acid spilled; considerable lid/jar separation
Sept 11	8:50	17091	10	- Complete destruction of cell jar

REFERENCES

1. The Institute of Electrical and Electronic Engineers Inc. IEEE 344. IEEE Recommended Practices for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations. New York. 1975.
2. The Institute of Electrical and Electronic Engineers, Inc. IEEE 501. IEEE Recommended Practices for Seismic Qualification of Relays.
3. Harris, Cyril M., and Charles E. Crede. "Shock and Vibration Handbook." Second Edition. McGraw Hill Book Company. Toronto, 1976.
4. Janis, W.J. (Report to follow).

Figure 01A

The Cell was Typically Mounted to the Tri-Axial Table as Shown.
Accelerometer directions were as indicated.

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RESPONSE SPECTRUM

FIGURE 01B

TEST ITEM

Station Cell, Gould, Model NCX-2250, Serial 17091, cell #4

PARTICULARS

Sept 11/85, Time 8:45, Temp(°C) 23, Humidity(%) 55, Press (kPa) 99.9,
Graph 5693

SPECIFICATIONS

Specs IEEE 501, Conditions 1.5 amp hour, span 7

ANALYSIS

Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis X,
Shaker tri-axial, ZPA=1.6g

ACCELEROMETER

Wilcoxon, Serial 1213, Range dB48, Location mounting beams, TT 0097,
Channel 1

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RESPONSE SPECTRUM

FIGURE 02

TEST ITEM

Station Cell, Gould, Model NCX-2250, Serial 17091, cell #4

PARTICULARS

Sept 11/85, Time 8:45, Temp(°C) 23, Humidity(%) 55, Press (kPa) 99.9,
Graph 5694

SPECIFICATIONS

Specs IEEE 501, Conditions 1.5 amp hour, span 7

ANALYSIS

Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Y,
Shaker tri-axial, ZPA=1.11g

ACCELEROMETER

Wilcoxon, Serial 1214, Range dB48, Location mounting beams, TT 0097,
Channel 2

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RESPONSE SPECTRUM

FIGURE 03

TEST ITEM

Station Cell. Gould. Model NCX-2250. Serial 17091. cell #4

PARTICULARS

Sept 11/85. Time 8:45. Temp(°C) 23. Humidity(%) 55. Press (kPa) 99.9.
Graph 5695

SPECIFICATIONS

Specs IEEE 501. Conditions 1.5 amp hour. span 7 : fragility level

ANALYSIS

Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis Z.
Shaker tri-axial. ZPA=1.29g

ACCELEROMETER

Wilcoxon. Serial S893. Range dB48. Location mounting beams. TT 0097.
Channel 3

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13 ABSTRACT (200 words or less) <p>The seismic-fragility response of naturally-aged nuclear station safety-related batteries is of interest for two reasons: (1) to determine actual failure modes and thresholds and (2) to determine the validity of using the electrical capacity of individual cells as an indicator of the potential survivability of a battery given a seismic event. Prior reports in this series discussed the seismic-fragility tests and results for three specific naturally-aged cell types: 12-year old NCX-2250, 10-year old LCU-13, and 10-year old FHC-19.</p> <p>This report focuses on the complementary approach, namely the seismic-fragility response of accelerated-aged batteries. Of particular interest is the degree to which such approaches accurately reproduce the actual failure modes and thresholds. In these tests the significant aging effects observed, in terms of seismic survivability, were: embrittlement of cell cases, positive bus material and positive plate grids; and excessive sulphation of positive plate active material causing hardening and expansion of positive plates. The IEEE Standard 535 accelerated aging method successfully reproduced seismically significant aging effects in new cells but accelerated grid embrittlement an estimated five years beyond the conditional age of other components.</p>			
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