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FERMI 2 TURBINE FAILURE

POST EVENT EARTHQUAKE INSTRUMENTATION DATA EVALUATION

Prepared for: Detroit Edison Company
Enrico Fermi 2 Job Site
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1.0 INTRODUCTION

1.1 Fermi 2 History

The Enrico Fermi Unit 2 Nuclear Power Plant is a 1,203-MV gross Boiling Water Reactor located outside Detroit, Michigan on Lake Erie. Fermi 2 has been in commercial operation since 1988, using a turbine manufactured by English Electric of Rugby, England, now part of G.E.C.-Alsthom. The facility site is located on stable land, and few large intensity earthquakes have occurred in the facility vicinity throughout documented history.

1.2 Turbine Failure

At approximately 13:15 on December 25, 1993, the turbine at the Enrico Fermi Unit 2 Nuclear Power Plant failed. The turbine failure included thrown blades, severed cooling system piping, turbine lubricating system failures, and a hydrogen explosion. Vibration imbalance in the main turbine generator activated a turbine alarm. Almost simultaneously, numerous alarms were received, including seismic event, additional turbine alarms, and reactor scram. Upon receiving the reactor scram alarm, the operator immediately began shutdown procedures of the turbine and reactor.

1.3 Shock Incident

Personal observations attest to a loud noise followed by a rumbling sound which lasted two to three minutes. The seismic event alarm and the reactor scram alarm were noticed concurrent with the loud noise and rumbling. Although the root failure cause is unclear at this time, the rumbling sound was attributed to vibration.

The passive peak shock record plates on the second and fifth floors of the Reactor/Auxiliary building recorded insignificant accelerations, or accelerations below the Operating Basis Earthquake (OBE).

The active strong motion time history accelerometers in the HPCI room and at the reactor pressure vessel (RPV) pedestal base recorded measurable accelerations. The accelerometers were preset to activate at a 0.01 g level. Subsequent to this activation, two impulsive acceleration excitation spikes were recorded after approximately two and sixty-three seconds. The passive peak shock record plates in the sub-basement of the Reactor/Auxiliary building (HPCI room) also recorded measurable accelerations.

instrumentation data from both active and passive sensors were evaluated and compared to those excitation levels in the Fermi 2 Updated Final Safety Analysis Report (UFSAR) to verify the continuing structural integrity of the Reactor/Auxiliary building and the equipment inside the building.

1.4 Seismic Event Procedure Requirements

Section 3.7.4.4 of the UFSAR states an earthquake has occurred if the seismic trigger is activated. If the seismic event exceeds the OBE, the reactor must be shut down as quickly as possible. Before normal operation can commence, the UFSAR requires data reduction, analysis, and interpretation of time histories and response spectra from instrumentation; and structure, system, and component inspection.

1.5 Results

Globally, the building did not experience an OBE event, and consequently, the Reactor/Auxiliary building was never exercised near OBE excitation levels as evidenced by the insignificant accelerations measured on the second and fifth floors of the building. Likewise, the equipment on the second and higher floors was never exercised near OBE excitation levels.

Below the second floor, at the RPV pedestal, the active instrumentation show OBE exceedences at high frequencies and both active and passive instrumentation exhibit OBE exceedences in the HPCI room. However, no anomalies were observed during the event, and a cursory inspection of both building and equipment after the event indicates there to be no apparent problems.

The two distinct tremors recorded by the active instrumentation mounted to the structural foundation exhibit those characteristics that would be anticipated from a surface wave system emanating from an impact at an adjacent surface location. These waves locally pass through the structural foundation with the path of the particle motion theoretically describing a single retrograde ellipse. They possess none of the energy characteristics of tectonic earthquake waves and do not result in the global structural excitation experienced during a traditional seismic event.

2.0 HISTORY

2.1 Seismic Events

2.1.1 Previous Seismic Events

Fermi 2 is located in a relatively seismic stable area. Approximately fifteen intensity VI (Modified Mercalli Scale) or greater earthquakes have occurred within a two hundred mile radius in the last two hundred years (Figure 2.1.1.1). Additionally, nine earthquakes of intensity V or less have occurred within a fifty mile radius of the facility (Figure 2.1.1.2). Although the Fermi 2 OBE is associated with an intensity VI seismic event, it is unlikely the facility will experience such an earthquake within its lifetime.

2.1.2 December 25, 1993

The National Geophysics Data Center and the National Oceanic and Atmospheric Administration show no seismic activity for December 25, 1993, within a five hundred km (310 mile) radius of Detroit. The center has immediate knowledge of all seismic activity in the Detroit vicinity of intensity III or greater.

The most recent seismic event within two hundred miles of the facility site had an intensity of approximately I and occurred in April of 1993. The passive peak shock recorder plates were calibrated and installed in July of 1993 (second and fifth floors) and September of 1993 (HPCI room). This evidence indicates the passive plate records contained only the turbine failure incident.

2.2 Sequence of Events

2.2.1 Turbine Failure and Damage

It is beyond the scope of this document to chronically arrange the events of the turbine failure on December 25, 1993.

At approximately 13:15 on December 25, 1993, the number 3 low-pressure turbine at Fermi 2 failed catastrophically. The turbine threw several blades. One blade ripped through the steel turbine casing. The other blades are believed to be in-

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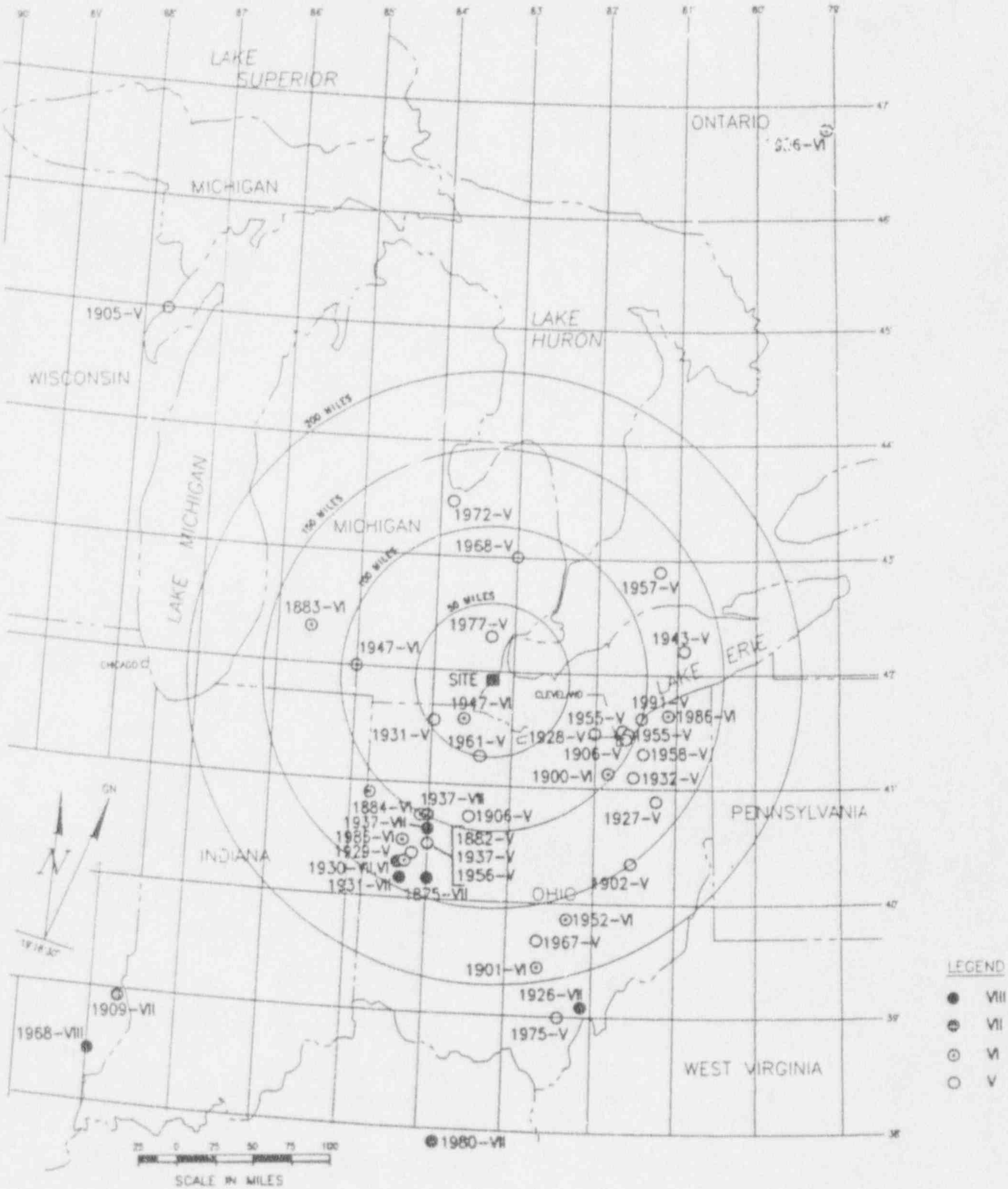

Epicenter Map, Detroit Area, Intensity V or Greater, 200 Mile Radius

Figure 2.1.1.1

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Epicenter Map, Detroit Area, All Earthquakes, 50 Mile Radius

Figure 2.1.1.2

side the condenser. Vibration caused measurements in excess of 37.5 mils peak-to-peak at the turbine bearings, recorded by the Diagnostic Vibration Analysis (DVA) System.

A small hydrogen explosion occurred near the number 9 bearing, and the resulting fire charred the shield wall. The fire or the steam from the turbine casing activated the fire protection system. Approximately six hundred thousand gallons of water poured into the turbine building. Additionally, a 2" cooling system pipe was severed, adding more water. The turbine lubricating system also failed, and approximately seventeen thousand gallons of oil poured onto the floor. The ensuing mixture drained into the turbine building basement.

Turbine vibration tore couplings, sheared bolts, and loosened the excitor from the main turbine generator.

2.2.2 Shutdown

The turbine failure activated the turbine, seismic event, and reactor scram alarms, and both the turbine and the reactor proceeded to shutdown. All safety systems responded to achieve a satisfactory shutdown of the turbine and the reactor. The event was declared an alert at approximately 13:52 due to fire potential, and later downgraded to an unusual event.

2.2.3 Observations

No personnel were in the vicinity of the turbine failure. Almost all personnel nearby heard a loud noise, followed by a rumbling, which lasted two to three minutes. Some personnel felt vibrations through the building. Almost simultaneously, personnel in the buildings heard the reactor scram alarm. Those near the turbine building reported heavy smoke.

Several personnel were directed to inspect the turbine building for fire. They noted damaged parts on the third floor, and a small fire at the generator brushes, which they extinguished with a CO2 fire extinguisher.

Remaining personnel proceeded in duties as directed to facilitate the reactor shutdown.

2.2.4 Human Sensitivity to Vibration

Work conducted by numerous researchers have established physiological limits of human perceptibility to vibration. The studies demonstrate humans can detect vibrations well below the current instrument sensitivity at Fermi 2 (Figure 2.2.4.1).

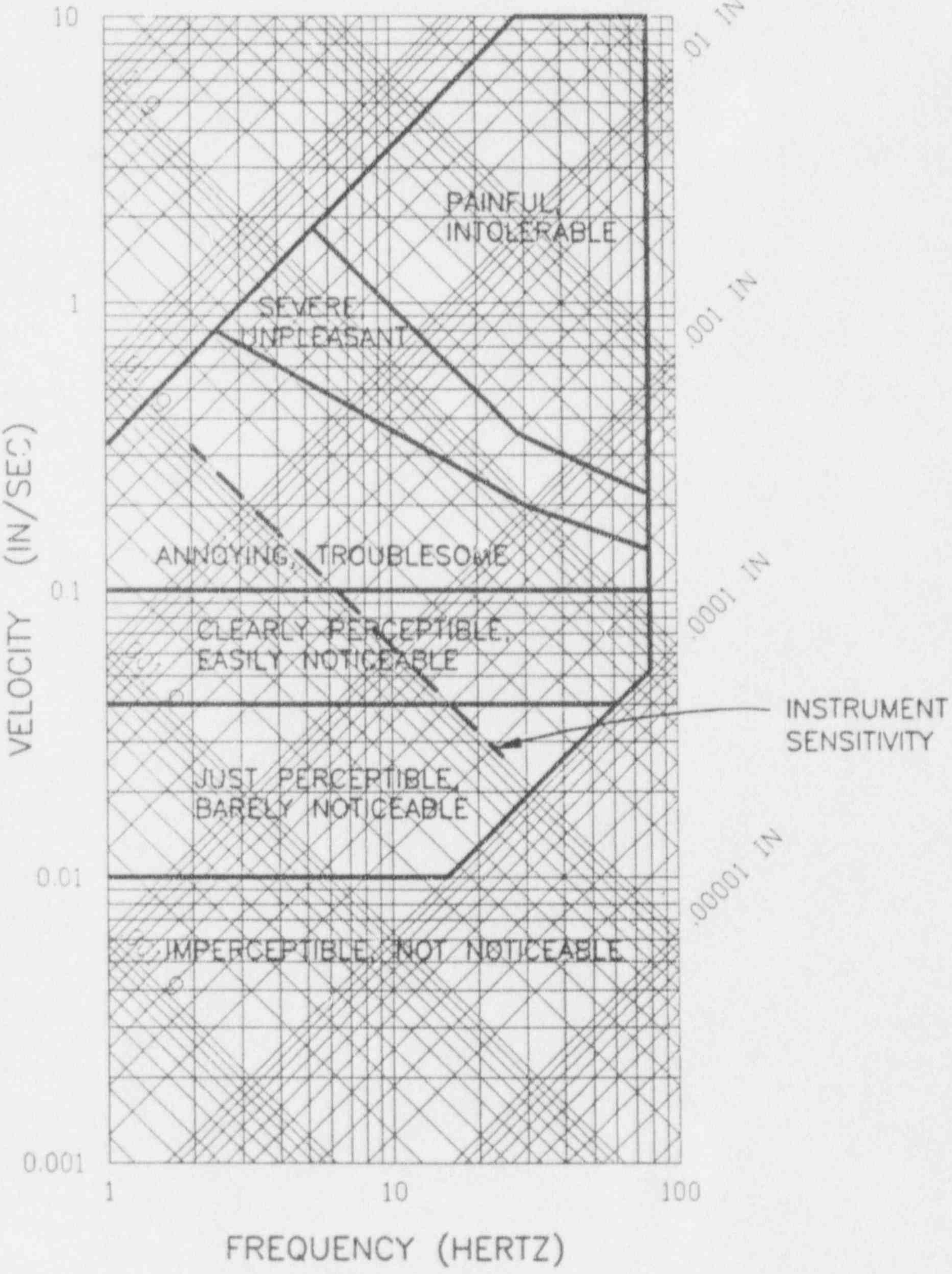
2.2.5 Fermi 2 Seismic Event Procedure Requirements

The turbine failure activated the seismic alarm and necessitated the reactor shutdown. The Fermi 2 UFSAR includes a required response when the seismic event alarm is activated (Figure 2.2.5.1). If the seismic event exceeds the OBE, the reactor must be shutdown as quickly as possible. The decision to shutdown involves examining the active traces from the HPCI room, utilizing the playback mode of recording instrumentation, and removing the HPCI room record plates and examining the data compared to the OBE. If the seismic event produced a horizontal acceleration greater than 0.05 g, or the relevant OBE is exceeded, the facility is shutdown, and further operation is not resumed until analysis and/or refurbishing of necessary structures, systems, or components is completed.

The turbine failure necessitated the reactor shutdown immediately, precluding the shutdown operating decision described above.

Additionally, the UFSAR requires data reduction, analysis, and interpretation of accelerometer time histories and response spectra from active instruments; response spectra from passive instruments; and physical facility structures, systems, and components inspection. If the event does not exceed Safe Shutdown Earthquake (SSE) validation levels, the item is considered safe for further operation. If the event exceeds validation levels, further investigation is required.

Investigation may include establishing realistic equipment fragility levels, detailed dynamic response analysis, or inspection. The investigation results in the item proclaimed acceptable, or the item refurbished, for normal facility operation to commence.



Human Vibration Sensitivity

Figure 2.2.4.1

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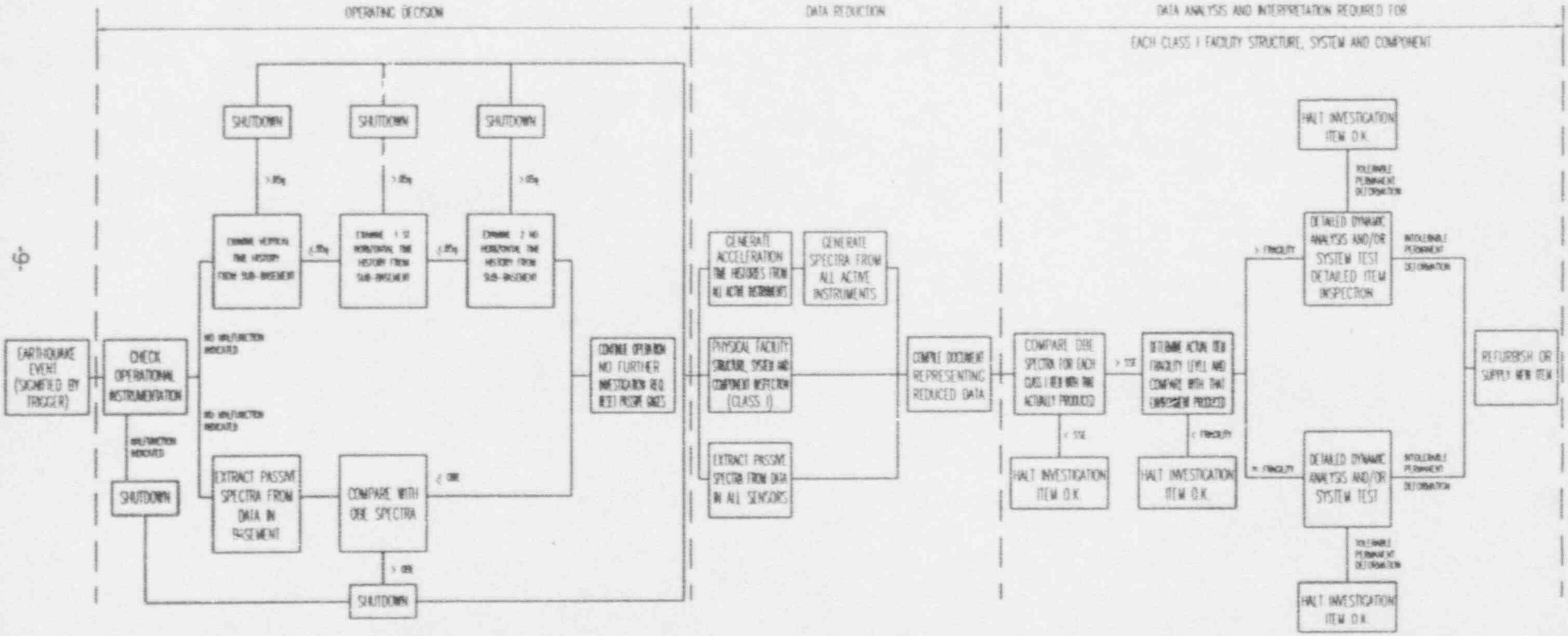


Data Analysis Flowchart

Figure 2.2.5.1

3.0 DATA

3.1 Instrumentation and Location

3.1.1 Passive Sensors

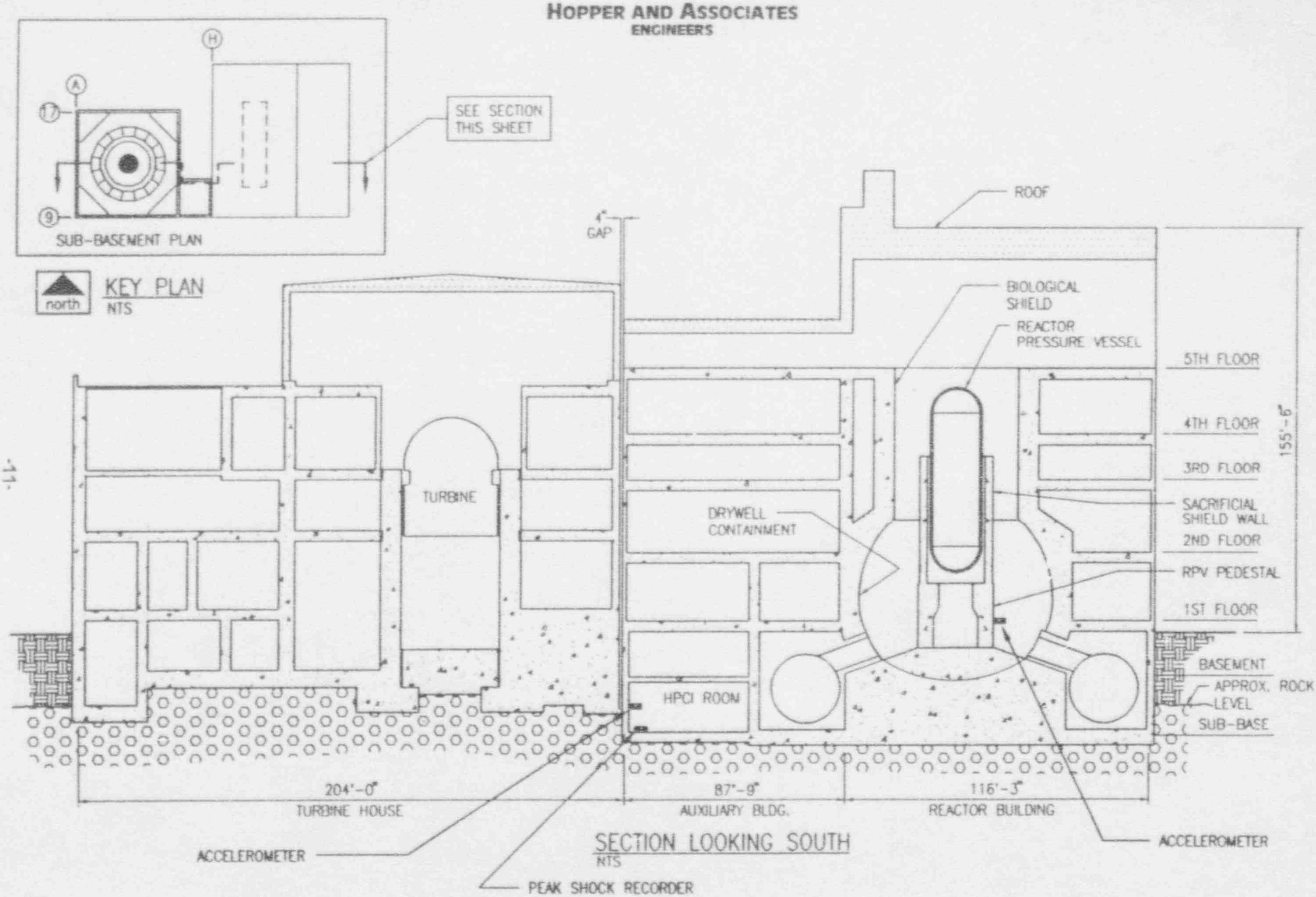
Engdahl PSR1200 peak shock recorders are the passive recording instrumentation located in the Reactor/Auxiliary building. The sensors record various ground motion and in-structure response shock spectra in three orthogonal directions. The sensors contain twelve reeds, each with a diamond tipped stylus, which etches a scribe mark on a metal record plate. Each reed is tuned to a predominant structural frequency, ranging from approximately two to twenty-five Hz. The record plate and the scribe mark provide a permanent indication of the dynamic excitation at a particular frequency. Reed deflection is calibrated as a linear function of acceleration. After a seismic event, the plates are removed and the reduced data establishes the response spectra.

Three Engdahl recorders are located in the Reactor/Auxiliary building, in the HPCI room, the second floor, and the fifth floor (Figures 3.1.1.1 through 3.1.1.3). The recorders are positioned to measure accelerations in the vertical, north/south, and east/west directions at each sensor.

Passive sensors are calibrated and the plates replaced after a seismic event or approximately every 18 months. The plates for the Reactor/Auxiliary building were last calibrated and replaced in July of 1993 on the second and fifth floors, and September of 1993 in the HPCI room.

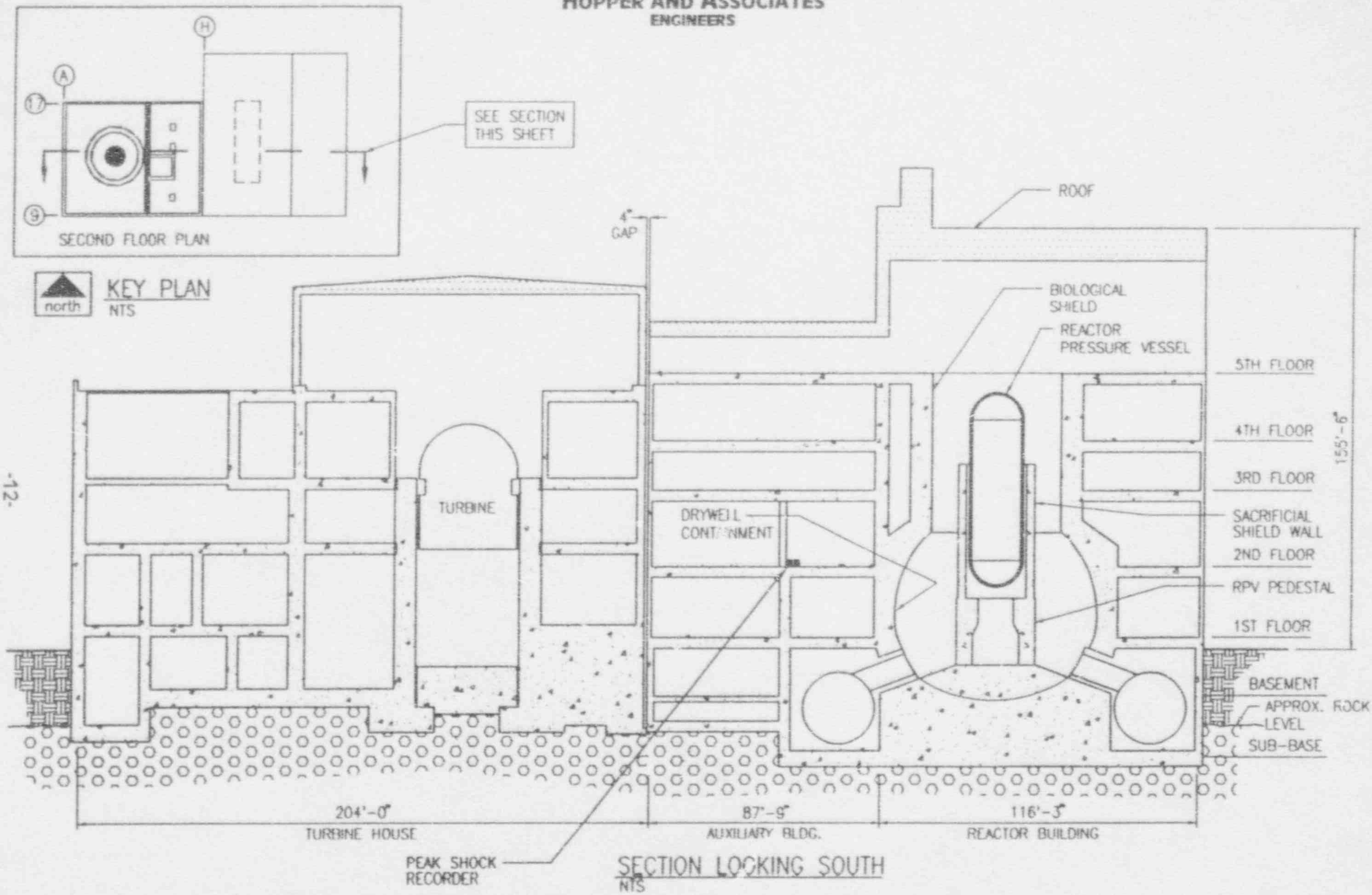
3.1.2 Active Sensors

Teledyne/Geotech Model 37800 strong motion triaxial time history accelerometers are the active recording instrumentation located in the Reactor/Auxiliary building. The active system includes the accelerometer sensors, seismic triggers, MTS-100B monitor and recorder, PMO-101/201 playback system, and an alarm panel. The accelerometers have a preset event trigger at 0.01 g, which energizes and activates the recording system. The system records over a frequency range of 0 to 40 Hz for a specified time length after motion has stopped. The output



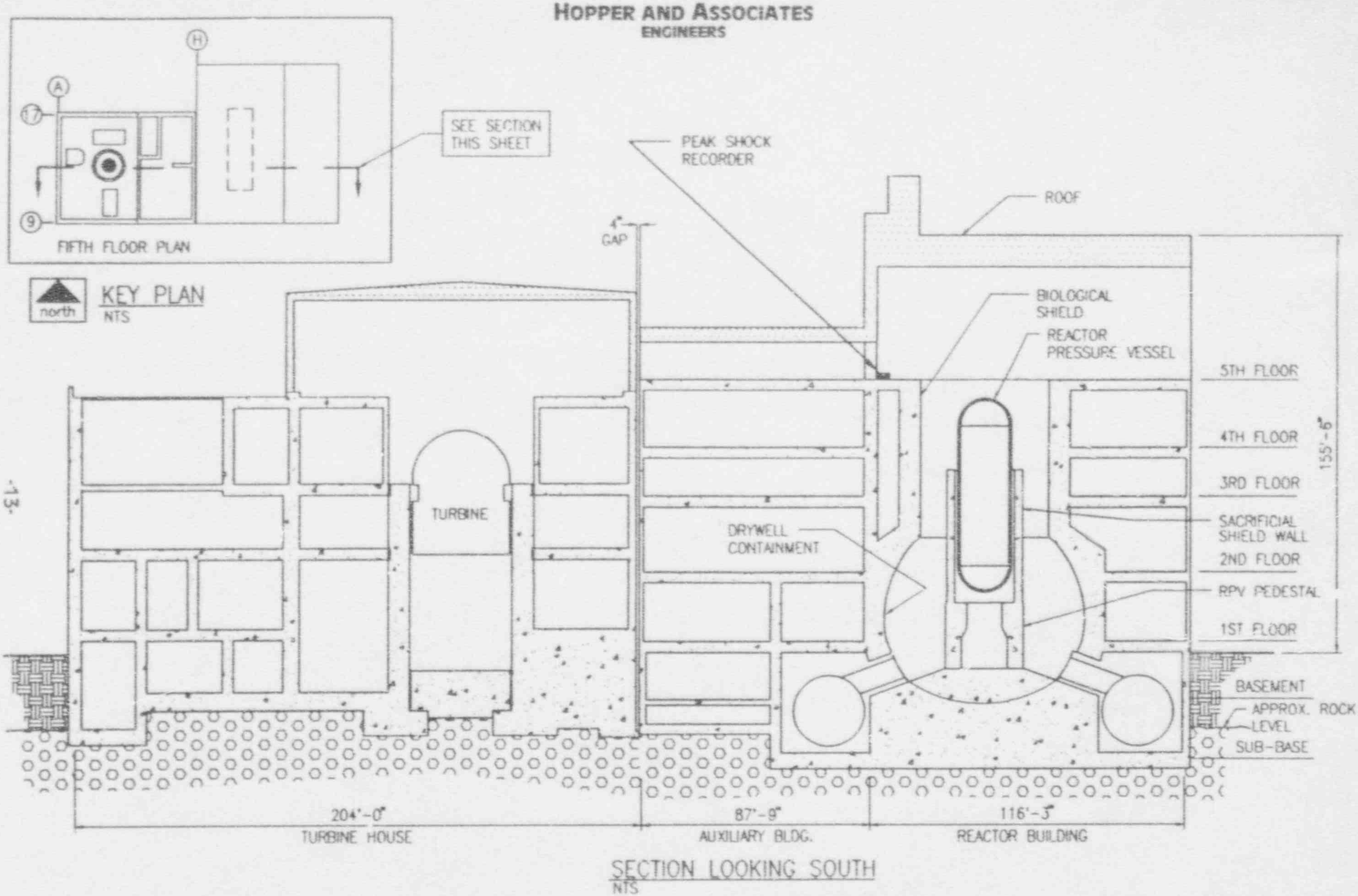
Passive and Active Instrumentation Location at HPCI Room and RPV Pedestal

Figure 3.1.1.1



Passive Instrumentation Location at Second Floor

Figure 3.1.1.2



Passive Instrumentation Location at Fifth Floor

Figure 3.1.1.3

produces a time history strip chart and a magnetic data tape of the event. The active instrumentation provides time histories from which response spectra may be generated.

Two Teledyne/Geotech accelerometers are located in the Reactor/Auxiliary building, in the HPCI room sub-basement and at the RPV pedestal (Figure 3.1.1.1). The accelerometers measure longitudinal, transverse, and vertical acceleration, which correspond to the vertical, north/south, and east/west directions of the passive recorders.

3.2 Data Reduction

3.2.1 Passive Sensors

The record plates from the three passive sensors in the Reactor/Auxiliary building were removed for data reduction. The plates were inspected for scribe marks, and the calculated accelerations were plotted against the relevant OBE and SSE response spectra (Tables 3.2.1.1 through 3.2.1.9 and Figures 3.2.1.1 through 3.2.1.9). Additionally, the instrument sensitivity was plotted. The passive sensor is capable of measuring accelerations greater than 0.01 g. The Engdahl peak shock recorders have 2% damping, and have $\pm$ 3% accuracy at 1 g.

The sensors were last calibrated and the plates replaced in July of 1993 (second and fifth floors) and in September of 1993 (HPCI room).

3.2.2 Active Sensors

Subsequent to the activation of the instrumentation, two distinct tremors were recorded. The first event occurred at approximately two seconds, with a duration of approximately 0.1 second, and the second event occurred at approximately one minute, also with a duration of approximately 0.1 second.

Time history acceleration data recorded by the two active sensors in the Reactor/Auxiliary building were digitized by Detroit Edison Company (Figures 3.2.2.1 through 3.2.2.6). A simple Fortran routine was used to produce the response spectra. The generated response spectra were plotted against the relevant OBE and SSE response spectra (Figure 3.2.2.7 through 3.2.2.12).

Reed No.	Hz	Measured mm	Inch	g/Inch	g
1	2.11	2.5	0.098	0.349	0.034
2	2.54	4.25	0.167	0.528	0.088
3	3.45	4.5	0.177	0.865	0.153
4	4.07	6.25	0.25	1.24	0.31
5	5.1	2.5	0.10	1.98	0.19
6	6.36	1.0	0.04	3.14	0.12
7	7.95	0.25	0.01	5.18	0.05
8	10.16	0.25	0.01	7.26	0.07
9	12.75	0.5	0.02	13.61	0.27
10	15.58	0.25	0.01	18.10	0.18
11	20.33	-		30.66	
12	25.25	-		46.98	

D30-N005 Passive Instrumentation, Vertical Direction Records - HPCI Room

Table 3.2.1.1

Reed No.	Hz	Measured mm	Inch	g/Inch	g
1	2	-		0.357	
2	2.5	0.5	0.02	0.52	0.01
3	3.17	-		0.84	
4	4.15	-		1.35	
5	4.95	-		1.90	
6	6.4	-		3.26	
7	7.75	-		4.69	
8	9.8	1.0	0.04	7.38	0.29
9	12.65	-		12.39	
10	15.9	-		18.11	
11	20.29	-		29.40	
12	25.41	-		45.50	

D30-N005 Passive Instrumentation, North/South Direction Records - HPCI Room

Table 3.2.1.2

Reed No.	Hz	Measured mm	Inch	g/Inch	g
1	1.96	2.75	0.108	0.376	0.041
2	2.39	6.0	0.236	0.556	0.131
3	3.16	6.5	0.256	0.89	0.23
4	3.96	3.2	0.126	1.29	0.16
5	5.05	2.0	0.079	2.10	0.17
6	6.32	-		3.18	
7	7.9	3.25	0.128	4.86	0.62
8	9.89	-		7.58	
9	12.27	-		11.58	
10	15.7	0.5	0.02	18.87	0.37
11	19.67	1.5	0.059	30.08	1.78
12	25.71	-		48.78	

D30-N005 Passive Instrumentation, East/West Direction Records - HPCI Room

Table 3.2.1.3

Reed No.	Hz	Measured mm	Inch	g/inch	g
1	2.05	-		0.322	
2	2.45	-		0.494	
3	3.21	-		0.784	
4	3.96	-		1.243	
5	4.86	-		1 918	
6	6.35	-		3.101	
7	7.84	-		4.9	
8	10.08	-		7.85	
9	12.59	-		11.7	
10	15.98	-		19.23	
11	20.49	-		29.85	
12	25.18	-		45.72	

D30-N601 Passive Instrumentation, Vertical Direction Records - Second Floor

Table 3.2.1.4

Reed No.	Hz	Measured mm	Inch	g/inch	g
1	1.99	-		0.362	
2	2.59	0.13	**0.005**	0.536	**0.003**
3	3.11	-		0.821	
4	3.93	-		1.31	
5	5.03	-		1.99	
6	6.39	-		3.21	
7	7.96	-		4.86	
8	10.13	-		7.44	
9	12.54	-		12.31	
10	15.88	-		18.35	
11	19.91	-		28.73	
12	25.04	-		47.04	

D30-N601 Passive Instrumentation, North/South Direction Records - Second Floor

Table 3.2.1.5

Reed No.	Hz	Measured mm	Inch	g/Inch	g
1	2.14	-		0.372	
2	2.54	-		0.524	
3	3.29	-		0.831	
4	3.95	-		1.32	
5	5.12	-		1.95	
6	6.33	-		3.17	
7	7.78	-		4.82	
8	9.92	-		7.48	
9	12.91	-		12.27	
10	15.89	-		18.61	
11	20.19	-		29.63	
12	25.53	-		45.99	

D30-N601 Passive Instrumentation, East/West Direction Records - Second Floor

Table 3.2.1.6

Reed No.	Hz	Measured mm	Inch	g/Inch	g
1	2	-		0.306	
2	2.58	-		0.508	
3	3.25	0.15	0.006	0.819	0.005
4	4.05	-		1.29	
5	5.05	-		2.01	
6	6.5	-		3.16	
7	7.85	-		5.5	
8	9.8	-		7.06	
9	12.8	-		11.96	
10	15.8	-		20.42	
11	20.2	-		28.99	
12	25.2	-		44.42	

D30-N006 Passive Instrumentation, Vertical Direction Records - Fifth Floor

Table 3.2.1.7

Reed No.	Hz	Measured mm	Inch	g/Inch	g
1	2.14	-		0.4	
2	2.38	-		0.518	
3	3.2	-		0.843	
4	4	-		1.29	
5	5.1	-		2.07	
6	6.45	-		3.28	
7	7.95	-		4.84	
8	10.05	-		7.75	
9	12.57	0.13	0.005	11.90	0.06
10	15.7	-		19.05	
11	20.3	-		29.2	
12	25.2	-		47.07	

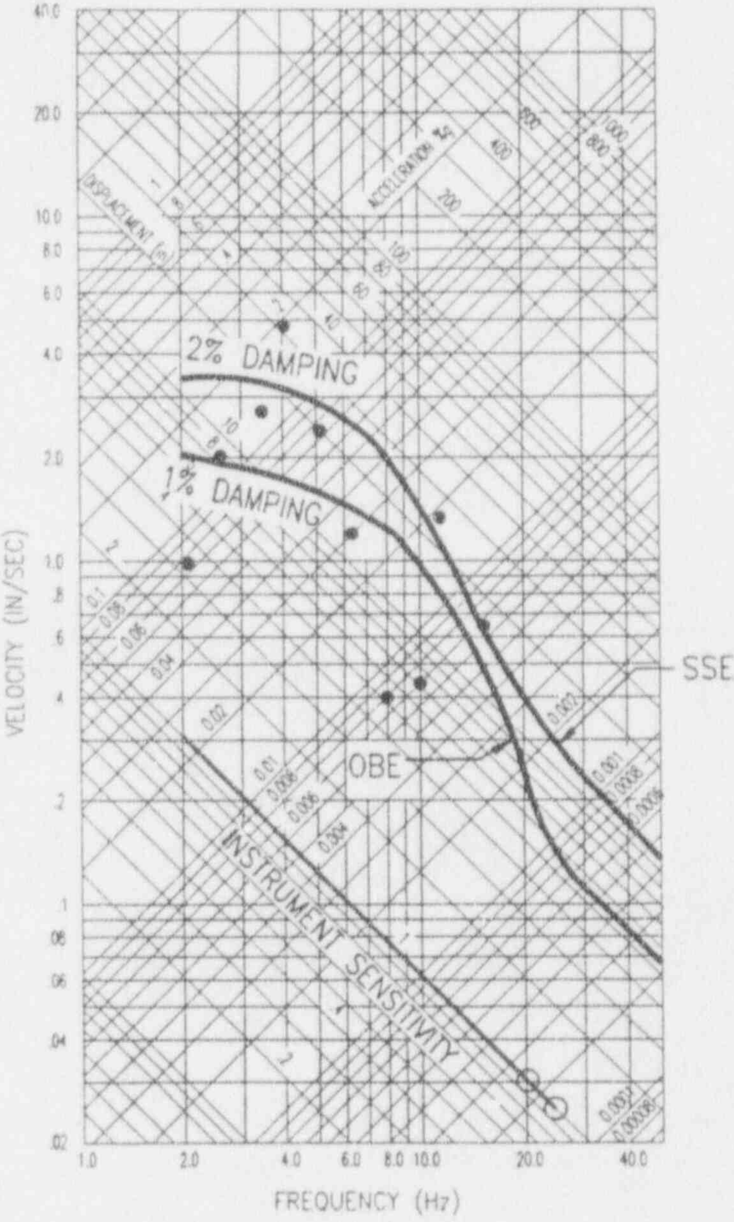
D30-N006 Passive Instrumentation, North/South Direction Records - Fifth Floor

Table 3.2.1.8

Reed No.	Hz	Measured mm	Inch	g/inch	g
1	2.11	-		0.371	
2	2.58	-		0.522	
3	3.25	-		0.833	
4	4.15	-		1.33	
5	4.9	-		1.85	
6	6.3	0.25	0.01	3.11	0.03
7	7.9	-		4.84	
8	10.2	-		7.31	
9	12.5	-		11.68	
10	15.8	0.125	0.005	17.62	0.09
11	20.1	-		28.59	
12	25.1	-		48.21	

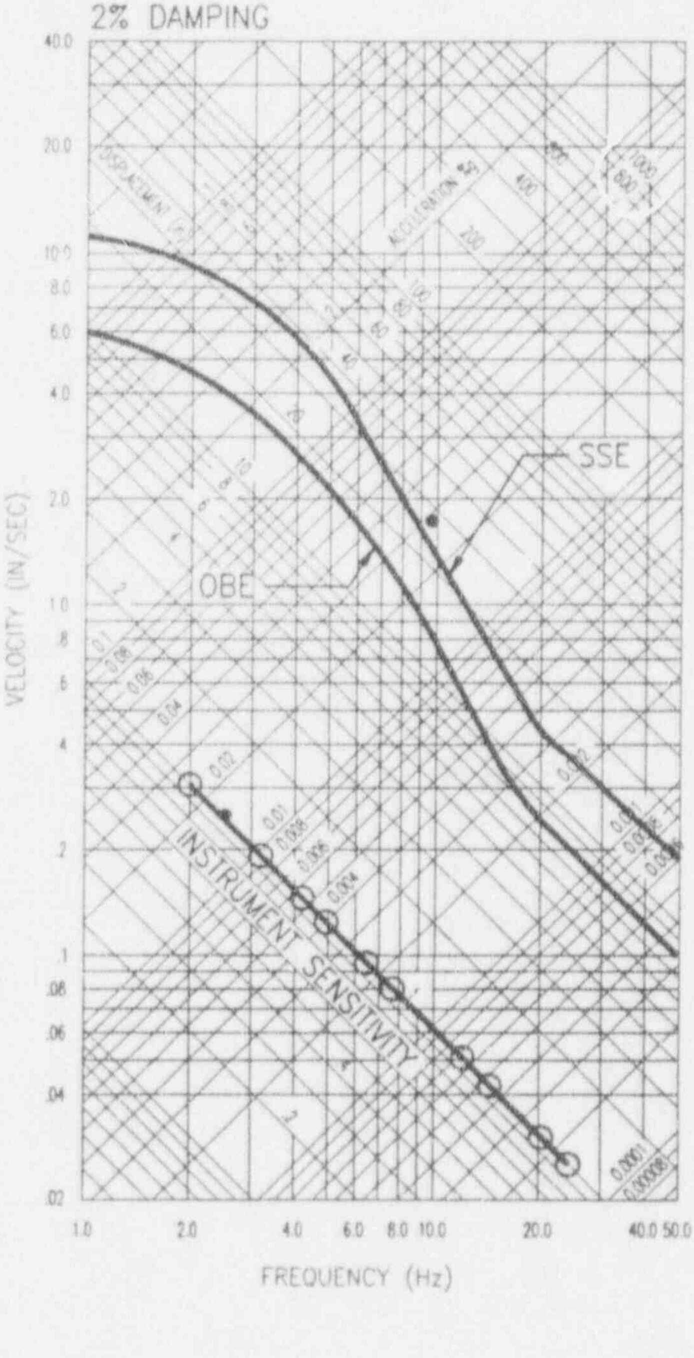
D30-N006 Passive Instrumentation, East/West Direction Records - Fifth Floor

Table 3.2.1.9



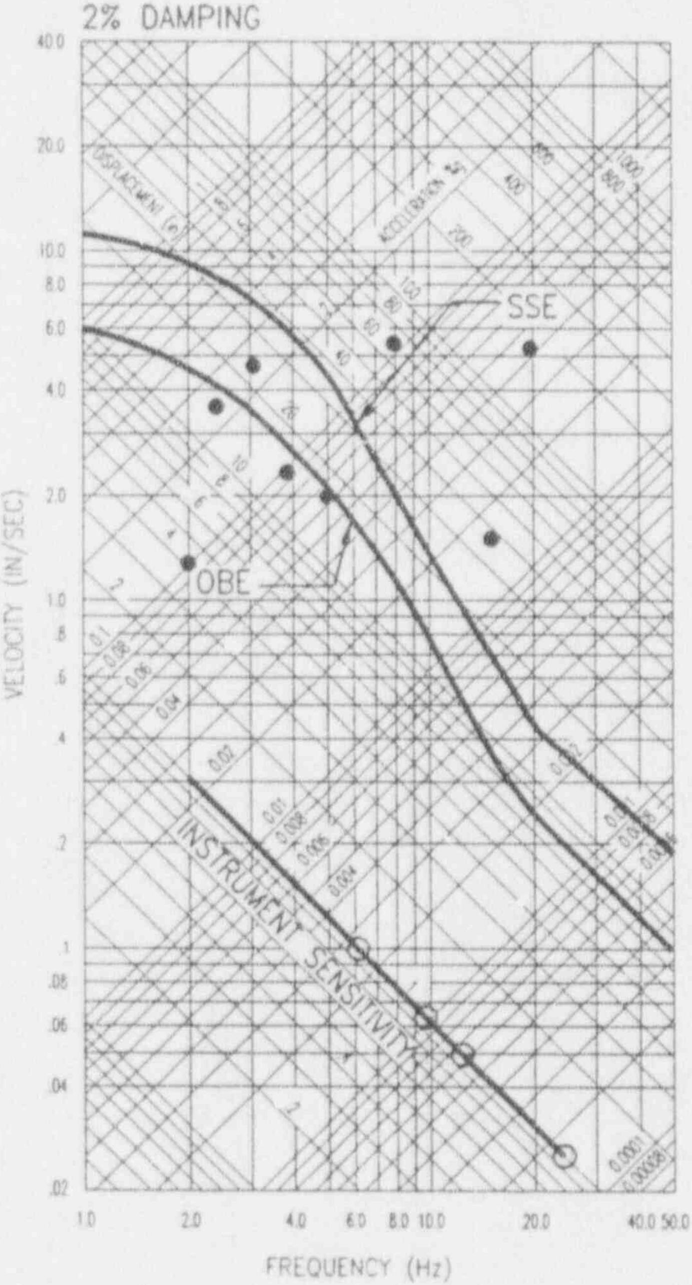
D30-N005 Passive Instrumentation, Vertical Response Spectra - HPCI Room

Figure 3.2.1.1



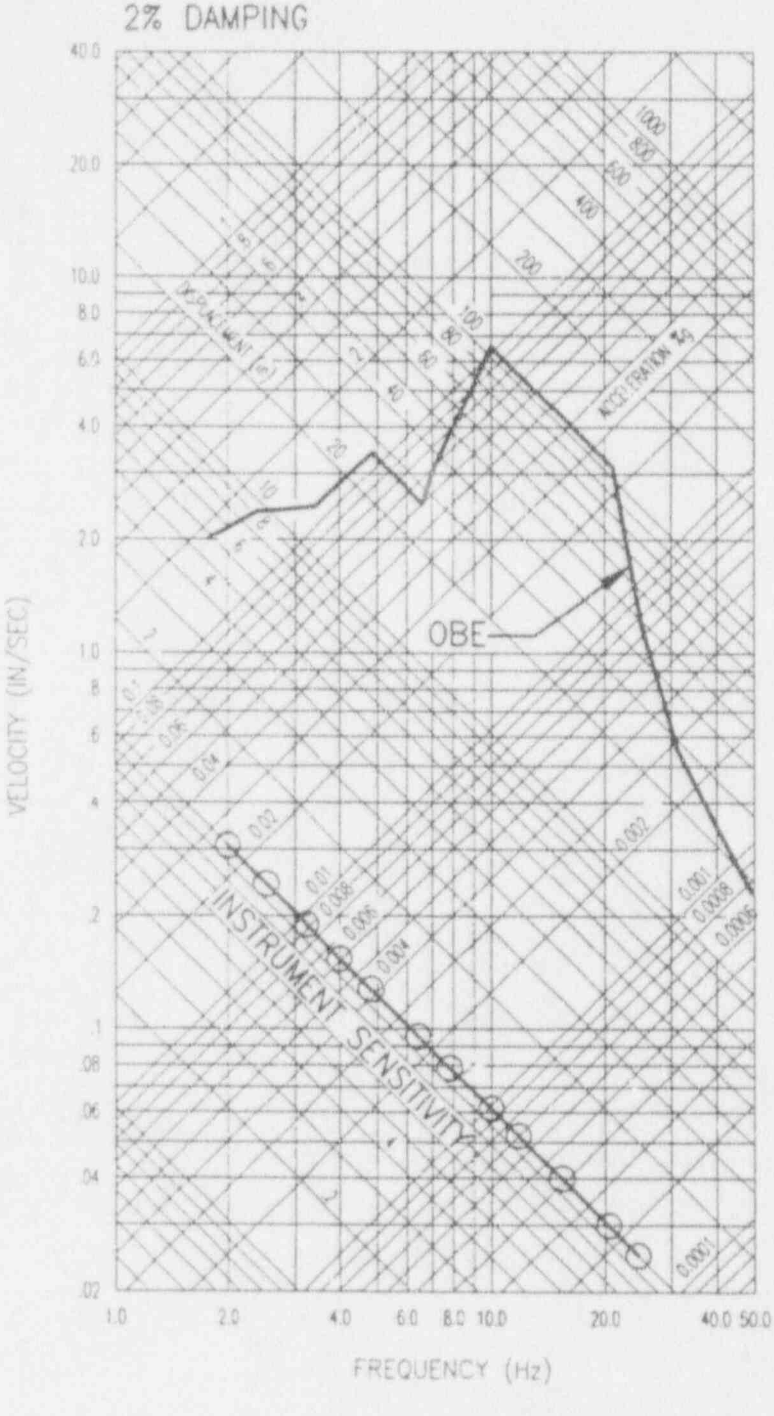
D30-N005 Passive Instrumentation, North/South Response Spectra - HPCI Room

Figure 3.2.1.2



D30-N005 Passive Instrumentation, East/West Response Spectra - HPCI Room

Figure 3.2.1.3



D30-N601 Passive Instrumentation, Vertical Response Spectra - Second Floor

Figure 3.2.1.4

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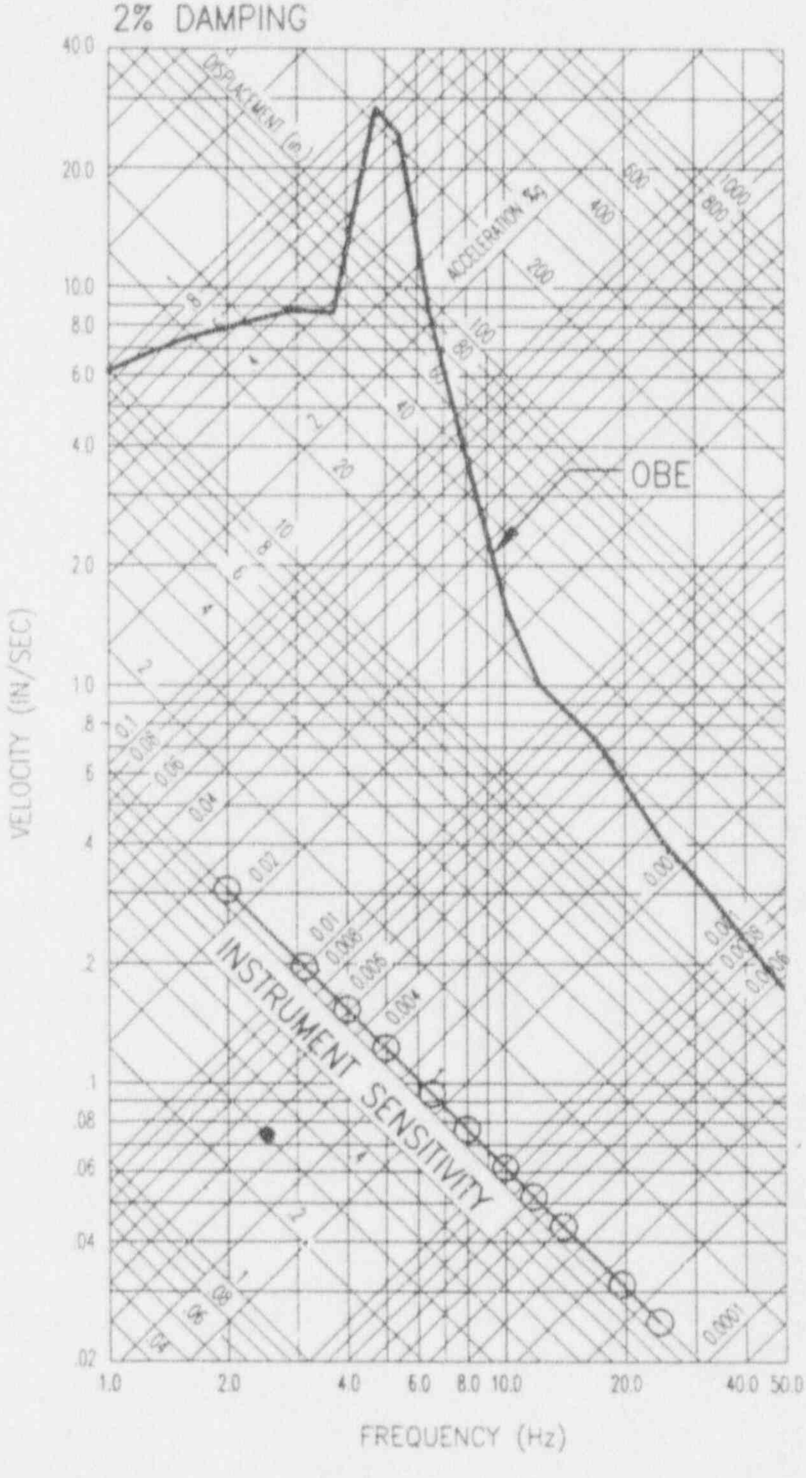
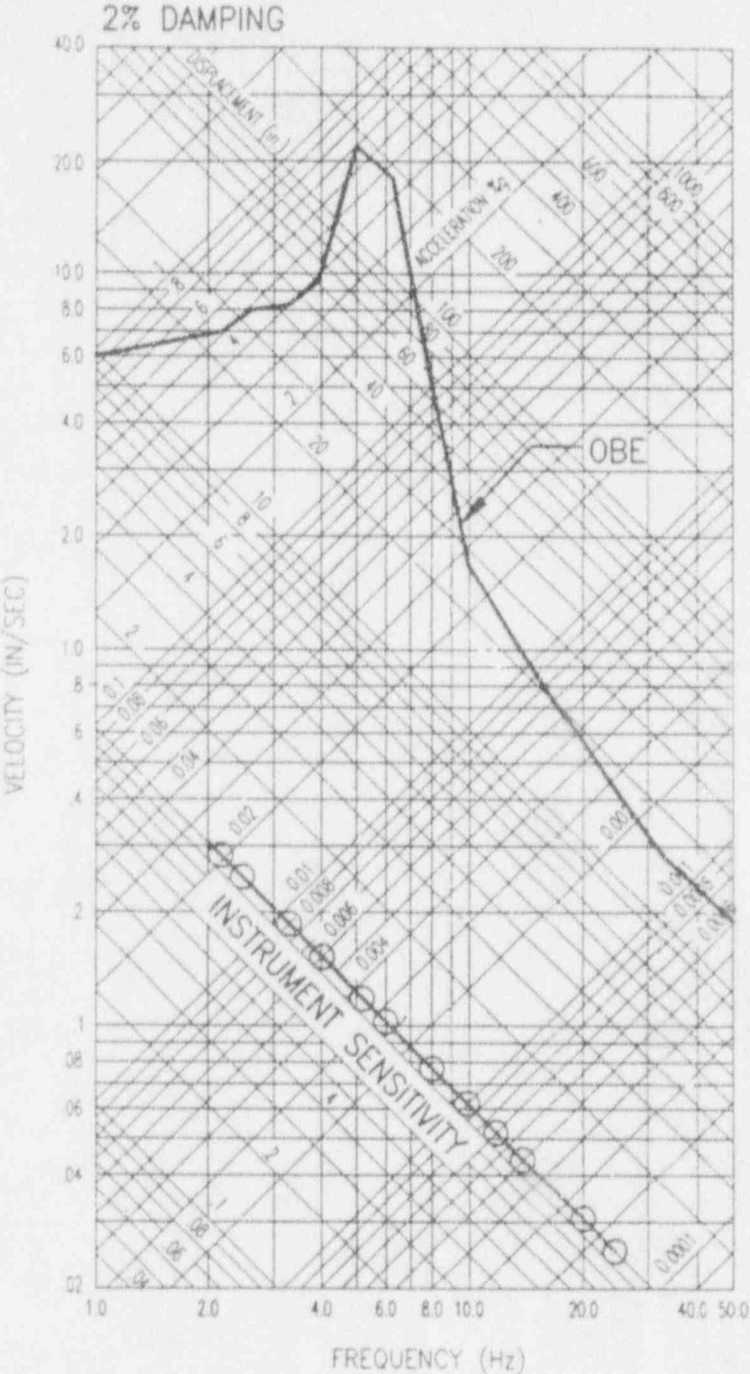


D30-N601 Passive Instrumentation, North/South Response Spectra - Second Floor

Figure 3.2.1.5



D30-N601 Passive Instrumentation, East/West Response Spectra - Second Floor

Figure 3.2.1.6

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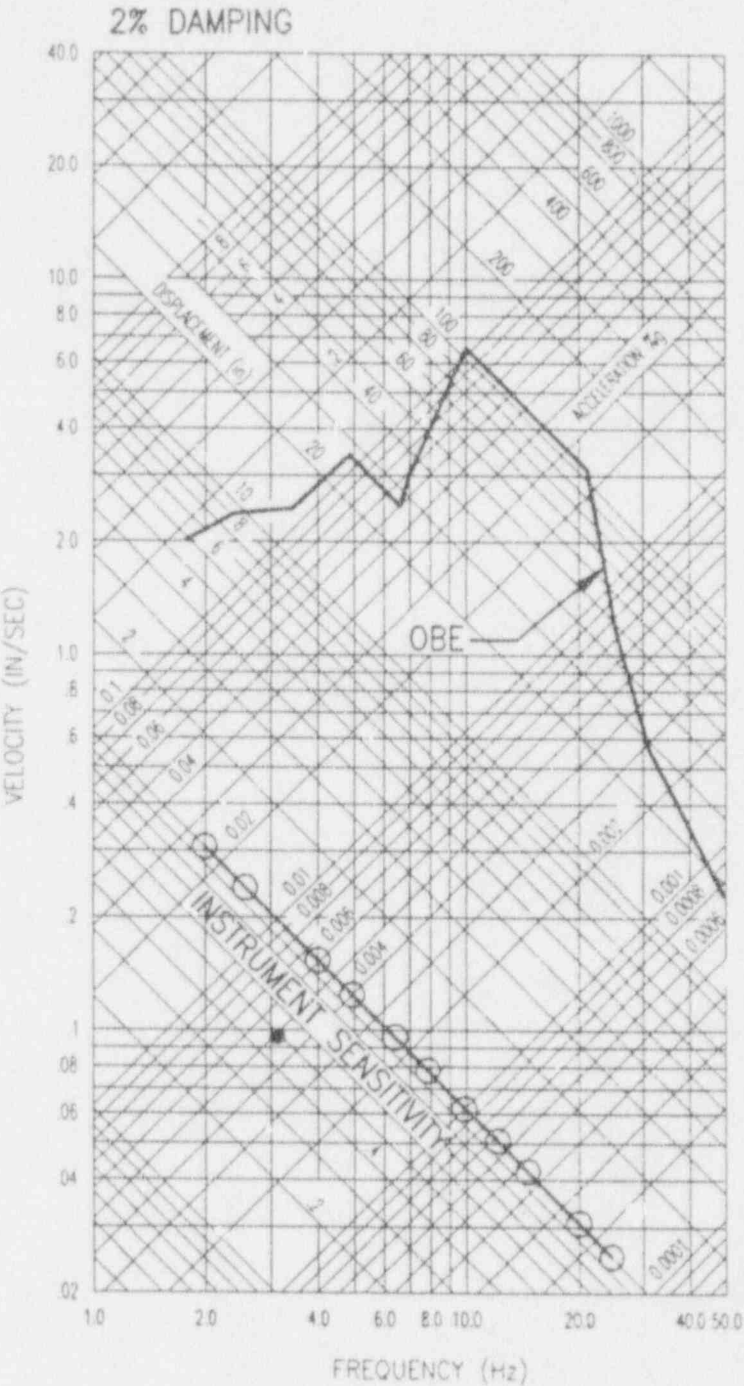
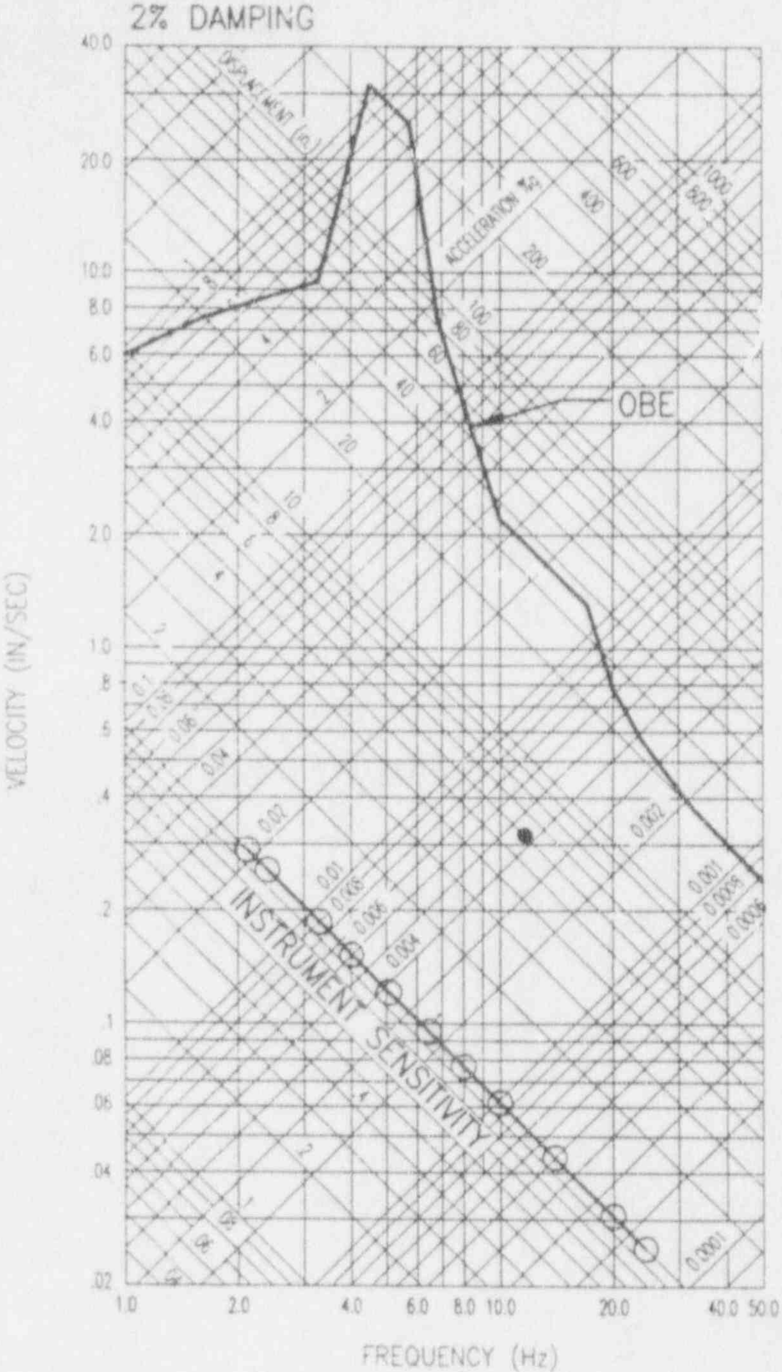


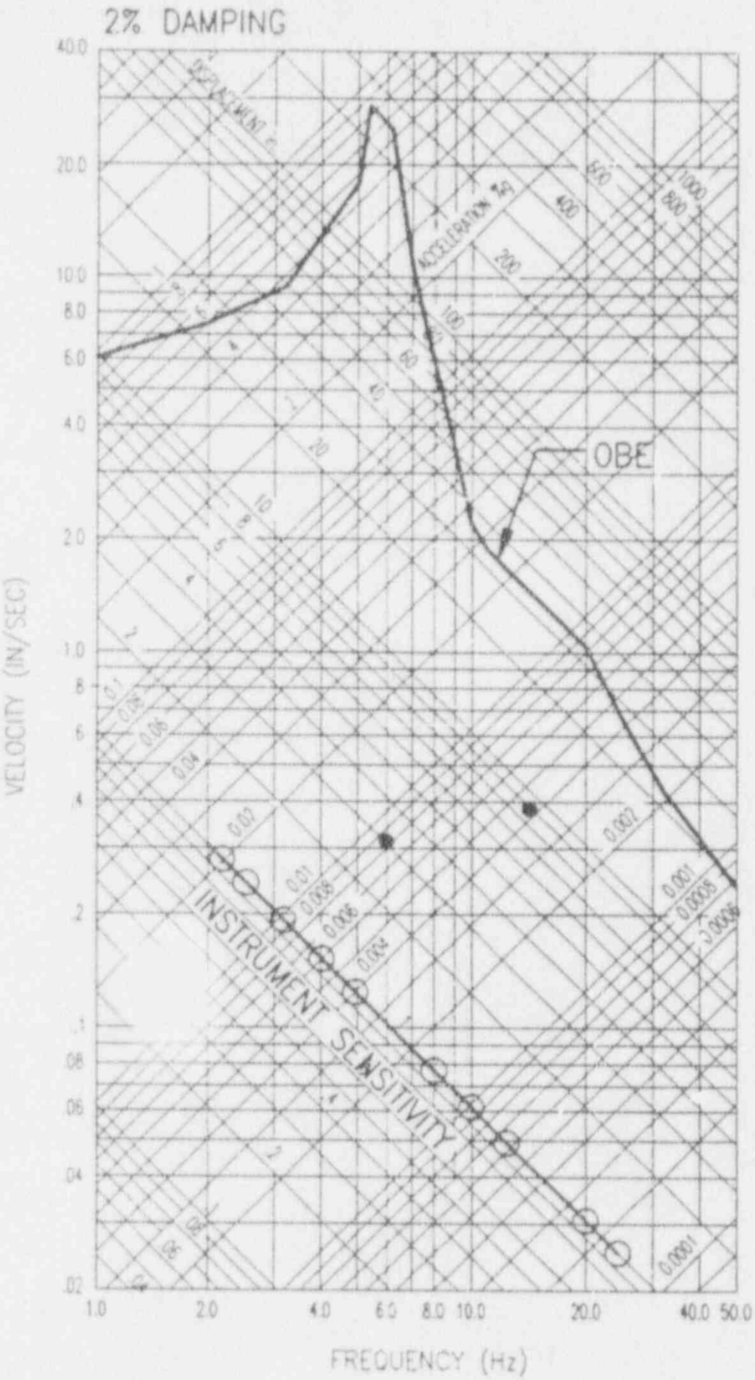
D30-N006 Passive Instrumentation, Vertical Response Spectra - Fifth Floor

Figure 3.2.1.7



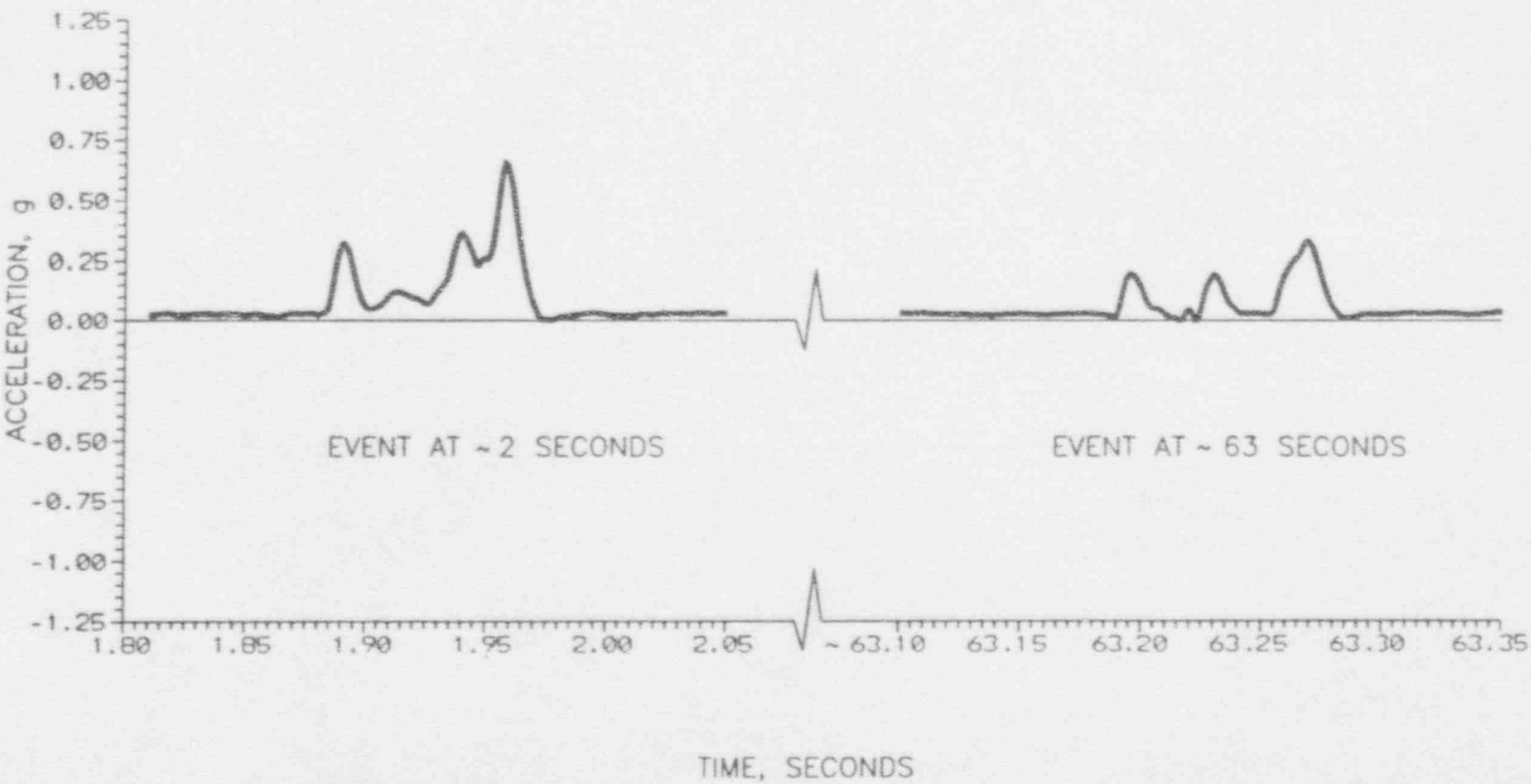
D30-N006 Passive Instrumentation, North/South Response Spectra - Fifth Floor

Figure 3.2.1.8



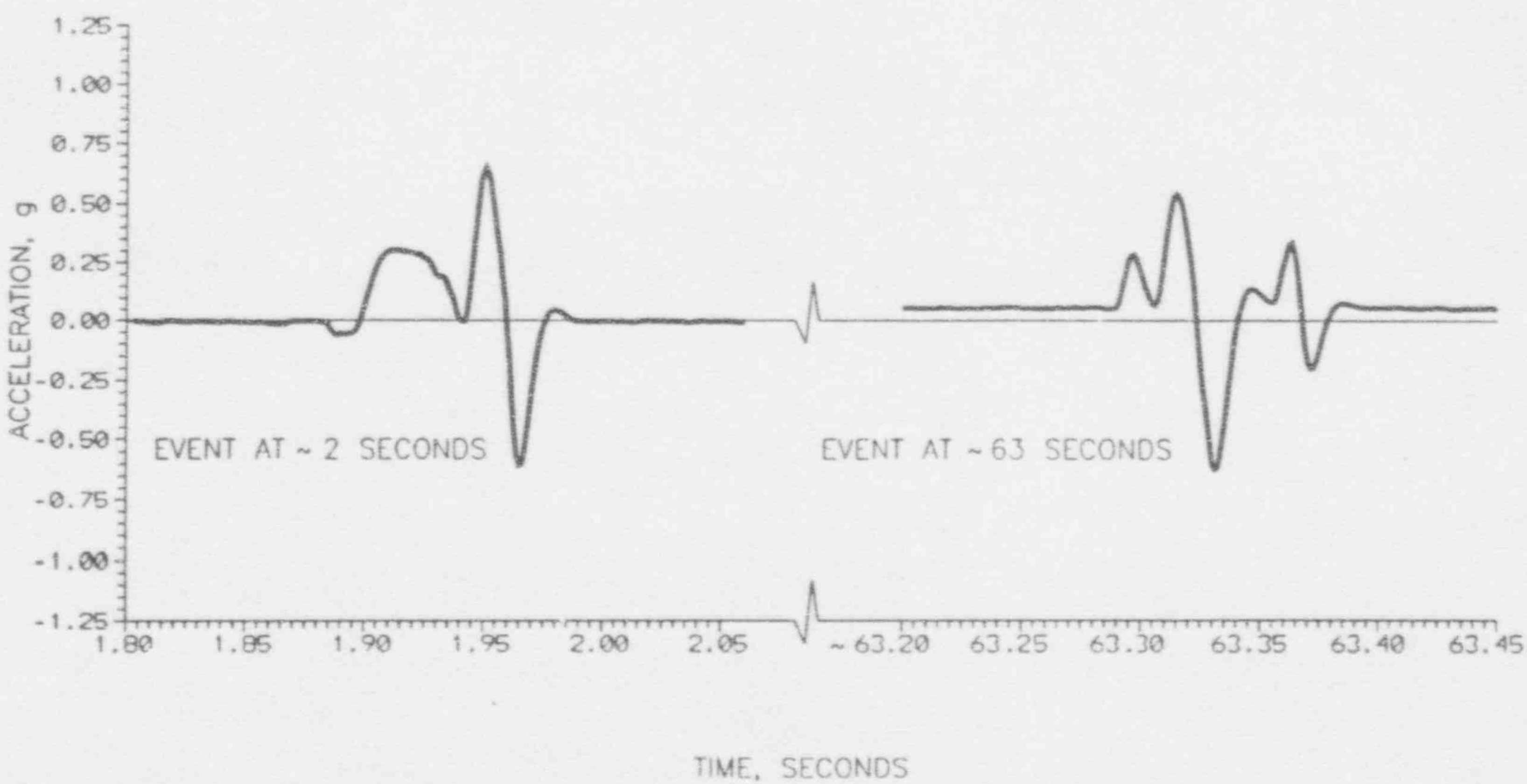
D30-N006 Passive Instrumentation, East/West Response Spectra - Fifth Floor

Figure 3.2.1.9



D30-N003 Accelerometer, Vertical Direction Time History - HPCI Room

Figure 3.2.2.1



D30-N003 Accelerometer, North/South Direction Time History - HPCI Room

Figure 3.2.2.2

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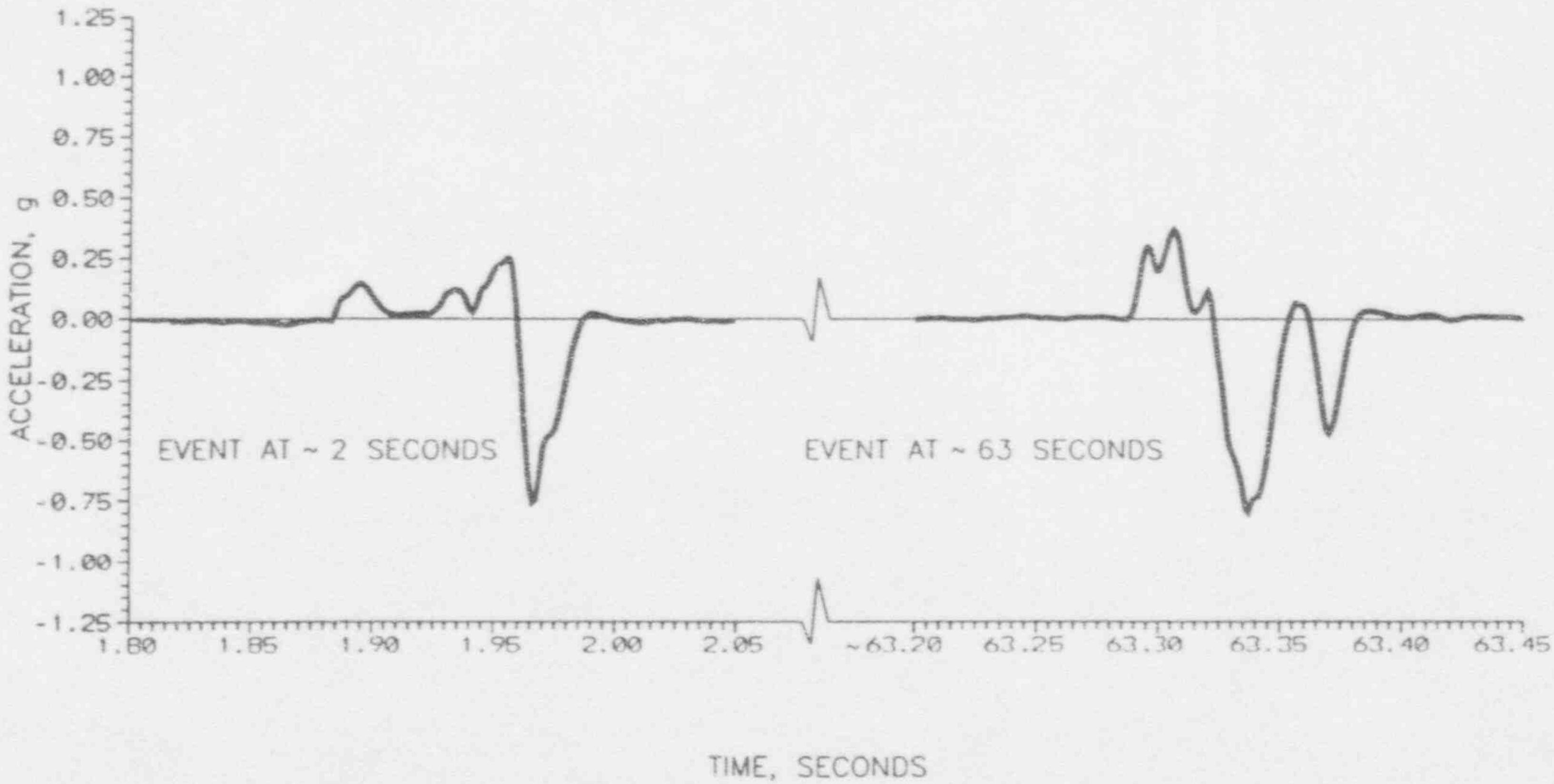
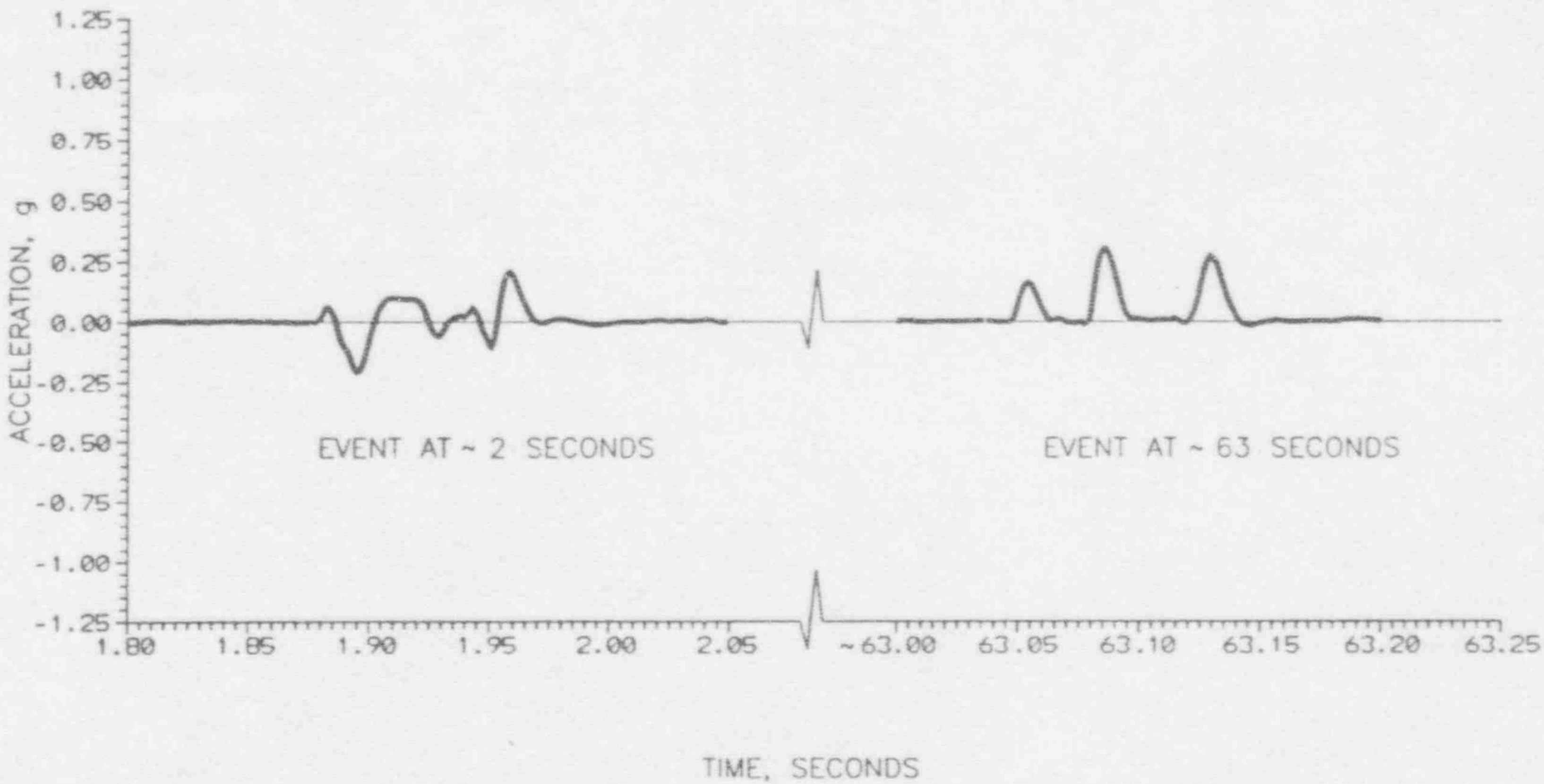


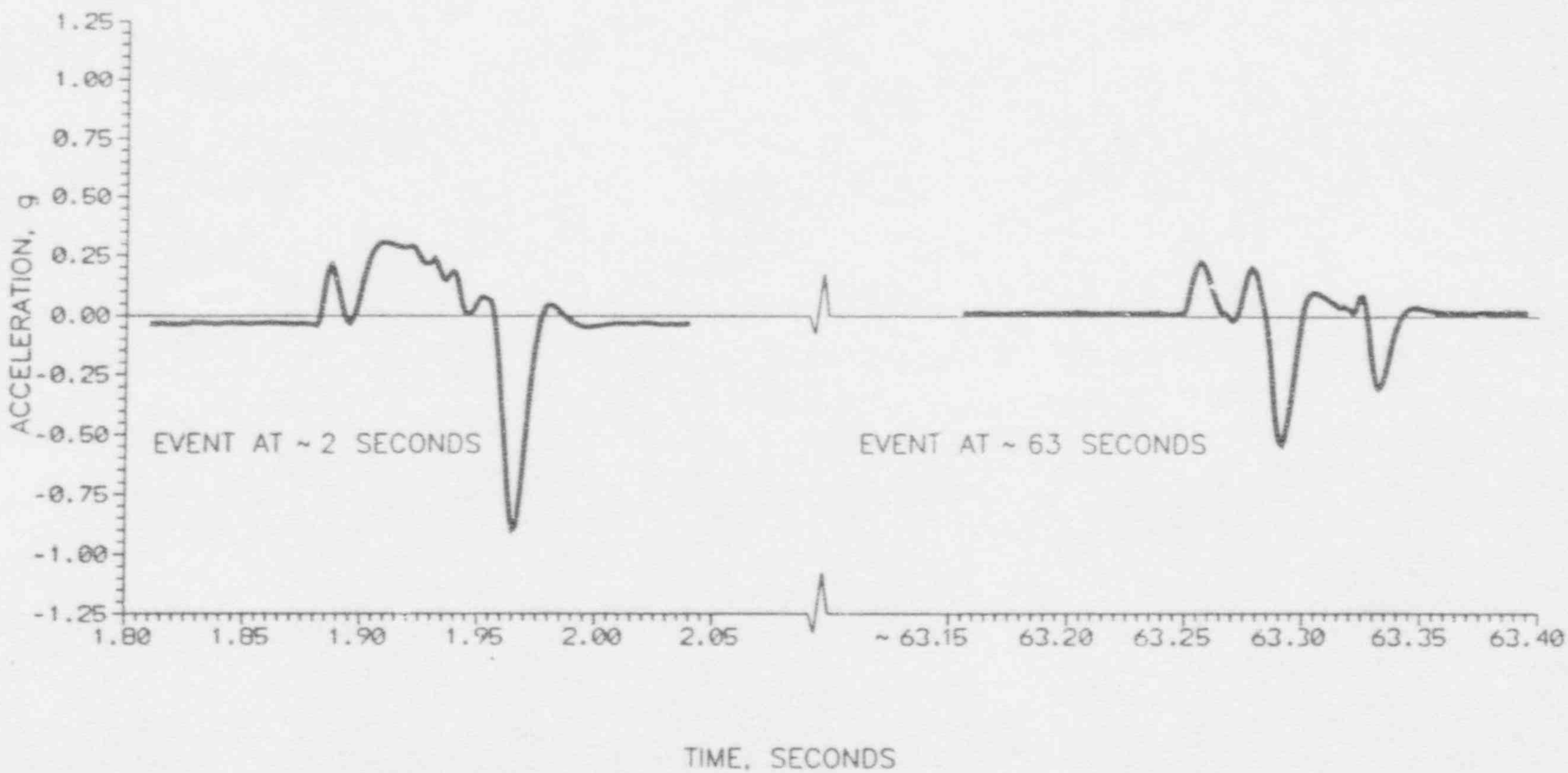
D30-N003 Accelerometer, East/West Direction Time History - HPCI Room

Figure 3.2.2.3



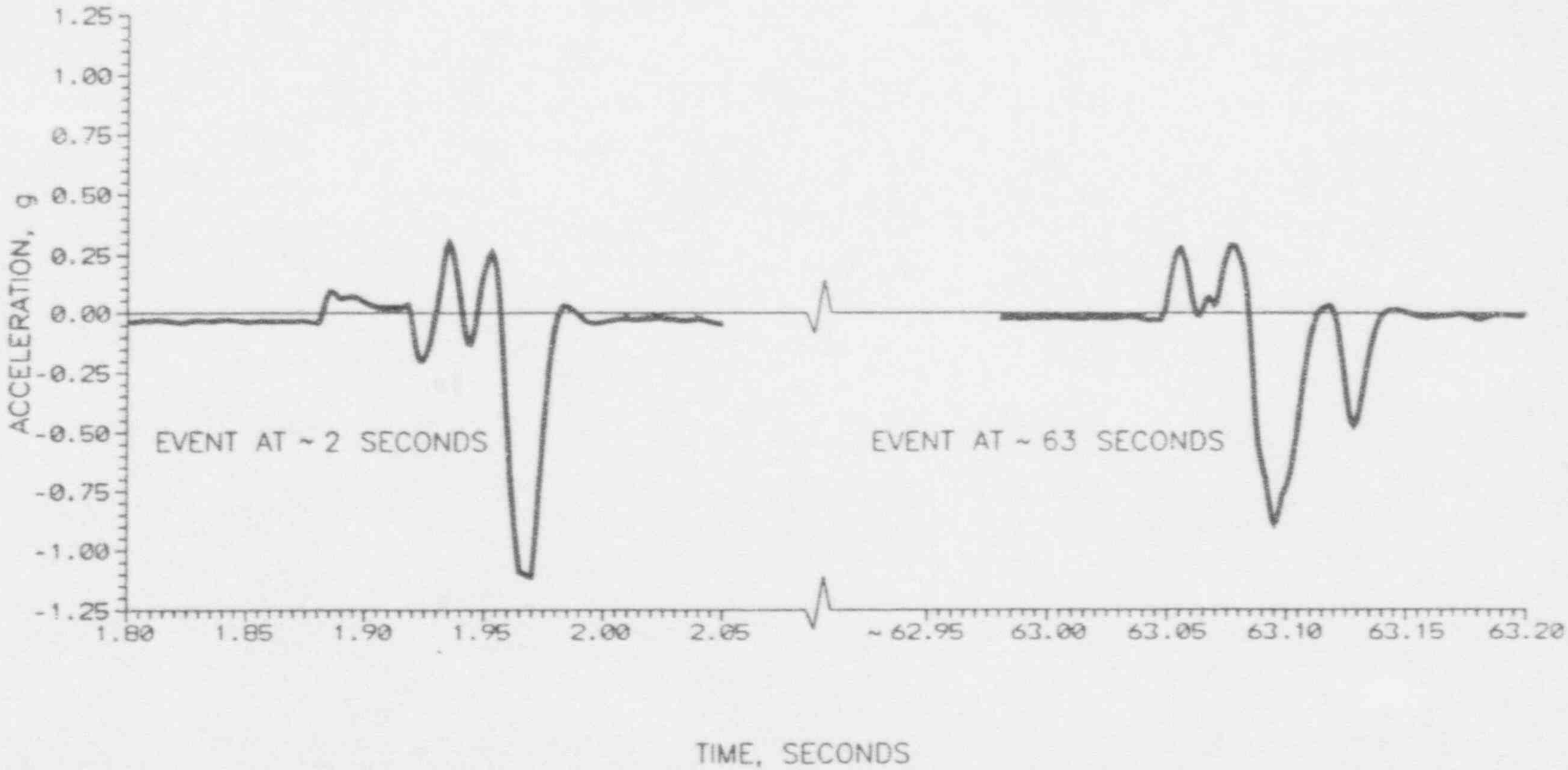
D30-N002 Accelerometer, Vertical Direction Time History - RPV Pedestal

Figure 3.2.2.4



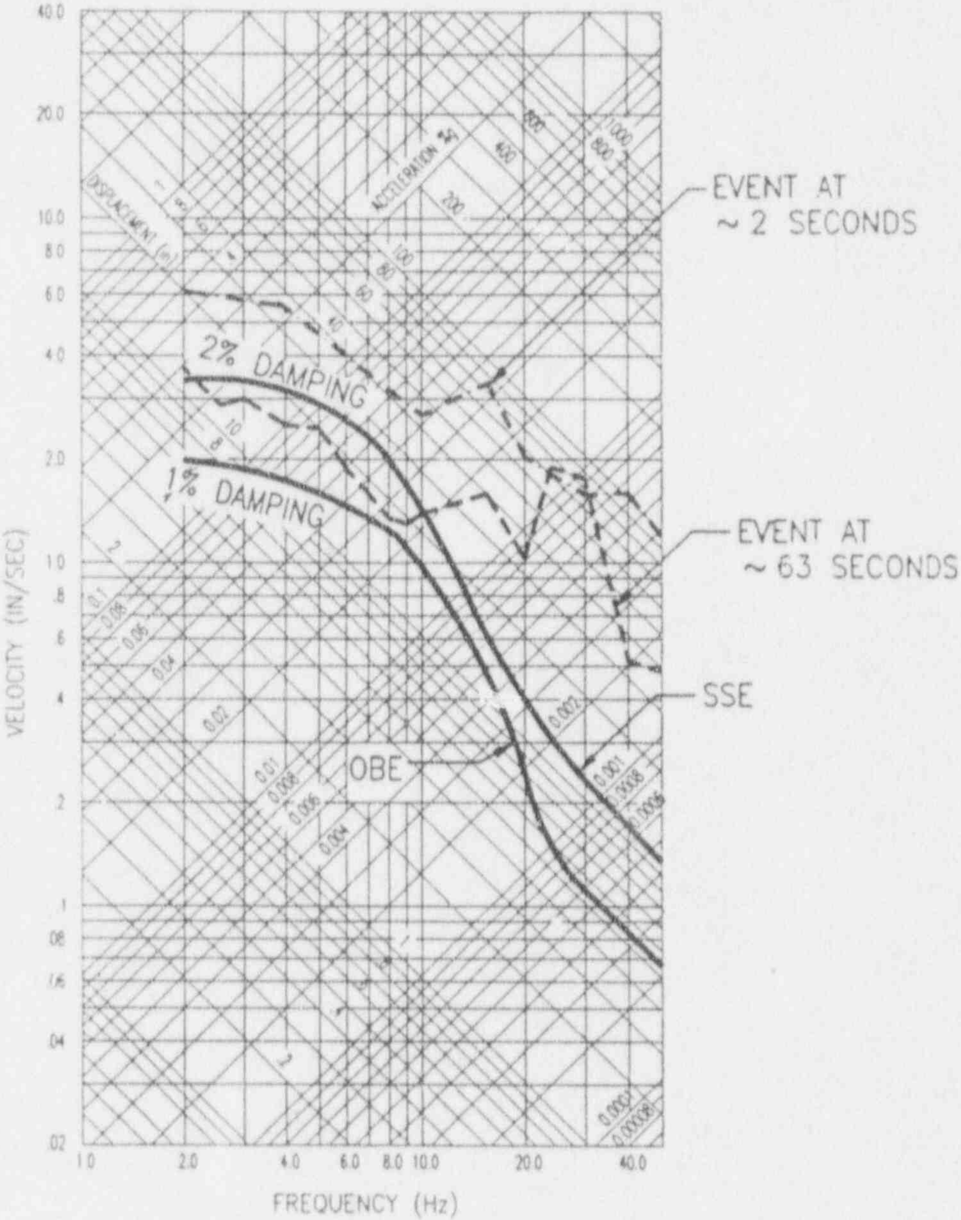
D30-N002 Accelerometer, North/South Direction Time History - RPV Pedestal

Figure 3.2.2.5



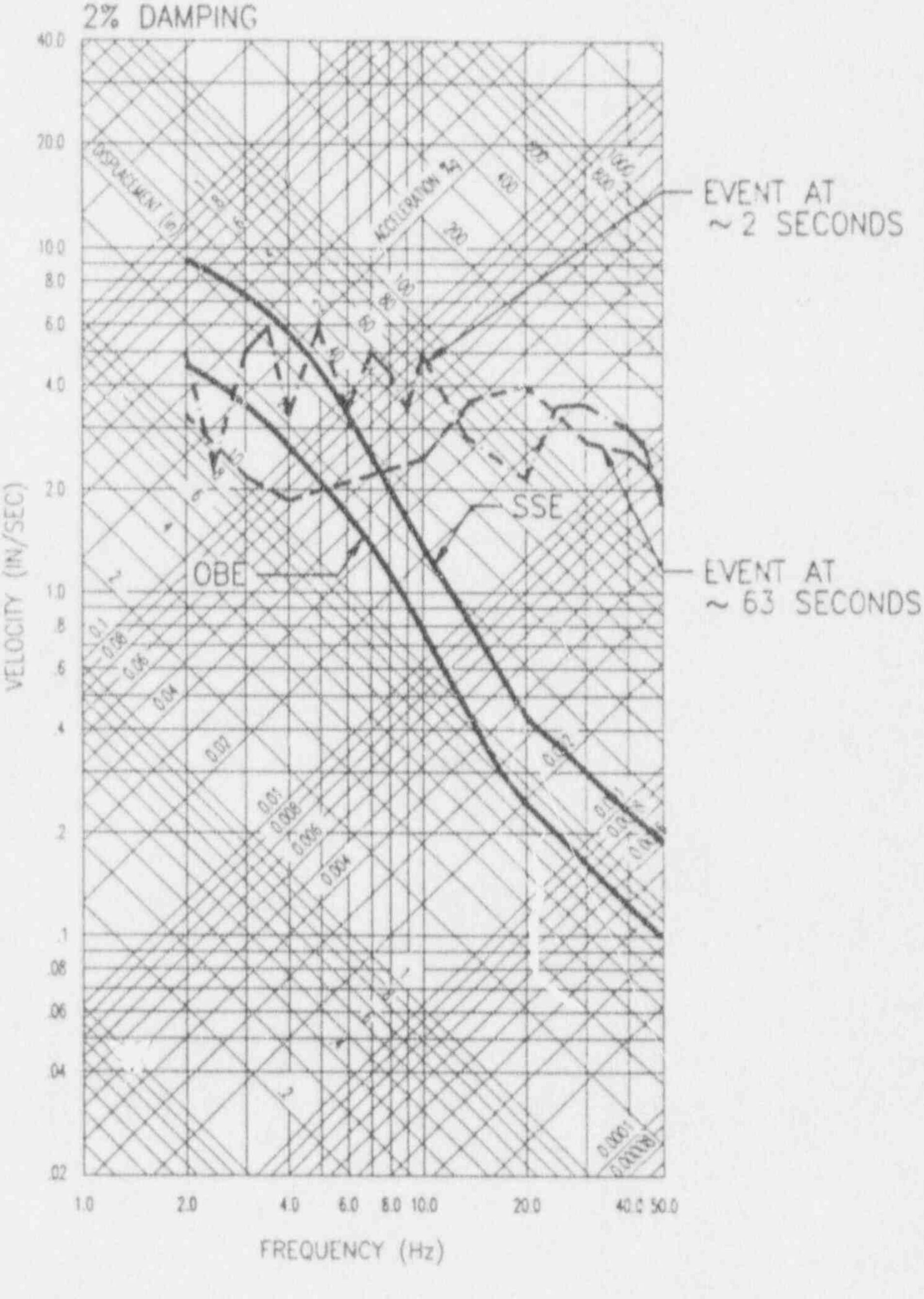
D30-N002 Accelerometer, East/West Direction Time History - RPV Pedestal

Figure 3.2.2.6



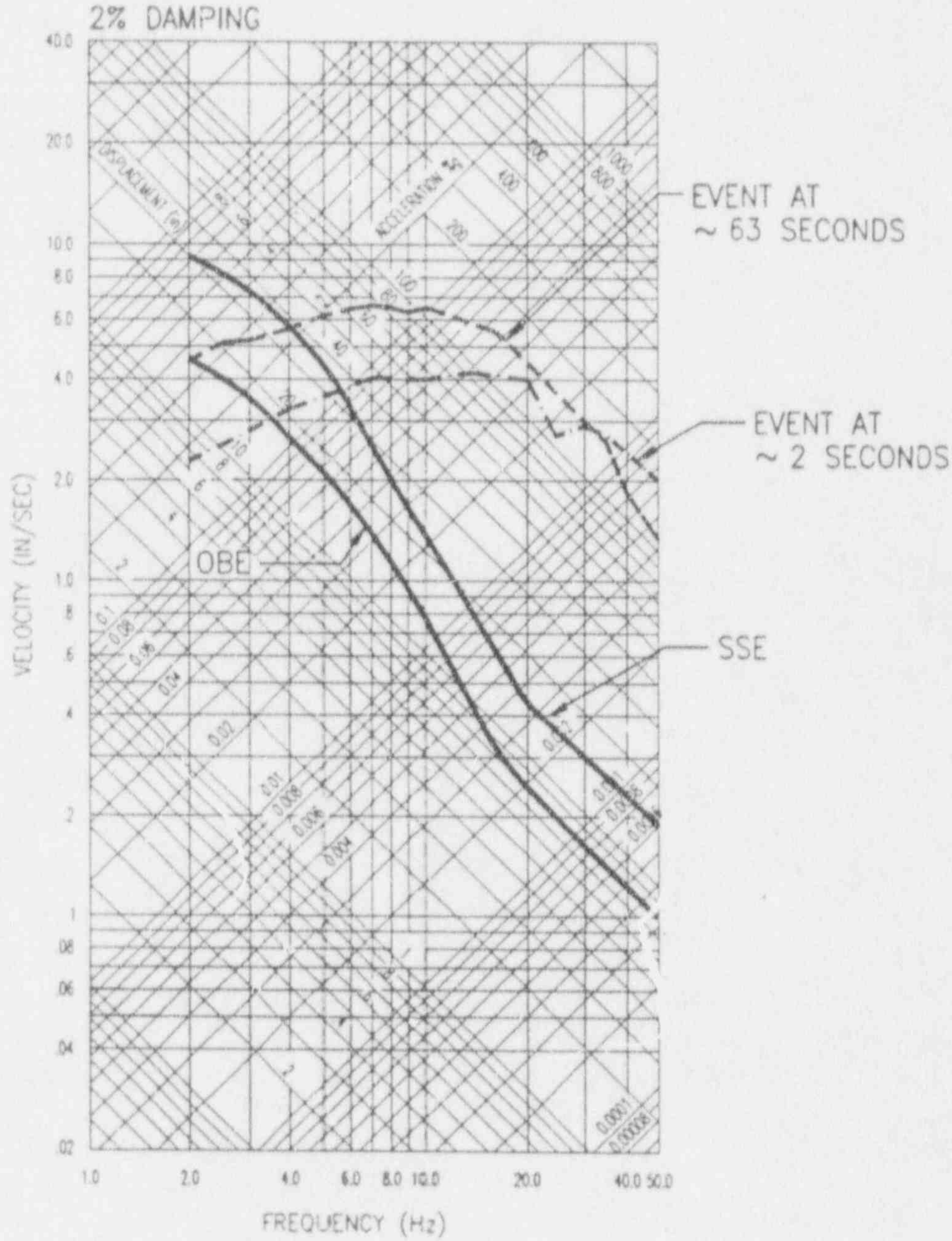
D30-N003 Accelerometer, Vertical Response Spectra - HPCI Room

Figure 3.2.2.7



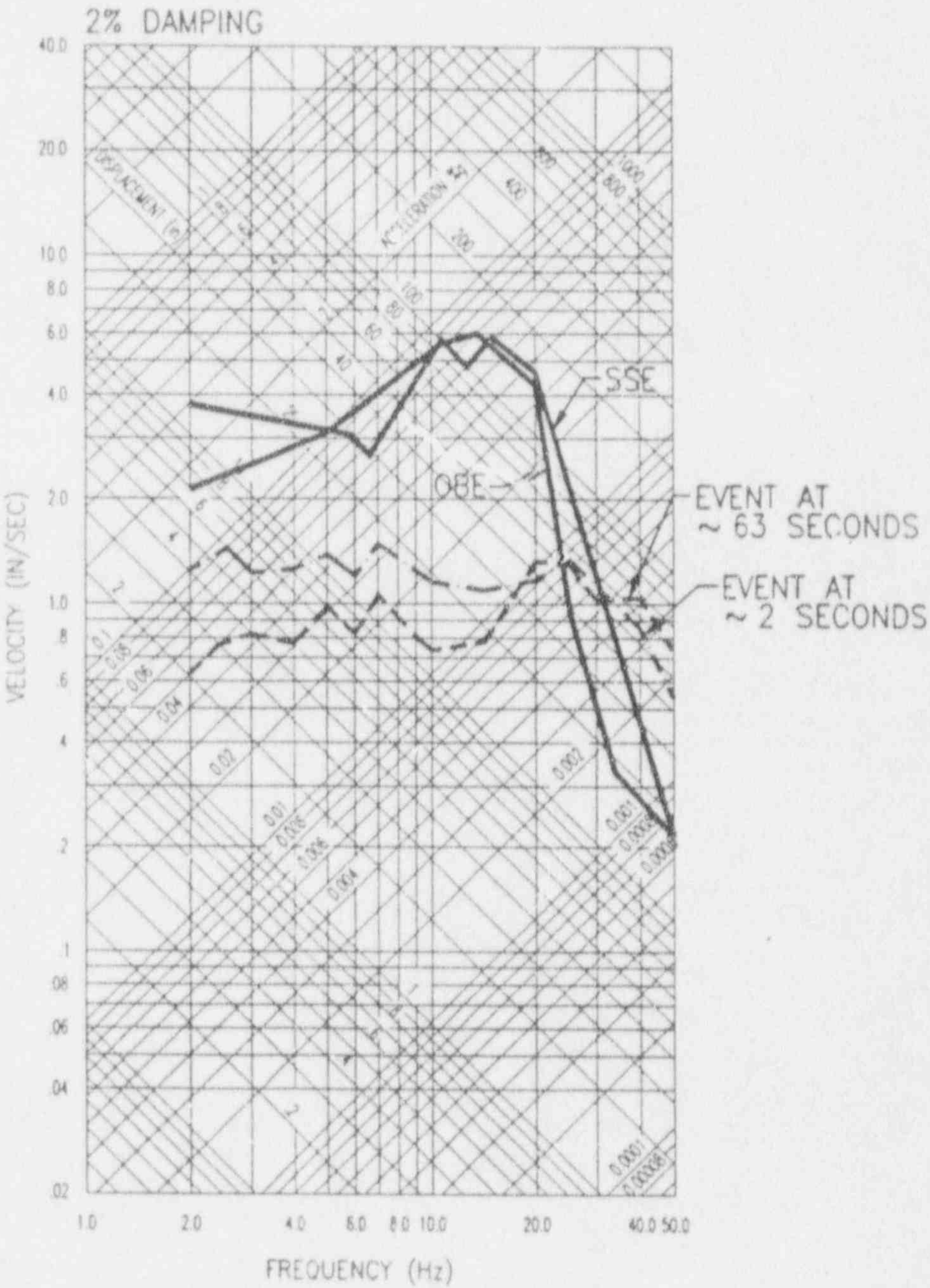
D30-N003 Accelerometer, North/South Response Spectra - HPCI Room

Figure 3.2.2.8



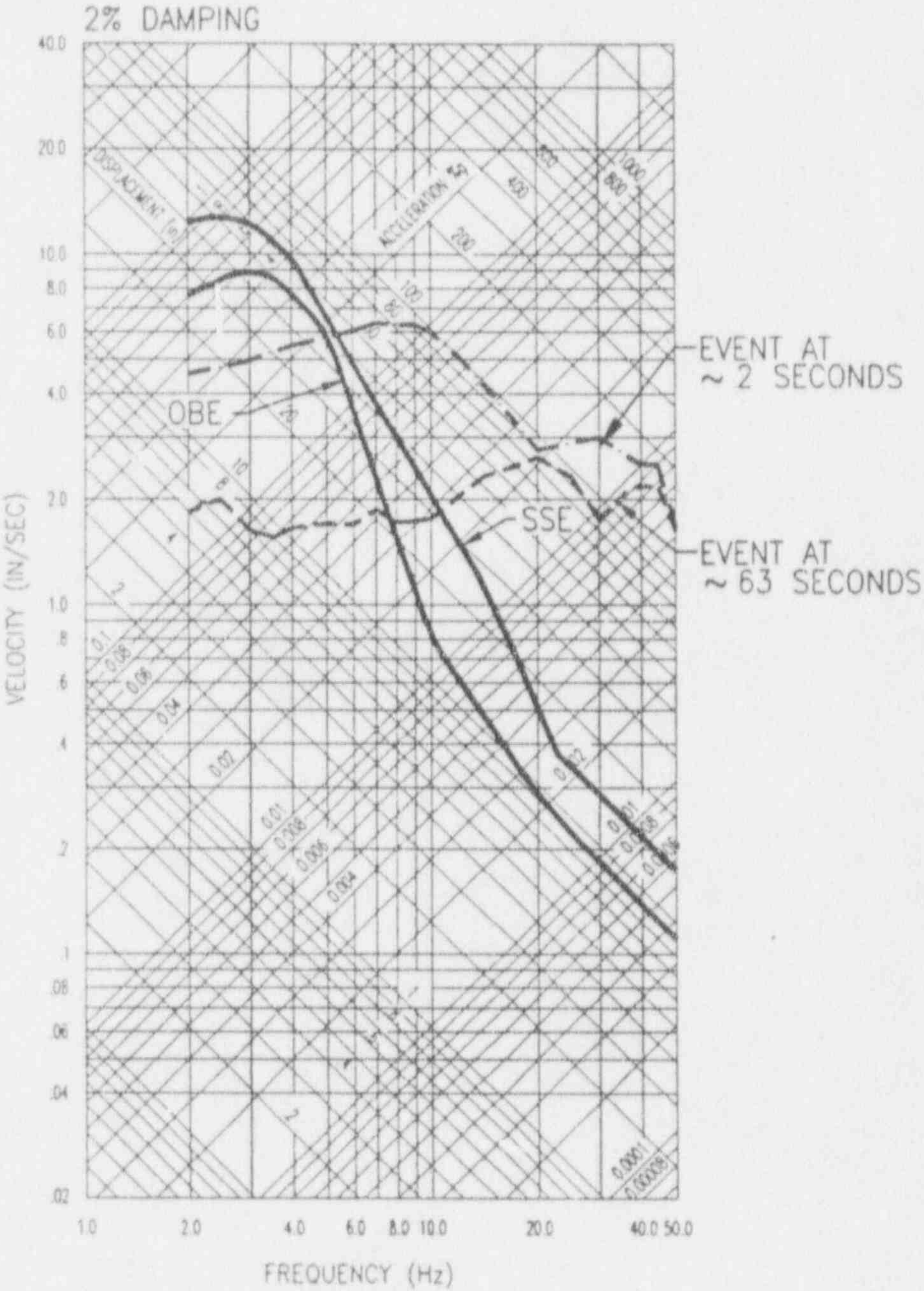
D30-N003 Accelerometer, East/West Response Spectra - HPCI Room

Figure 3.2.2.9



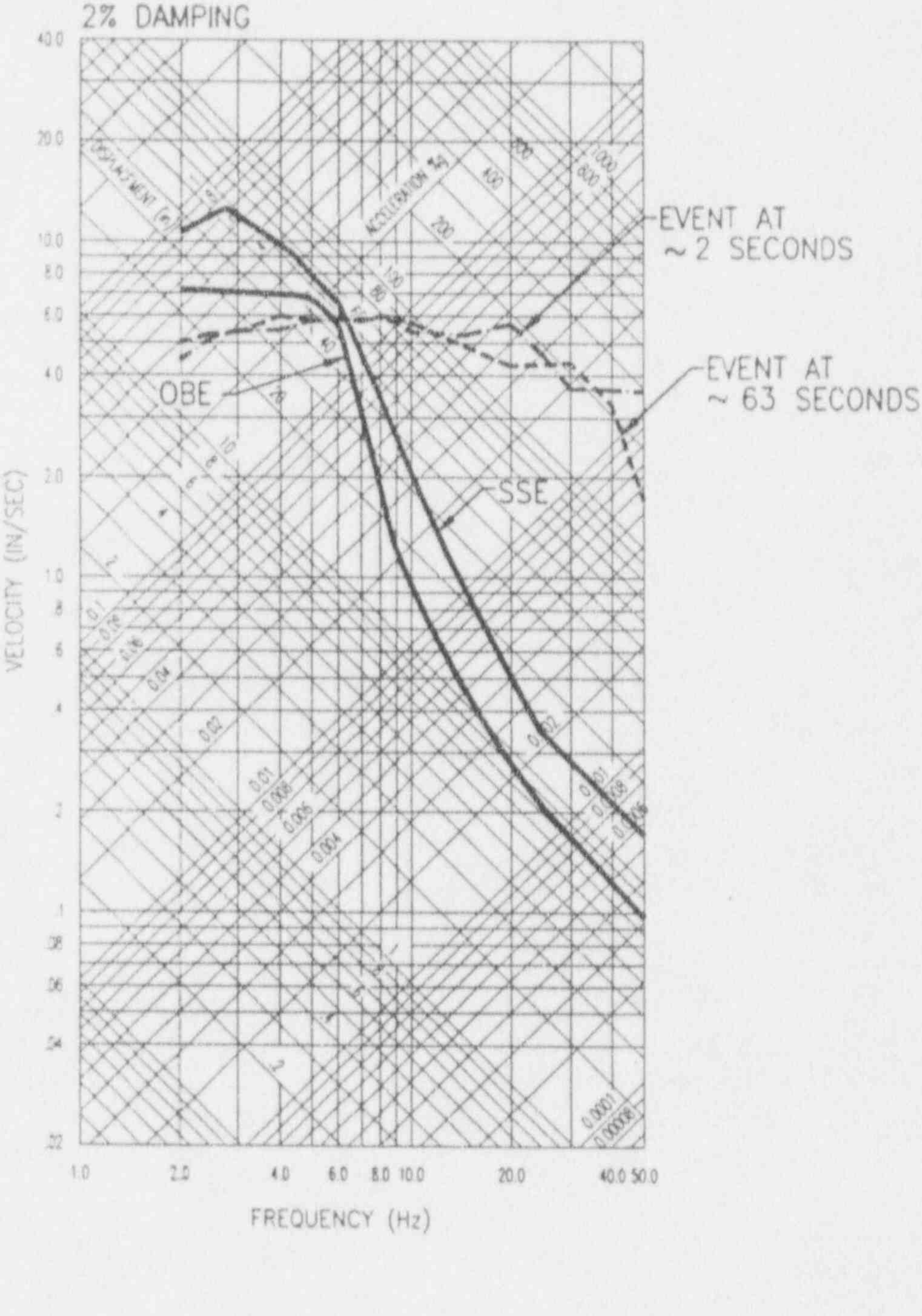
D30-N002 Accelerometer, Vertical Response Spectra - RPV Pedestal

Figure 3.2.2.10



D30-N002 Accelerometer, North/South Response Specura - RPV Pedestal

Figure 3.2.2.11



D30-N002 Accelerometer, East/West Response Spectra - RPV Pedestal

Figure 3.2.2.12

3.2.3 Active and Passive Data Correlation Comparison

The HPCI room passive instrumentation data for the vertical and east/west directions exhibited similar data trends and acceleration magnitudes compared to the active instrumentation. However, precise amplitude correlation at all frequencies was not possible.

Reasons for the anomalies likely are associated with the short duration of the events, and the intrinsic differences between the recording methods of the two instrumentation systems.

To fully understand the discrepancies, a further comprehensive study would need to be undertaken. However, the phenomenological similarity of the data is sufficient quantitatively to establish essential structural and equipment response characteristics at this time.

3.3 Results

The turbine failure on December 25, 1993, did not result in a significant Reactor/Auxiliary building dynamic excitation or a building global exceedence of the OBE. This was demonstrated by the insignificant accelerations recorded by the passive sensors on the second and fifth floors of the Reactor/Auxiliary building.

Below the second floor in the foundation, the building and equipment experienced local OBE and SSE exceedences recorded by the active and passive sensors located at the RPV pedestal and the HPCI room sub-basement.

The active instrumentation at the RPV pedestal exhibit OBE and SSE exceedences at higher frequencies in all directions. The RPV pedestal sensor in the vertical direction is less severe than the HPCI room vertical direction, while the other directions are similar.

Instrumentation in the HPCI room also experienced local OBE and SSE exceedences. The active instrumentation exhibit OBE and SSE exceedences in the vertical direction, and OBE exceedences in the high frequencies in the north/south and east/west directions. The passive exhibit OBE exceedences in the low and high frequencies. The HPCI room vertical and east/west passive plates show very similar data trends and acceleration magnitudes compared to the HPCI room active vertical and east/west data records.

Generally, the event at time two seconds was more severe than the event at time one minute.

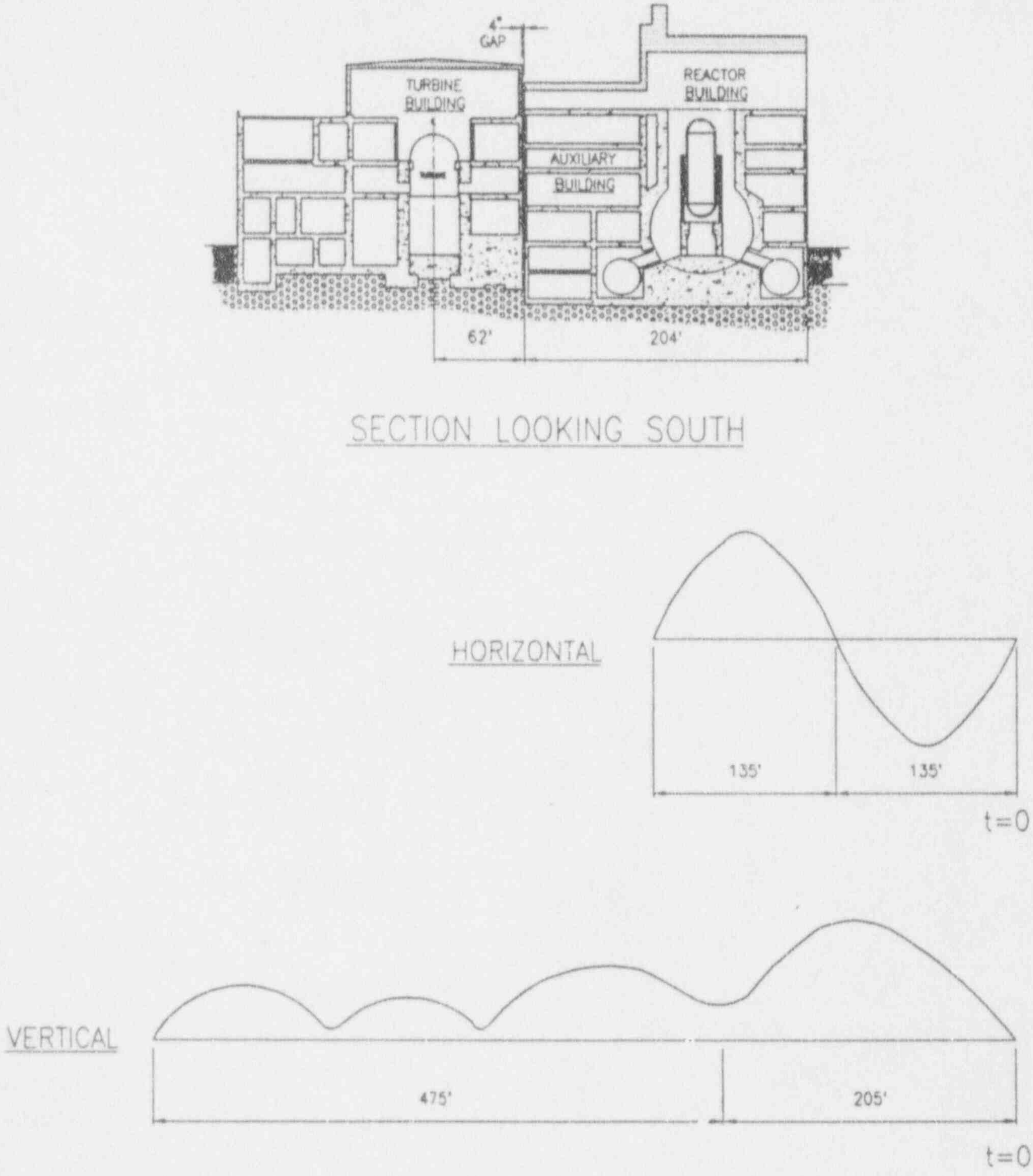
All equipment in the building functioned as expected during the turbine failure and reactor shutdown. An inspection after the event produced no indications of structural damage. Furthermore, the extant safe shutdown equipment adequacy was proven by the satisfactory safe shutdown experience.

4.0 CONCLUSION

The turbine failure at Fermi 2 on December 25, 1993, should not be compared with a tectonic earthquake, and globally, the Reactor/Auxiliary building did not experience OBE excitation levels. The turbine failure was a shock incident, resulting in dynamic response phenomena or two single cycle waves propagating through the building foundation without exciting the structure above (Figure 4.0.1).

An earthquake imparts long duration, broad range frequencies, and high energy into a structure, while a shock impulse imparts short duration, high amplitude, and low energy into a structure. Industry standards recognize shock impulses do not cause significant structural stresses (Figure 4.0.2).

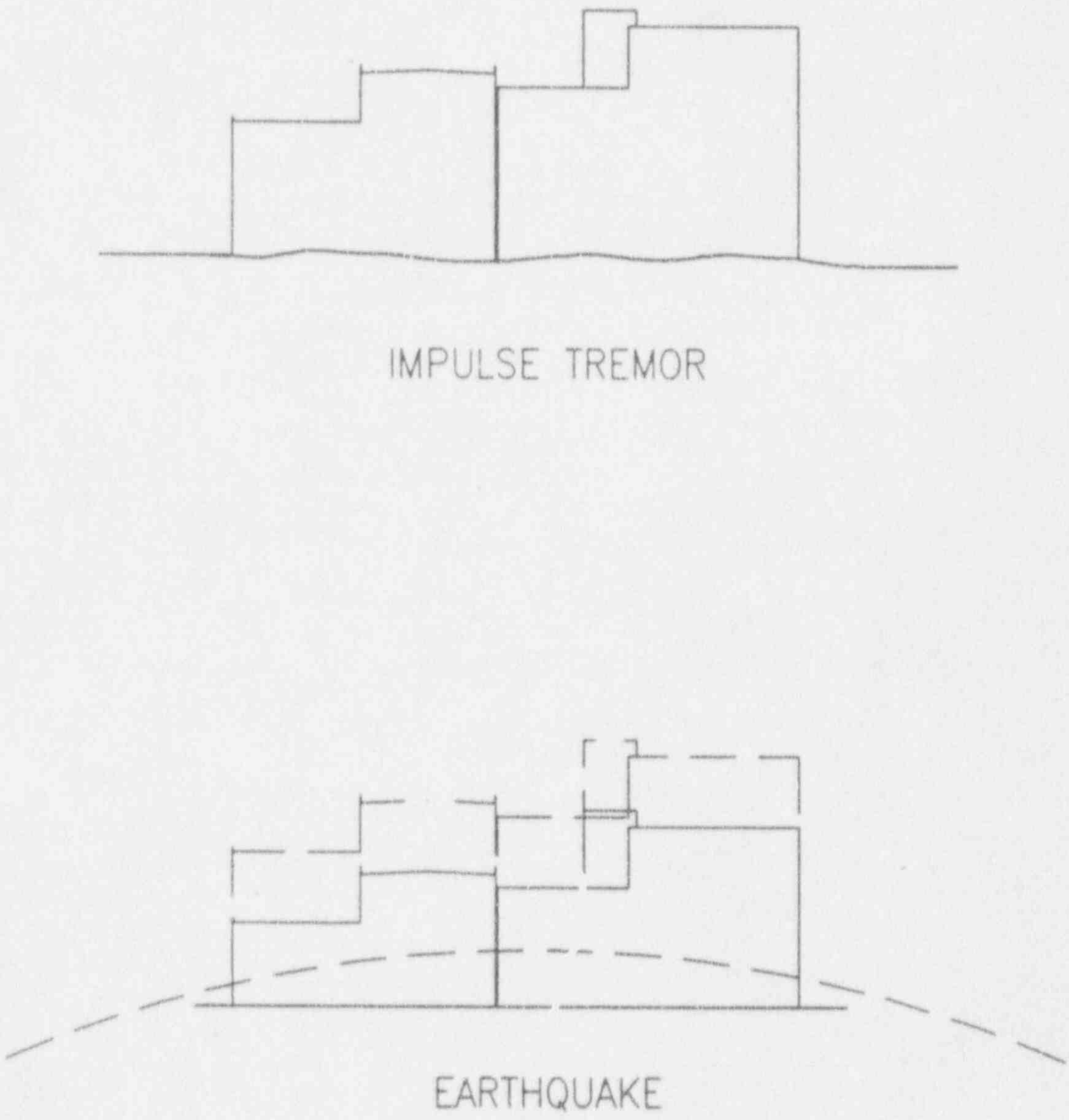
The shock wave length resulting from the turbine event at Fermi 2 was small compared to the building, and therefore produced local high accelerations, but the short duration, low energy, and small deformations associated with these high frequency accelerations did not compromise the structural integrity of the Reactor/Auxiliary building or the equipment therein.



Schematic Representation of Shock Impulse Wave Length

Compared to Building Dimension

Figure 4.0.1



Schematic Representation of Impulse Tremor Versus

Earthquake Wave - Vertical Direction

Figure 4.0.2

5.0 REFERENCES

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