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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

MAR 3 1980

MEMORANDUM FOR: S. A. Varga, Acting Assistant Director
for Light Water Reactors
Division of Project Management

FROM: J. P. Knight, Assistant Director
for Engineering
Division of Systems Safety

SUBJECT: BOARD NOTIFICATION REGARDING NUREG/CR-0345 ENTITLED "AN EVALUATION OF SEISMIC QUALIFICATION TESTS FOR NUCLEAR POWER PLANT EQUIPMENT"

We have reviewed the attached subject report. The staff evaluation of this report is attached. Because the information in the report and the staff evaluation are relevant to all plants in licensing, we recommend that this information be provided to all Boards before which there are pending applications.

Since equipment qualification was a matter before the Diablo Canyon Board and since the Appeal Board is now considering the Intervenor's brief on the Diablo Canyon appeal and the Staff's and Applicant's responses, we request that the Diablo Canyon Appeal Board and Licensing Board be provided with this information as soon as possible.

J. P. Knight, Assistant Director
for Engineering
Division of Systems Safety

cc: R. Mattson
D. Ross
D. Eisenhut
L. Shao
V. Noonan
R. Bosnak

NRR Staff Evaluation of NUREG/CR-0345

I. PURPOSE OF THIS RESEARCH:

To meet seismic requirements safety related equipment is generally qualified by testing. The test input (shake table motion) is expected to adequately simulate the specific seismic environment and to consider its sensitivity to equipment response, which may vary greatly from case to case. Since the regulatory position must be general in nature, the selection of a test input for a specific application needs experience and engineering judgement. Because simpler test inputs have been used in many cases for equipment qualification before the existence of the current criteria, this research program was requested and intended to provide a basis for comparing the effectiveness of various test inputs.

II. ACHIEVEMENTS & COMMENTS:

Studies were conducted by subjecting one typical electrical cabinet to shake table tests using different wave forms. No internal electrical equipment of any kind was tested with the cabinet, and the effects of the test input on equipment operating function was not included in the investigation.

Primary findings and staff comments are as follows:

1. A numerically defined "Damage Severity Factor" (DSF) was developed and introduced as a way for comparing severity of various types of seismic qualification test inputs.

   When the DSF is fully developed, it may have the potential to assess relative damage that can be inflicted by earthquake transients or test inputs to structural components. However, no immediate application of the DSF to equipment seismic qualification is recommended in its present form. The relationship between DSF and equipment operability requires further investigation.

2. The research results concluded that the single frequency sine dwell and sine beat tests are far more severe in general than the biaxial random tests for verifying structural integrity of passive equipment and supports.

   We are aware that the single frequency sinusoidal test input at resonance is generally a very severe structural test, but this is not the case from the standpoint of verifying the operability of active equipment. Single frequency sinusoidal testing also does not necessarily yield valid results when testing to determine resonance. This fact was known to the staff through licensing reviews since 1972 when a revision of IEEE Standard 344, 1971 was initiated at the request of NRC. Nevertheless, these research results provide a useful independent conformation of the above facts.

3. It was found that there were some differences between modal data obtained from the same cabinet when mounted to a concrete floor and when mounted on the shake table.

It is a well known fact to dynamicists that modal data will be effected whenever the boundary conditions are changed and whenever dynamic coupling exists between the fixture and the test item. An MEB Branch Position developed in 1973 emphasized that items being tested should simulate service mounting and should avoid dynamic coupling with the fixture. This position was later adopted in the Standard Review Plan, Section 3.10 issued in 1974 and also incorporated in the revised IEEE Standard 344 in 1975. Equipment mounting has remained a concern of the SQRT audit program since its initiation in 1974 and continues to receive special attention in our review process. The research results provided further justification that our concerns are valid.

4. It was revealed that some deficiencies may exist in the use of response spectrum for seismic qualification testing. It was stated that the criterion requiring the response spectrum of testing input (TRS) to envelope the specific response spectrum required for the equipment qualification (RRS) may not ensure proper energy distribution through the range of frequencies tested and may actually induce an excessive zero period acceleration (ZPA), which, in turn, may cause an over test.

   Although the development of explicit and generic guidance to achieve proper energy distribution and proper ZPA has not yet been completed, these shortcomings can be avoided if the wave form of the test input is carefully reviewed. The complex wave forms used by Westinghouse in their 1974 and 1975 generic testing programs were typical examples of carefully reviewed test input wave forms. The staff has constantly addressed such concerns in licensing reviews since 1974, when SQRT started systematic plant seismic audits, especially on those items of equipment tested at an earlier date. The research results have provided further evidence of our concerns. In order to improve the regulatory process, further efforts in this area have been recommended and have been incorporated into a request for contract proposal to be issued by the Office of Nuclear Regulatory Research in the near future. The IEEE Standards Committee responsible for developing equipment seismic qualification guidance was also informed of the research results for possible refinement of their current criteria.

III. CONCLUSIONS:

In summary, the research results provide a useful and independent confirmation of certain staff concerns which have existed for several years. These concerns are either already explicity stated in the existing regulatory position, or have been addressed in past licensing reviews. These research results do not impact the regulatory process at the present time but future efforts by RES or the IEEE Standards Committee refining their current criteria may have impact.

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Bailly	50-367(CPE)
Barnwell	70-1729
Barton 1-4	50-524-527
Big Rock	50-155
Black Fox	50-556,557
Blue Hills 1 & 2	50-510,511
Braidwood	50-456-457
Browns Ferry 1 & 2	50-259,260OL
Byron	50-454,455
Carroll County Site	50-599,600
Cherokee 1, 2 & 3	50-491-493
Clinton 1 & 2	50-461,462
Comanche 1 & 2	50-445,446
Davis-Besse	50-500,501
Davis-Besse 1	50-346(SP)
Diablo Canyon 1 & 2	50-275,323OL
Douglas Point 1 & 2	50-448,449
Dresden 2 & 3	50-237,249
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Erie 1 & 2	50-580,581
EXXON Nuclear	50-564
Fermi-2	50-341
Floating Nuclear Power	50-437
Fort Calhoun Unit 2	50-548
Fulton	50-463,464
GE Morris (Amendment)	70-1308(EA)
GE Morris (Renewal)	70-1308
Ginna 1	50-244
Greene County	50-549
Greene County	50-549A
Greenwood 2 & 3	50-452,453
Hartsville 1-4	50-518-521
Haven	50-502
Hope Creek	50-354,355
Humboldt Bay	50-133
Indian Point 1, 2 & 3	50-3,286(SC)
Indian Point 2	50-247
Indian Point 3	50-286
Jamesport 1 & 2	50-516,517
La Crosse BWR	50-409
Marble Hill 1 & 2	50-546,547
McGuire 1 & 2	50-369,370
McGuire 1 & 2/Oconee	70-2623
Midland 1 & 2 (OL)	50-329,330OL
Midland 1 & 2 (Remand)	50-329,330
Monticello	50-263
New Haven 1 & 2	50-596,597
North Anna 1 & 2 (OL)	50-338,339OL
North Anna 1 & 2 (SP)	50-338,339SP
North Coast	50-376
Nuclear Fuel Services	50-201
Palisades	50-255SP
Palo Verde 4 & 5	50-592,593
Peach Bottom 2 & 3	50-277,278
Pebble Springs	50-514,515
Perkins 1, 2 & 3	50-488-490
Perkins 1, 2 & 3/Cherokee 1, 2 & 3	50-488,491
Perry 1 & 2	50-440,441
Phipps Bend 1 & 2	50-553,554
Pilgrim	50-471
Point Beach 1 & 2	50-266,301
Rancho Seco	50-312(SP)
River Bend 1 & 2	50-458,459
Robinson	50-261OL
Salem 1	50-272

FACILITY	DOCKET NO.
San Onofre 2 & 3	50-361,362OL
Seabrook Station 1 & 2	50-443,444
Shearon Harris 1, 2, 3 & 4	50-400-403
Sheffield Low-Level (NECO)	27-39
Shoreham	50-322
Skagit	50-522,523
South Texas	50-498,499
St. Lucie 2	50-389
Sterling 1	50-485
Summer	50-395
Sundesert	50-582,583
Susquehanna 1 & 2	50-387,388
Three Mile Island 1	50-289
Three Mile Island 2	50-320
Trojan	50-344(CB)
Turkey Point	50-250,251
Vallecitos	50-70
Vallecitos	50-70(SC)
Vallecitos	70-754
Waterford 3	50-382
Wm. H. Zimmer 1	50-358
Wolf Creek	50-482
WPPSS 1 & 4	50-460,513
Yellow Creek 1 & 2 (Appeal Board)	50-566,567A
Yellow Creek 1 & 2 (Licensing Board)	50-566,567
Zion 1 & 2	50-295,304

NAME	DOCKET NO.
Aamodt, Marjorie M.	50-289
Abate, Samuel J.	50-596,597
Abbott, William S.	50-471
Abrams, Harold P.	50-437
Adams, Dirk S.	50-485
Adler, Theodore A.	50-463,464
Adler, Theodore A.	50-289
Agee, Dean P.	50-338,339OL
Ahearne, John F.	
Allen, June	50-338,339OL
Anderson, George C.	50-409
Anderson, George C.	50-255SP
Anderson, George C.	50-485
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Anderson, Terence J.	50-289
Anderson, W. W.	50-277,278
Andrews, William	50-367
Apfelberg, Elizabeth	50-275,323OL
Asperger, Robert G.	50-452,453
Attalla, Mitchell	50-437
Axelrad, Maurice	50-367
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Axelrad, Maurice	50-344(CB)
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Bachrach, Shirley L.	50-516,517
Backus, Robert A.	50-443,444
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Baldwin, Andrew	50-70(SC)
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Bard, Larry	50-592,593
Barnes, Michael R.	50-448,449
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Barry, III, David N.	50-592,593
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Bechhoefer, Esq., Charles	50-387,388
Bechhoefer, Esq., Charles	50-358
Beckwith, David	50-502
Begany, George V.	50-3,286(SC)
Begany, George V.	50-247
Begany, George V.	50-286
Bell, Nina	50-344(CB)
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Berrynill, Frieda	50-289
Bickwit, Leonard	50-3,286(SC)
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Bielawski, Alan P.	50-556,557
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Bishop, Margaret	50-466
Blake, E.	50-382
Blankenburg, Richard E.	50-275,323OL
Blau, Howard L.	50-322
Blau, Joel	50-516,517
Blinn, William A.	50-440,441

NAME	DOCKET NO.
Block, Joseph D.	50-247
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Bloom, Myron	50-277,278
Blum, Shelley	50-369,370
Bock, C. Allen	50-456-457
Boomsma, George L.	50-463,464
Boskey, Bennett	70-1729
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Cole, Richard F.	50-367(CPE)
Cole, Esq., Richard	50-445,446
Coleman, Jr., Alfred C.	50-272
Coll, Norman A.	50-389
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Collister, Jr., Edward G.	50-482
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Conner, Jr., Troy B.	50-277,278
Conner, Jr., Troy B.	50-458,459
Conner, Jr., Troy B.	27-39

NAME	DOCKET NO.
Conner, Jr., Troy B.	50-358
Conrad, Vaughn L.	50-556,557
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Coufal, Esq., Frederic J.	50-488,491
Cowan, Barton Z.	50-437
Cowan, Frederick P.	50-259,260OL
Cowan, Frederick P.	50-580,581
Cowan, Frederick P.	50-329,330OL
Cowan, Frederick P.	50-201
Cox, Jr., John W.	50-599,600
Crane, Jr., Philip A.	50-275,323OL
Crane, Jr., Phillip A.	50-133
Craythorn, Gary E.	50-592,593
Cumings, Elinore P.	50-466
Cunningham, Jordan D.	50-289
Cunningham, Jr., Walker C.	50-546,547
Daiber, Franklin C.	50-3,286(SC)
Daiber, Franklin C.	50-247
Daiber, Franklin C.	50-286
Dalton, Jr., Andrew T.	50-556,557
D'Alvia, Carl R.	50-247
D'Alvia, Carl R.	50-286
Daly, Helen	50-596,597
Dammann, Thomas	50-155
Dattilo, Thomas M.	50-546,547
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Daugherty, Thomas M.	50-437
Davis, H. Lee	50-596,597
Davis, Mary	50-488-490
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Davis, R. L.	50-329,330
Davis, R. L.	50-329,330OL
Deale, Esq., Valentine B.	50-338,339SP
Deale, Esq., Valentine B.	50-522,523
DeBoer, T. K.	50-3,286(SC)
Decker, Ralph S.	50-516,517
Decker, Ralph S.	50-409
Degnan, John J.	50-437
Dellums, Ronald W.	50-70(SC)
deSylva, Donald P.	50-491-493
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deSylva, Donald P.	50-460,513
Diamond, Tom	50-592,593
Dickerson, Carrie	50-556,557
Dickson, Kathryn Burkett	50-592,593
Dickson, Kathryn Burkett	50-582,583
Diddle, Gerald F.	50-556,557
Dietrich, Margaret	50-338,339OL
Dignan, Jr., Thomas G.	50-443,444
Doggett, Stephen A.	50-466
Doherty, John F.	50-466
Dolins, Stanley L.	50-592,593
Dougherty, James B.	50-338,339SP
Dubert, Jim	50-599,600
Durbin, Emily A.	50-582,583
Durham, James W.	50-514,515
Durham, James W.	50-522,523
Dworkin, Carl G.	50-516,517
Eastvold, Ike	50-582,583
Eaton, Michael R.	50-312(SP)
Ebersole, Jesse C.	
Edelman, Murray R.	50-440,441
Edgar, George	50-70
Edgar, George	50-70(SC)
Edgar, George	70-754
Egemeier, Stephen J.	50-596,597
Eichhorn, William H.	50-367
Eichhorn, William H.	50-367(CPE)

NAME	DOCKET NO.
Eisenberg, Harold	50-582,583
Eissler, Frederick	50-275,323OL
Ellis, Juanita	50-445,446
Ellis, III, Leroy J.	50-518-521
Ellison, Christopher	50-312(SP)
Engel, David H.	50-549
Engel, David H.	50-549A
Engel, David H.	50-596,597
Erwin, Thomas	50-400-403
Etherington, Harold	
Ewing, T. N.	50-556,557
Falk, Kathleen M.	50-266,301
Farrar, Michael C.	50-466
Farrar, Michael C.	50-461,462
Farrar, Michael C.	50-437
Farrar, Michael C.	50-546,547
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Farrar, Michael C.	50-400-403
Farrar, Michael C.	50-358
Farrar, Michael C.	50-482
Farrar, Esq., Michael C.	50-3,286(SC)
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Farrar, Esq., Michael C.	50-277,278
Farrar, Esq., Michael C.	50-522,523
Farrar, Esq., Michael C.	50-498,499
Farrar, Esq., Michael C.	50-389
Farris, Joseph R.	50-556,557
Fazio, Jr., Peter V.	50-461,462
Feinstein, Richard P.	50-596,597
Ferguson, George A.	50-549
Ferguson, George A.	50-549A
Ferguson, George A.	50-440,441
Fernos, Gonzalo	50-376
Fickies, Robert	50-596,597
Firestone, Edward A.	50-70(SC)
Firestone, Edward A.	70-1308
First, Mark L.	50-354,355
Fischer, George	50-395
Fischer, Harris	50-516,517
Flatau, Adelaide	50-516,517
Fleischaker, David S.	50-275,323OL
Fleischaker, David S.	50-564
Fleischaker, David S.	50-3,286(SC)
Fleischaker, David S.	70-2623
Fleming, Raye	50-275,323OL
Fontana, Luke	50-382
Foreman, Harry	50-70
Foreman, Harry	50-70(SC)
Foreman, Harry	70-754
Foreman, Harry	50-382
Foster, Ralph	50-482
Foster, Richard M.	50-338,339OL
Fouke, Richard	50-445,446
Freedman, J. Carl	50-514,515
Frey, David G.	50-546,547
Fryling, Jr., Richard	50-354,355
Fryling, Jr., Richard	50-272
Frysiak, John M.	50-201
Frysiak, John M.	50-440,441
Fudala, Jeanne F.	50-596,597
Fuente, Eddie	50-566,567A
Fuente, Eddie	50-566,567
Gadler, Steve J.	50-329,330
Gadler, Steve J.	50-329,330OL

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Gagler, Steve J.	50-263
Gallagher, Phyllis M.	50-361,362OL
Gallo, Joseph	50-556,557
Gallo, Joseph	50-155
Gallo, Robert M.	50-387,388
Gambardella, Anthony J.	50-338,339OL
Garner, William E.	50-259,260OL
Gay, Geoffrey M.	50-445,446
Gehr, Arthur C.	50-275,323OL
Gehr, Arthur C.	50-592,593
Gerusky, Thomas M.	50-387,388
Gerusky, Thomas M.	50-289
Giambrone, Frank G.	50-452,453
Gibbs, Mark R.	50-596,597
Gibbs, Martha E.	50-556,557
Gilinsky, Victor	50-546,547
Gilinsky, Victor	50-592,593
Gilman, David W.	50-361,362OL
Gilmartin, David H.	50-516,517
Gilmartin, David H.	50-322
Glenister, Clara	50-596,597
Godard, Donald W.	50-514,515
Godard, Donald W.	50-522,523
Godwin, Aubrey	50-524-527
Godwin, Barbara	50-155
Gogel, Edward	50-599,600
Gonzalez, German A.	50-376
Gooch, R. Gordon	50-466
Goodhope, Andrew C.	70-1308(EA)
Goodhope, Andrew C.	50-549
Goodhope, Andrew C.	50-549A
Goodhope, Andrew C.	50-471
Goodhope, Andrew C.	27-39
Goodhope, Andrew C.	70-1308
Gordon, M. David	50-400-403
Gordon, Thomas J.	50-456-457
Gorlick, Samuel	50-592,593
Gorske, Robert H.	50-502
Graham, Robert L.	50-367
Graham, Robert L.	50-367(CPE)
Gramer, Joseph C.	50-516,517
Granttham, Caryl R.	50-516,517
Gray, Robert	50-546,547
Green, Harold P.	50-437
Grey, Robert	50-596,597
Griffen, Thomas G.	50-596,597
Griffin, William H.	50-482
Griffith, John B.	50-277,278
Griffith, Robin	50-466
Groscup, Garrett W.	50-440,441
Grossman, Herbert	50-395
Grossman, Herbert	50-244
Grossman, Herbert	50-70
Grossman, Herbert	50-70(SC)
Grossman, Herbert	70-754
Grossman, Herbert	50-155
Grossman, Esq., Herbert	50-367(CPE)
Guste, Jr., William J.	50-458,459
Gutterman, Alvin H.	50-518-521
Haber, G. Jeffrey	50-596,597
Haden, Gary	50-482
Hall, Esq., Robert Edward	70-1729
Hand, Jr., Cadet H.	50-500,501
Hand, Jr., Cadet H.	50-369,370
Hand, Jr., Cadet H.	70-2623
Hand, Jr., Cadet H.	50-361,362OL
Hand, Jr., Cadet H.	50-346(SP)
Hanley, William Charles	50-502
Hansell, Dean	27-39
Harnage, Henry H.	50-250,251
Hastings, Warren	50-522,523

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Hatling, Russell J.	50-263
Hauser, Donald H.	50-440,441
Hauser, Donald H.	50-346(SP)
Hawkins, Alman J.	50-596,597
Hearne, Treva J.	50-482
Heile, W. Peter	50-358
Helm, Joseph B.	50-546,547
Hendrie, Joseph	50-546,547
Hennegar, Richard W.	50-502
Herrmann, Henry	50-471
Hetrick, David L.	50-500,501
Hetrick, David L.	50-437
Hetrick, David L.	50-389
Hicks, Lyn Harris	50-361,362OL
Hiestand, O. S.	50-409
Hill, Ernest E.	50-354,355
Hill, Ernest E.	50-338,339SP
Hill, Ernest E.	50-553,554
Hinderstein, Carro	50-466
Hluchan, Richard M.	50-437
Hluchan, Richard M.	50-272
Hodder, Martin Harold	50-389
Hogan, Jr., Timothy S.	50-358
Hollerich, Cornelius J.	27-39
Holton, Robert L.	50-599,600
Hooper, Frank	50-389
Hooper, Frank F.	50-440,441
Hooper, Frank F.	50-458,459
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Hooper, Frank F.	50-395
Hooper, Frank F.	50-358
Horine, Marie	50-546,547
Horner, William	50-354,355
Hotaling, John D.	50-596,597
Hovis, Raymond L.	50-277,278
Howarth, David N.	50-599,600
Howell, David E.	50-341
Howie, Gordon	50-155
Hoyt, Gordon W.	50-592,593
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Hubbard, William B.	50-553,554
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Human, Maynard	50-556,557
Humphreys, III, James A.	50-463,464
Humphreys, III, James A.	50-277,278
Humphreys, III, James A.	50-320
Ireland, Bernice	50-514,515
Irizarry Gonzalez, Jose F.	50-376
Irving, Stephen M.	50-382
Irwin, Donald P.	50-463,464
Jackson, Charles W.	50-3,286(SC)
Jacobi, Mary Lou	50-266,301
Jimenez, Franciso	50-376
Johnson, Elizabeth B.	50-237,254
Johnson, Phillip B.	50-454,455
Johnson, Ronald W.	50-344(CB)
Johnson, W. Reed	50-556,557
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Johnson, W. Reed	50-275,323OL
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Johnson, W. Reed	50-389
Johnson, W. Reed	50-320
Johnson, W. Reed	50-344(CB)
Johnson, W. Reed	50-295,304
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Johnsrud, Judith H.	50-354,355
Johnsrud, Judith H.	50-387,388
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Johnston, Leotis	50-466
Jones, Richard	50-2610L
Jones, Richard E.	50-400-403
Jones, T. Ray	50-448,449
Jones, Yale I.	50-275,3230L
Jones, Jr., Lyman L.	50-382
Jordan, Walter H.	50-491-493
Jordan, Walter H.	50-452,453
Jordan, Walter H.	50-263
Jordan, Walter H.	50-596,597
Jordan, Walter H.	50-514,515
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Jordan, Walter H.	50-346(SP)
Jordan, Walter H.	50-289
Josselson, Frank	50-514,515
Jumper, Dora Susan	70-1729
Kafin, Robert J.	50-596,597
Kamras, Jonathan	50-466
Kaplan, David S.	50-312(SP)
Kayuha, Thomas A.	50-580,581
Keck, Holly S.	50-289
Keeping, William	50-596,597
Keller,, Edward H.	50-524-527
Kelley, Frank J.	50-329,3300L
Kelly, Frederick L.	50-448,449
Kennedy, Richard	50-546,547
Kenny, Patrick J.	50-471
Kepford, Chauncey	50-289
Kepford, Chauncey R.	50-463,464
Kepford, Chauncey R.	50-320
Kerr, Janice E.	50-275,3230L
Kerr, Janice E.	50-592,593
Kerr, Janice E.	50-361,3620L
Kerr, Janice E.	50-582,583
Kerr, William	
Kinder, E. Tupper	50-443,444
Kinsey, William W.	50-344(CB)
Kintigh, A. E.	50-516,517
Klein, J. Anthony	50-275,3230L
Klimberg, Stanley B.	50-596,597
Knotts, Jr., Joseph B.	50-460,513
Kocher, Charles R.	50-361,3620L
Kodner, Jan L.	50-599,600
Konter, Rick	50-295,304
Kosik, Leah S.	50-358
Krackeler, Christine	50-596,597
Kroot, Irwin B.	50-338,339SP
Kullberg, John A.	50-344(CB)
La Roche, W. Walter	50-553,554
La Roche, W. Walter	50-566,567A
La Roche, W. Walter	50-566,567
Lamarsh, John R.	50-354,355
Lamb, III, James C.	50-272
Lamb, III, James C.	50-498,499
Lanpher, Lawrence C.	50-582,583
Latham, Stephen B.	50-322
Laudig, Stephen	50-367(CPE)
Lawrence, Frederick H.	50-516,517
Lawroski, Stephen	
Lawson, Edward F.	50-448,449
Lawson, Edward F.	50-463,464

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Lawson, Quinten	50-488-490
Lazo, Esq., Robert M.	50-461,462
Lazo, Esq., Robert M.	50-548
Lazo, Esq., Robert M.	50-369,370
Lazo, Esq., Robert M.	50-263
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Lazo, Esq., Robert M.	70-1729
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Ledbetter, J. Leonard	70-1729
Lee, Jane	50-289
Leed, Roger M.	50-522,523
Leeds, Jr., J. V.	50-518-521
Leeds, Jr., J. V.	50-400-403
Leeds, Jr., J. Venn	50-461,462
Leeds, Jr., J. Venn	50-329,330
Leeds, Jr., J. Venn	50-329,330OL
Lefkowitz, Louis J.	50-201
Lehman, Orin	50-596,597
Leininger, Jr., George A.	50-546,547
Leithauser, John A.	50-155
Lemanowicz, Irene	50-387,388
Lemmer, Rosemary N.	50-466
Levin, John	50-289
Levin, Kenneth F.	50-454,455
Lewald, George H.	50-471
Lewis, Harold W.	
Lewis, Marvin I.	50-289
Lewis, Nicholas D.	50-522,523
Lewis, Nicholas D.	50-460,513
Like, Irving	50-516,517
Like, Irving	50-322
Like, Irving	50-596,597
Linder, Frank	50-409
Linenberger, Gustave A.	50-466
Linenberger, Gustave A.	50-463,464
Linenberger, Gustave A.	50-133
Linenberger, Gustave A.	50-546,547
Linenberger, Gustave A.	50-376
Linenberger, Gustave A.	50-440,441
Linenberger, Gustave A.	50-522,523
Linenberger, Gustave A.	50-395
Linenberger, Gustave A.	50-320
Linenberger, Gustave A.	50-70
Linenberger, Gustave A.	50-70(SC)
Linenberger, Gustave A.	70-754
Linenberger, Gustave A.	50-329,330OL
Link, Susan	50-596,597
Lippert, II, J. Richardson	50-201
Little, Linda W.	50-510,511
Little, Linda W.	50-237,249
Little, Linda W.	70-1308(EA)
Little, Linda W.	27-39
Little, Linda W.	50-295,304
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Little, Linda W.	50-289
Livingston, M. Stanley	50-255SP
Lockyear, Thomas A.	50-502
Lowenstein, Robert	50-522,523
Lowerre, Richard	50-466
Lowerre, Richard W.	50-498,499
Luebke, Emmeth A.	50-548
Luebke, Emmeth A.	50-369,370
Luebke, Emmeth A.	70-2623
Luebke, Emmeth A.	50-329,330
Luebke, Emmeth A.	50-329,330OL
Luebke, Emmeth A.	50-266,301
Luebke, Emmeth A.	50-498,499
Luebke, Emmeth A.	50-250,251
Luebke, Emmeth A.	50-244
Luebke, Emmeth A.	50-361,362OL

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MacArtor, June D.	50-272
MacDonald, J. Bruce	50-201
MacKenzie, Vincent V.	50-564
Madison, Samuel R.	50-596,597
Madson, Scott	27-39
Magavern, James L.	50-201
Magnuson, Robert	50-452,453
Mahler, Julianne	50-454,455
Makul, Raymond E.	50-272
Malone, Gilbert G.	50-463,464
Manning, Peter F.	50-546,547
Marbet, Lloyd K.	50-514,515
Marbet, Lloyd K.	50-522,523
Mark, J. Carson	
Marquardt, Peter A.	50-341
Marquardt, Peter A.	50-452,453
Marrack, D.	50-466
Marrs, John	50-275,323OL
Marsh, Colleen	50-387,388
Marshall, Wendell H.	50-329,330OL
Martin, David K.	50-546,547
Martin, David K.	50-358
Martin, William E.	50-275,323OL
Martin, William E.	50-514,515
Mastbaum, David	50-592,593
Mathis, William M.	
Matias, Thomas R.	50-596,597
Maupin, Michael W.	50-338,339OL
Maupin, Michael W.	50-338,339SP
Mause, Philip	50-448,449
McCollom, Kenneth A.	50-338,339OL
McCollom, Kenneth A.	50-443,444
McCollom, Kenneth A.	50-344(CB)
McCorkle, Brenda A.	50-466
McCormack, Tim	50-346(SP)
McCoy, David B.	50-344(CB)
McGarry, III, J. Michael	50-491-493
McGarry, III, J. Michael	50-369,370
McGarry, III, J. Michael	70-2623
McGarry, III, J. Michael	50-488-490
McGarry, III, J. Michael	50-488,491
McGorum, Jr., William B.	50-500,501
McGrath, James P.	50-596,597
McMullen, Patrick R.	50-522,523
McRae, D. J.	27-39
Mecray, Jr., Paul	50-354,355
Mellon, Knox	50-582,583
Merritt, Grant J.	50-329,330
Merritt, Grant J.	50-329,330OL
Meyer, Michael B.	50-471
Meyers, Ira L.	50-566,567A
Meyers, Ira L.	50-566,567
Mezo, Clifford	50-367(CPE)
Mikeska, John R.	50-466
Milhollin, Gary L.	50-237,254
Milhollin, Esq., Gary L.	50-272
Miller, Andrew P.	50-448,449
Miller, Byron L.	50-592,593
Miller, Marshall E.	70-2623
Miller, Marshall E.	50-329,330
Miller, Michael I.	50-556,557
Miller, Michael I.	50-329,330
Miller, Michael I.	50-329,330OL
Miller, Michael I.	50-255SP
Miller, Thomas A.	50-599,600
Miller, Esq., Marshall E.	50-510,511
Miller, Esq., Marshall E.	50-456-457
Miller, Esq., Marshall E.	50-266,301
Miller, Esq., Marshall E.	50-458,459
Miller, Esq., Marshall E.	50-344(CB)
Miller, Esq., Marshall E.	50-454,455

NAME	DOCKET NO.
Minor, Gregory	50-295,304
Moeller, Dade W.	
Moore, Thomas S.	50-409
Moore, Thomas S.	50-275,323OL
Moore, Thomas S.	50-295,304
Moore, Thomas S.	50-272
Moore, PhD, Patrick	50-522,523
Moran, Esq., William J.	50-358
Morey, Sharon	50-485
Mowry, John M.	50-596,597
Mulloy, James L.	50-592,593
Murphy, Paul M.	50-456-457
Murphy, Paul M.	50-454,455
Newman, Jack R.	50-466
Newman, Jack R.	50-498,499
Newman, Jack R.	50-582,583
Nickolitch, John	50-549
Nickolitch, John	50-549A
Northrup, David	50-440,441
Norton, Bruce	50-275,323OL
Norton, Bruce	50-133
Novarro, J. P.	50-322
Nygaard, George R.	50-409
Okrent, David	
Olson, Jocelyn F.	50-263
Oncavage, Mark P.	50-250,251
O'Neill, III, John	50-155
Onsdorff, Keith A.	50-437
Osann, Jr., Edward W.	50-367
Osann, Jr., Edward W.	50-367(CPE)
O'Toole, John D.	50-3,286(SC)
O'Toole, John D.	50-247
Owen, Jr., Robert H.	50-409
Paradis, Margaret R. A.	50-548
Paris, Oscar H.	50-564
Paris, Oscar H.	50-354,355
Paris, Oscar H.	50-596,597
Paris, Oscar H.	50-322
Paris, Oscar H.	50-387,388
Paris, Oscar H.	50-250,251
Paris, Oscar H.	50-566,567A
Paris, Oscar H.	50-566,567
Paris, Oscar H.	50-155
Parkowski, F. Michael	50-354,355
Paulson, Glenn L.	50-437
Paxton, Hugh C.	50-564
Paxton, Hugh C.	50-201
Paxton, Hugh C.	50-458,459
Paxton, Hugh C.	50-344(CB)
Pearce, Gordon	50-582,583
Perez, Charles Andrew	50-466
Perrenod, William	50-466
Pfefferkorn, William G.	50-488-490
Pfefferkorn, William G.	50-488,491
Philip, Robert F.	50-452,453
Phillips, John R.	50-275,323OL
Pickard, Ralph C.	50-546,547
Piepmeyer, James R.	50-466
Pierce, Phylis	50-553,554
Pierson, Charles S.	50-592,593
Pigott, David R.	50-361,362OL
Pinkney, Robert N.	50-244
Plesset, Milton S.	
Plettman, Stanely	50-458,459
Plettman, Stanley	50-510,511
Pollard, Robert Q.	50-289
Pooler, Rosemary S.	50-549
Pooler, Rosemary S.	50-549A
Porter, William L.	50-491-493
Porter, William L.	70-2623
Porter, William L.	50-488-490

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Porter, William L.	50-488,491
Porter, William Larry	50-369,370
Potter, Jr., William C.	50-329,330
Potthoff, III, F. H.	50-466
Powell, David G.	50-259,260OL
Preister, David J.	50-445,446
Purdom, Paul W.	50-556,557
Purdom, Paul W.	50-338,339OL
Purdom, Paul W.	50-266,301
Pyle, Robert	50-518-521
Quarles, Lawrence R.	50-3,286(SC)
Quarles, Lawrence R.	50-247
Quarles, Lawrence R.	50-409
Quarles, Lawrence R.	50-201
Quarles, Lawrence R.	50-514,515
Quarles, Lawrence R.	50-358
Quigley, Richard Q.	50-460,513
Rader, Robert M.	50-437
Raney, Jr., William A.	50-488-490
Raney, Jr., William A.	50-488,491
Ravasz, Rudolf C.	70-1729
Ray, Jeremish J.	
Ray, Michael J.	50-596,597
Reder, Mary	50-358
Redmond, James	50-448,449
Reilly, Esq., Thomas W.	50-259,260OL
Reis, Harold F.	50-329,330
Reis, Harold F.	50-329,330OL
Reis, Harold F.	50-389
Reis, Harold F.	50-250,251
Reis, Mark M.	50-564
Remick, Forrest J.	50-237,249
Remick, Forrest J.	70-1308(EA)
Remick, Forrest J.	50-518-521
Remick, Forrest J.	27-39
Remick, Forrest J.	50-295,304
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Remick, Forrest J.	70-1308
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Rentfro, Wayne	50-466
Resnikoff, Marvin	50-201
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Reuter, Arthur L.	50-549A
Reveley, III, W. Taylor	50-516,517
Reveley, III, W. Taylor	50-322
Reynolds, Nicholas S.	50-445,446
Rhodes, Suzanne	70-1729
Ridings, Donald J.	50-546,547
Riesel, Daniel	50-549
Riesel, Daniel	50-549A
Riley, Jesse L.	50-369,370
Riley, Jesse L.	70-2623
Robbins, Richard L.	50-367
Robbins, Richard L.	50-367(CPE)
Robertson, Arthur	50-452,453
Robinson, M. J.	50-556,557
Rodgers, Jr., William H.	50-338,339OL
Roe, David B.	50-592,593
Roe, Lowell E.	50-500,501
Roe, Lowell E.	50-346(SP)
Rogert, Emett	50-548
Roisman, Anthony Z.	50-237,254
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Rorem, Bridget Little	50-456-457
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Rosenberg, Vivian	50-596,597
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Rosenthal, Alan S.	50-461,462

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Rosenthal, Alan S.	70-2623
Rosenthal, Esq., Alan S.	50-466
Rosenthal, Esq., Alan S.	50-491-493
Rosenthal, Esq., Alan S.	50-500,501
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Rosenthal, Esq., Alan S.	50-338,339OL
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Rosenthal, Esq., Alan S.	50-488-490
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Rosenthal, Esq., Alan S.	50-443,444
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Rosenthal, Esq., Alan S.	50-400-403
Rosenthal, Esq., Alan S.	27-39
Rosenthal, Esq., Alan S.	50-522,523
Rosenthal, Esq., Alan S.	50-485
Rosenthal, Esq., Alan S.	50-320
Rosenthal, Esq., Alan S.	50-344(CB)
Rosenthal, Esq., Alan S.	50-482
Rosenthal, Esq., Alan S.	50-566,567A
Rosolie, Eugene	50-344(CB)
Ross, Everett C.	50-592,593
Ross, Norman	50-443,444
Ruebhausen, Oscar M.	50-201
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Russell, Robert	27-39
Ryan, Kevin M.	50-522,523
Sack, Edward J.	50-286
Sager, Lawrence	50-463,464
Salo, Ernest O.	50-524-527
Salo, Ernest O.	50-443,444
Salo, Ernest O.	50-320
Salzman, Richard S.	50-556,557
Salzman, Richard S.	50-491-493
Salzman, Richard S.	50-500,501
Salzman, Richard S.	50-564
Salzman, Richard S.	50-452,453
Salzman, Richard S.	50-354,355
Salzman, Richard S.	50-516,517
Salzman, Richard S.	50-329,330
Salzman, Richard S.	50-514,515
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Salzman, Richard S.	50-498,499
Salzman, Richard S.	50-389
Salzman, Richard S.	50-485
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Salzman, Richard S.	50-295,304
Salzman, Esq., Richard S.	50-275,323OL
Salzman, Esq., Richard S.	50-437
Salzman, Esq., Richard S.	50-546,547
Salzman, Esq., Richard S.	50-471
Salzman, Esq., Richard S.	50-358
Salzman, Esq., Richard S.	50-460,513
Salzman, Esq., Richard S.	50-272
Sandvik, Richard M.	50-514,515
Sandvik, Richard M.	50-522,523
Sandvik, Richard M.	50-344(CB)
Schiff, Peter H.	50-247
Schimmel, Ralph	50-596,597
Schink, David R.	50-341
Schink, David R.	50-437
Schink, David R.	50-133
Schink, David R.	50-553,554

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AN EVALUATION OF SEISMIC QUALIFICATION TESTS FOR NUCLEAR POWER PLANT EQUIPMENT

FINAL REPORT
September 1, 1976 - August 31, 1978

Daniel D. Kana
Robert W. LeBlanc

Southwest Research Institute

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ABSTRACT

A series of different seismic qualification tests has been conducted on a typical nuclear power plant electrical cabinet in order to provide comparative data. Acceleration and strain responses were measured for four different ground level and six different floor level specifications. The test types include resonance search, biaxial independent random, biaxial dependent random, uniaxial random, sine beat, and sine dwell excitations. Tests involving random motion were derived both from a random generator and earthquake signal source. Response data are initially presented in terms of transfer functions, time histories and response spectra. Then, analytical parameters are developed for correlation of the data in terms of peak responses, time-average RMS responses, and a new parameter defined as a damage severity factor.

Several important conclusions result from the data correlation for the various tests. Typical sine dwell and sine beat tests are found to be far more severe in general, than biaxial random simulations. The developed damage severity factors indicate this result vividly, and also provide a useful design tool for comparison of test severities before the tests are conducted, so that a choice can be made. It is found that the choice of random generated or earthquake sources is immaterial for test development. Modification to test procedures are recommended for cases where differences may be anticipated in floor mounted and simulator mounted resonance tests. Furthermore, a significant discrepancy is discovered in the simple specification that a TRS match or overlap an RRS. In certain cases this requirement is found to be inadequate for assuring a valid test in which all structural modes respond properly. This result is particularly important for those cases where subsequent component qualification tests are to be based on response spectra generated from response measurements at component attach points on the basic cabinet.

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1.0 INTRODUCTION

Seismic qualification of Class I equipment for use in nuclear power plants is a rather complex process which is influenced by a variety of factors. Qualification can be demonstrated by analysis or test, or both in combination, depending on the exact nature of the equipment and its function. Applicable procedures are affected by the location of the equipment within the plant as well as the geographical location of the plant, along with the particular characteristics and function of a given item of hardware. In view of the many combinations of parameters that are possible, it is obvious that some standardization of qualification procedures is necessary, and for several years the Nuclear Regulatory Commission along with other organizations have developed guidelines for this purpose. The NRC R.G. 1.100(1) and other regulatory guides, as well as IEEE standards(2,3) specifically govern seismic qualification tests of Class I equipment. For years, these guidelines generally have increased in complexity, as safety requirements have become increasingly more rigid.

In view of the vast variety of equipment and parameters that must be considered, useful guidelines must of necessity be general in nature, and application of them to specific cases must be accomplished with considerable experience and engineering judgement. This is certainly true of the present NRC and other guidelines mentioned above. Furthermore, the use of simpler procedures for qualification of earlier items poses the question of a possible requirement for requalification to newer standards for some equipment already in use. As a result, it is possible that several significantly different detailed qualification procedures, all of which fall within the general guidelines, could be prescribed for a current equipment item, and these procedures may or may not be more conservative than earlier ones. On the other hand, very little quantitative data is available to date as to which procedures best represent the design environment, or indeed, which detailed practices might even cause significant differences in the final results of the qualification procedure. It is obvious that the existence of any comparative data would be extremely useful in the decision to use a specific qualification procedure, or to determine whether requalification of operating equipment is appropriate. Further, such data would be indispensable for convincing an equipment vendor that a more complex (and expensive) procedure is more appropriate than a simpler, less expensive one.

The purpose of this report is to present the results of a research program having the objective of providing some answers to the above-described questions, as they affect qualification by testing only. It was considered reasonable to concentrate on the test phase of qualification, for testing is generally recognized as the preferred method of equipment qualification, since functional operability is usually difficult, if not impossible to demonstrate by analysis for many items. Furthermore, we emphasize that this has been a research program, so that all information required for a given qualification test will not be given in every case, but in fact, a much more detailed analysis of data will be performed. Thus, the objective was to conduct a series of tests which provide data with which to compare the results of several tests that can be prescribed for a typical Class IE electrical equipment item under the general guidelines, or may have been prescribed under earlier versions of the guidelines. The series was divided into two distinct groups, ground level and floor level tests. At the same time, particular attention was given to detailed procedures which experience has indicated may cause significant differences in the final results. A technical paper which summarizes some of these problem areas was also developed under this program, and has already been published elsewhere.(4) The findings presented herein are intended to provide a quantitative basis to aid in the decision to use a particular type of test for a given item, to help determine whether requalification of existing items is appropriate, and to provide a basis for possible future refinements of the currently accepted standard guidelines. Although attention has been focused on an electrical equipment specimen, virtually all of the conclusions can be applied to seismic qualification tests of mechanical and other types of equipment, in general.

We begin with a description of the test specimen chosen for the test series, the apparatus and instrumentation, and an outline of the test matrix and associated procedures. Thereafter, results of resonance search tests are presented, followed by typical samples of preliminary data acquired from the various earthquake simulated tests. This information leads to an analytical development of correlation parameters which are designed to provide a comparative basis for the effects of the various tests. Subsequently, a thorough analysis and comparison of test results are presented. Finally, a summary of conclusions and recommendations of further work are included.

2.0 DESCRIPTION OF TEST SPECIMEN

2.1 Physical Design

The test unit is a Bailey Meter Company Control and Instrumentation Cabinet as described in Figure 2.1 and Bailey Meter Company drawing No. D 3052169. The cabinet contains two interior panels. Each panel consists of four panel sections. Mounted in the top panel section are sixteen male, 18-pin connectors. Heavy duty instrumentation cables with female connectors were installed in the male connectors and routed out through the top of the cabinet. The cables were then routed through the top into the cabinet on the back side and installed in the second panel. On the three lower sections of each interior panel are mounted cable termination strips. Each panel section contains eight 12-point terminal strips; see Figure 2.1.

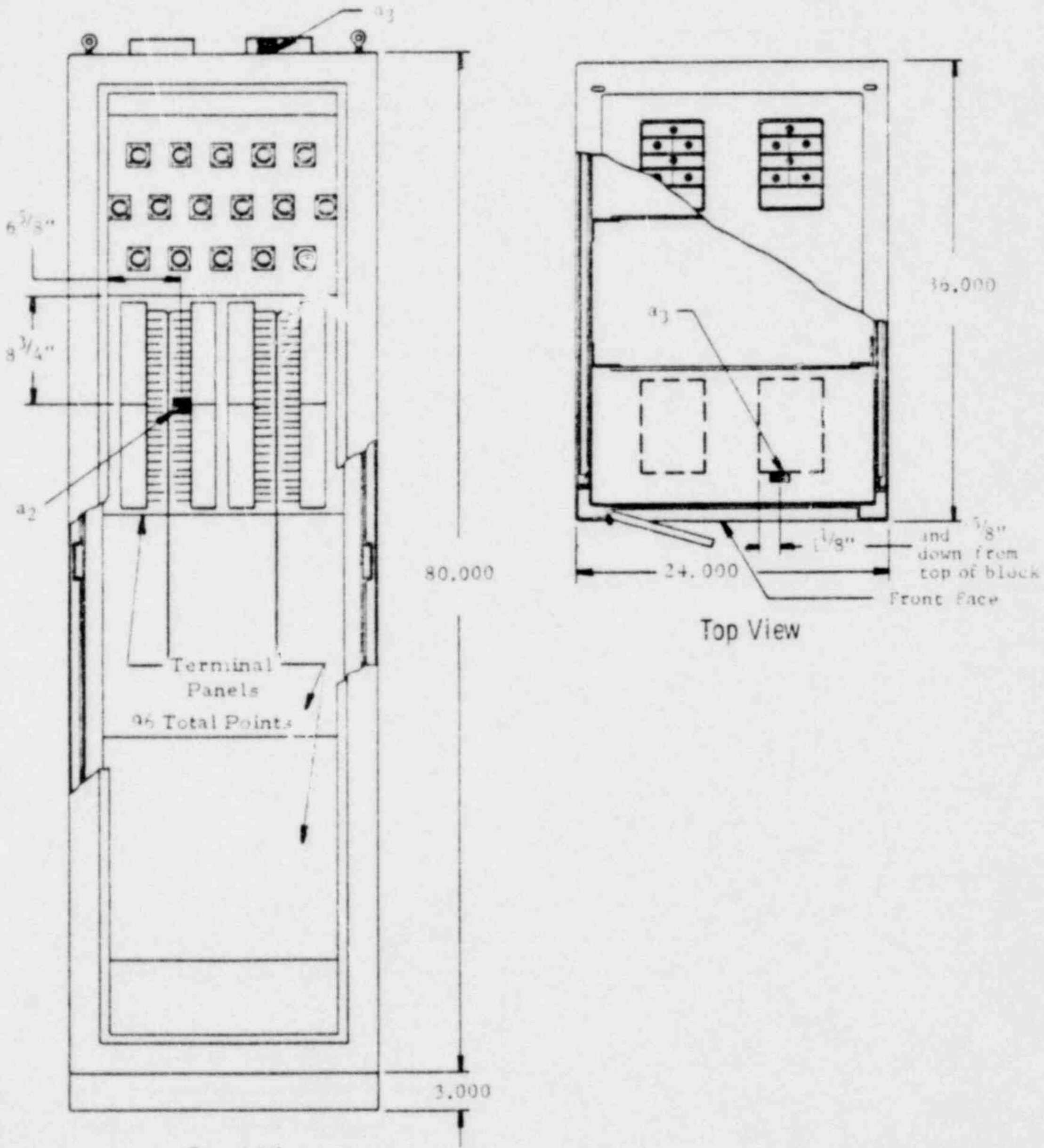
The four panel sections are mounted in a common mounting frame which, in turn, is bolted to the cabinet by a series of 8 bolts, four per side. During the initial setup runs, these bolts were found to be vibrating loose. To eliminate the possibility of the interior panels becoming loose during a test, these bolts were replaced. The replacement bolts were installed using a second nut as a lock nut as well as using "lock-tight" on the bolt threads to insure that the nuts would not vibrate loose.

The electrical cabinet was welded directly to a 1-inch thick, 4 foot by 4 foot steel plate. The cabinet's base was welded along its front and back edges as shown in Figure 2.2.

The terminal connections on the interior panels were connected to a series of wires to simulate a possible control panel wiring configuration. Since this arrangement was not considered a typical electrical system, it was concluded that the most reasonable approach to evaluating the cabinet was to measure mechanical responses which could readily be related to the operation of specific electrical components. It is our opinion that the cabinet can be considered mechanically typical, and for this reason we have concentrated on mechanical failure criteria.

2.2 Instrumentation

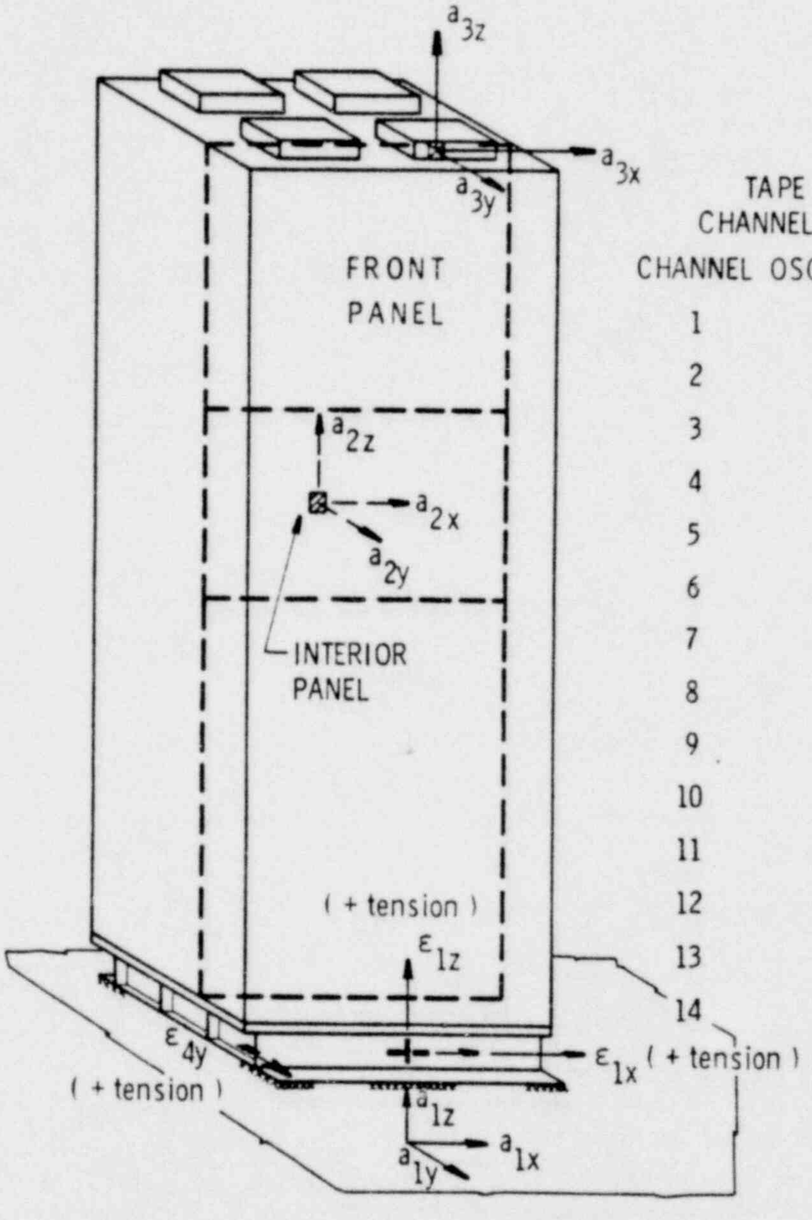
The tape recorder channel assignment and transducer locations are shown in Figures 2.1 and 2.2. Nine accelerometers were required to measure



Front View
with Door Removed

Top View

FIGURE 2.1. SKETCH OF ELECTRICAL PANEL SPECIMEN



TAPE RECORDER
CHANNEL ASSIGNMENT

CHANNEL	OSCILLOGRAPH	TAPE
1	a_{3x}	a_{3x}
2	a_{3y}	a_{1H}
3	a_{3z}	a_{3y}
4	a_{2x}	a_{1T}
5	a_{2y}	a_{3z}
6	a_{2z}	a_{1z}
7	ε_{1x}	a_{2x}
8	ε_{4y}	ε_{1x}
9	ε_{1z}	a_{2y}
10	a_{1x}	ε_{1z}
11	a_{1y}	a_{2z}
12	a_{1z}	ε_{4y}
13	-	X_{CH}
14	-	X_{CZ}

CONTROL ACCELERATION, a_{1x}, a_{1y}, a_{1z}

COMMAND DISPLACEMENT, x_{cH}, x_{cz}

Figure 2.2. Positions for Instrumentation

the cabinet response at the three measurement locations. The accelerometers were calibrated in accordance with SwRI Nuclear Projects Operating Procedure XII-EE-101-0. The arrow for each accelerometer indicates the direction of positive acceleration. The coordinate system differs from the normal right-hand system because the original data analysis was performed utilizing a standard table output format which later disagreed with the planned cabinet coordinate system. In an attempt to keep the results consistent, the format indicated was utilized throughout the testing. In the production of this report, acceptance of this coordinate system was found to be expedient.

The location of the three strain gage installations is also included in Figure 2.2. A detailed sketch of the ε_{4y} strain gage installation can be found in Figure 2.3. Two gage installations were used to record data for this location. During the floor mounted resonance searches, the ε_{4y} data was recorded from location 1. Figure 2.3 shows the final configuration of the welding in the area of the ε_{4y} strain gages. The initial weld did not extend past the gusset as shown, but stopped 0.4 inch before the gusset. The floor mounted and initial simulator mounted resonance searches were the only tests performed with this configuration. All the earthquake time history runs were performed using the gage at location 2, with the welding as shown. It should be noted that the resonance searches were repeated after the weld change. The modification is covered more fully in Section 3.4.

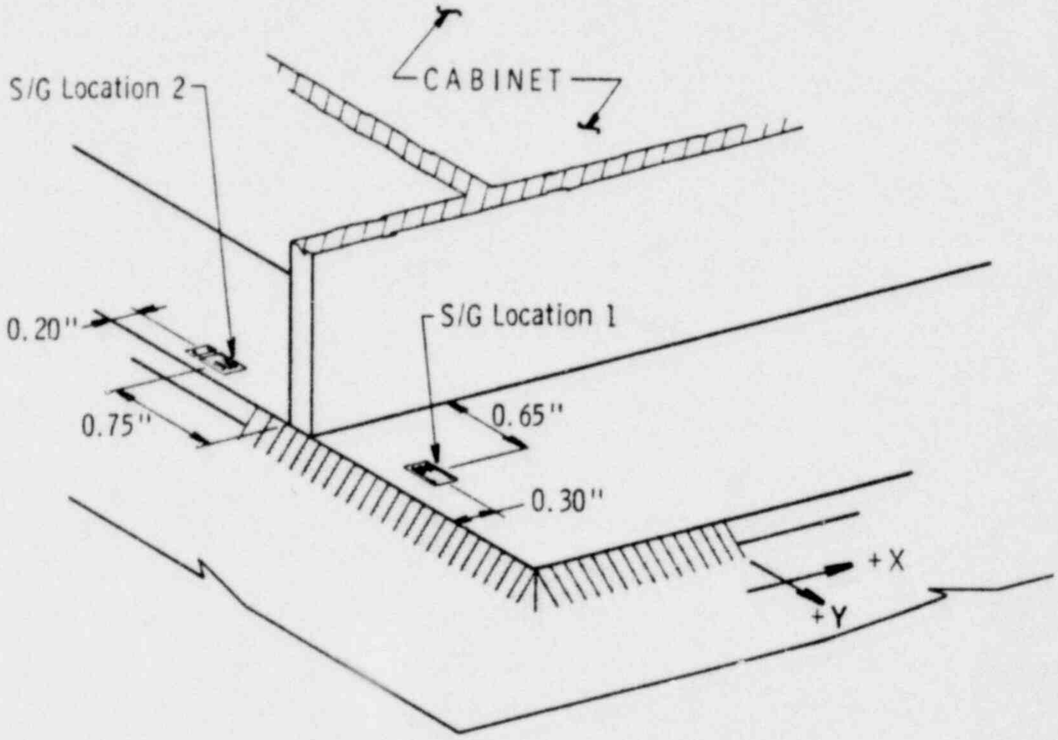


Figure 2.3. Detail of Cabinet Base, Left Front Corner

3.0 TEST PROCEDURE

3.1 Floor Mounted Tests

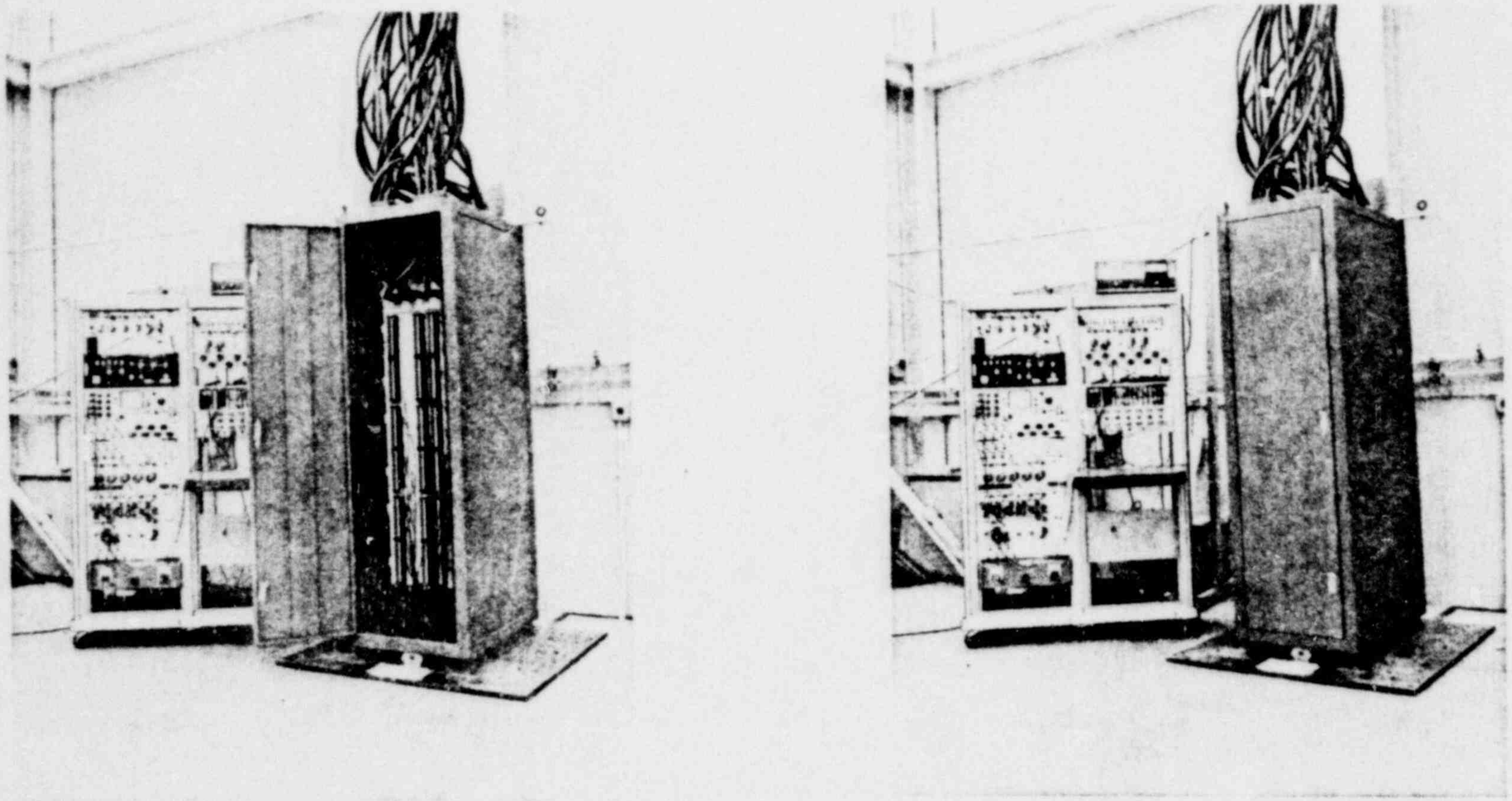
The test unit was welded to a mounting plate which, in turn, was bolted either directly to the floor or to the seismic shaker facility. The photographs in Figure 3.1 illustrate the mounting arrangement for the floor-mounted resonant frequency searches. The resonance searches were performed utilizing a swept sinusoidal input over a 2 to 50 Hz frequency range. A magnetic shaker was mounted to input a constant peak force excitation level into the top of the cabinet. The frequency sweep rate throughout the resonance searches was one octave per minute or less, to assure maximum response at resonance. The floor mounted tests were run for one axis at a time in the two major horizontal axes as defined in the X and Y directions, previously identified in Figure 2.2. Response curves for all data channels were recorded individually to obtain an accurate three-dimensional transfer function for the responses to each axis of excitation.

3.2 Earthquake Simulator Mounted Tests

Figure 3.2a shows the test unit mounting as it was bolted to the seismic shaker facility. Although not shown in the photograph, it should be noted that the cables at the top of the cabinet are supported by an overhead crane. Figure 3.2b illustrates the instrumentation equipment utilized to control the seismic shaker table as well as record and analyze the test data. A control and analysis diagram of the equipment utilized for the earthquake time history tests is shown in Figure 3.3; for more information, see Reference 5. A series of resonance frequency searches were performed on the simulator mounted test unit individually along the three major axes. The hydraulic simulator table was controlled to input a constant 0.2g acceleration into the base of the test unit. The controller was used to sweep from 2 to 50 Hz at a sweep rate of one octave per minute, or less. The outputs of the data channels were individually recorded on an X-Y plotter during the resonance sweeps. An elaborate series of earthquake tests were also performed and are described below.

3.3 Earthquake Simulation Test Matrix

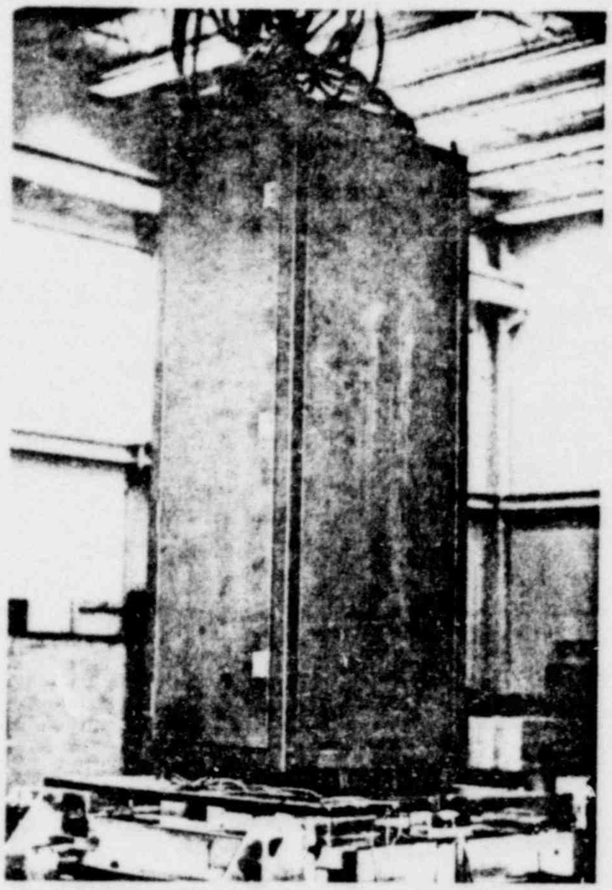
A planned series of seismic tests was conducted according to the Test Matrix included as Table III-1. The order of the tests as listed in



(a) Cabinet Internal View

(b) Overall View

FIGURE 3.1. FLOOR-MOUNTED ARRANGEMENT FOR CABINET AND APPARATUS



a. Cabinet on Simulator

b. Instrumentation View

FIGURE 3.2. SIMULATOR-MOUNTED ARRANGEMENT FOR CABINET AND APPARATUS

POOR ORIGINAL

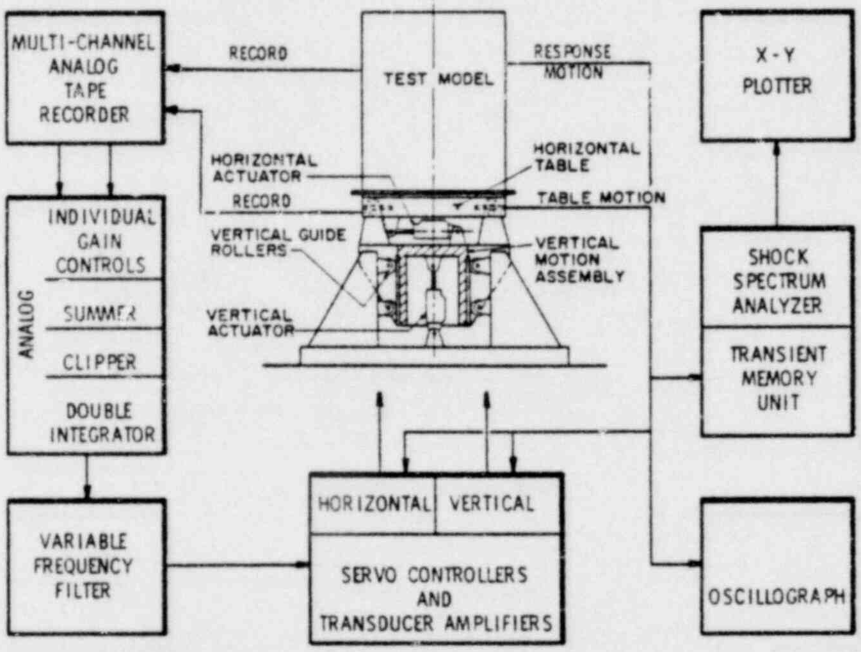


Figure 3.3. Control and Analysis Diagram for Biaxial Seismic Simulator

TABLE III-1. TEST MATRIX FOR ELECTRICAL CABINET

Test No.	Run No.	Test Type	Excitation Directions	Signal Source	Remarks
Ground Level Tests					
1	1	Biax. Ind.	Y-Z	Random (2H,2V)	
1	2	Biax. Ind.	X-Z	Random (3H,3V)	
2	1	Biax. Ind.	Y-Z	Random (1H,1V)	
2	2	Biax. Ind.	X-Z	Random (4H,4V)	
3	1	Biax. Dep.	Y-Z	Random (2V,2V)	Horiz.+Z; Vert.+Z
3	2	Biax. Dep.	Y-Z	Random (2V,2V)	Horiz.-Z; Vert.+Z
3	3	Biax. Dep.	X-Z	Random (3V,3V)	Horiz.+Z; Vert.+Z
3	4	Biax. Dep.	X-Z	Random (3V,3V)	Horiz.-Z; Vert.+Z
4	1	Biax. Ind.	Y-Z	Earthquake (5H,5V)	
4	2	Biax. Ind.	X-Z	Earthquake (6H,6V)	
Floor Level Tests					
5	1	Biax. Ind.	Y-Z	Earthquake (7H,7V)	
5	2	Biax. Ind.	X-Z	Earthquake (8H,8V)	
6	1	Biax. Ind.	Y-Z	Random (10H,10V)	
6	2	Biax. Ind.	X-Z	Random (11H,11V)	
7	1	Biax. Ind.	Y-Z	Random (9H,9V)	
7	2	Biax. Ind.	X-Z	Random (12H,12V)	
8	1	Uniaxial	Y	Random (10H)	
8	2	Uniaxial	Z	Random (10V)	
8	3	Uniaxial	X	Random (11H)	
9	1	Biax. Ind.	Y-Z	Sine Beat	13.0 Hz (H&V)
9	2	Biax. Ind.	Y-Z	Sine Beat	27.0 Hz (H&V)
9	3	Biax. Ind.	Y-Z	Sine Beat	7.0 Hz (H); 16.5 Hz (V)
9	4	Biax. Ind.	X-Z	Sine Beat	7.0 Hz (H); 16.5 Hz (V)
9	5	Biax. Ind.	X-Z	Sine Beat	9.8 Hz (H&V)
9	6	Biax. Ind.	Y-Z	Sine Best	23.0 Hz (H&V)
10	1	Uniaxial	Y	Sine Dwell	13.0 Hz, 0.17g
10	2	Uniaxial	Y	Sine Dwell	7.0 Hz, 0.75g
10	3	Uniaxial	Y	Sine Dwell	27.0 Hz, 0.75g
10	4	Uniaxial	Z	Sine Dwell	16.5 Hz, 0.21g
10	5	Uniaxial	X	Sine Dwell	7.0 Hz, 0.65g
10	6	Uniaxial	X	Sine Dwell	9.8 Hz, 0.20g
10	7	Uniaxial	Y	Sine Dwell	23.0 Hz, 0.37g

the matrix, is not indicative of the order in which the individual tests were performed. Since each test was considered to be completely independent of the other tests, the Y-Z direction tests generally were performed prior to remounting the cabinet for the X-Z tests. As each test was performed, all data were recorded using an analog tape recorder, for later playback and analysis.

The test matrix is divided into two classes of tests, the ground level tests and the floor level tests. The ground level tests, Tests 1 through 4, are generally more severe at the lower frequencies than the floor level tests. The details of the specific requirements for, and the development of these earthquake time histories is covered in Section 4.0. The time history earthquake signals were used to form biaxial independent, biaxial dependent, and uniaxial command signals. The type of signal configuration used for each test is listed in the column entitled, Test Type. The Excitation Directions column designates the direction or directions in which the electrical cabinet was excited during any given run. The Signal Source column specifies the type of source from which the drive signal was derived as well as identifying each time history with an individual source number. Referring to Table III-1, it can, therefore, be seen that the same vertical source signal was used for Test 1, Run 1 and Test 3, Run 1.

Each of the tests, 1 through 10, are comprised of a group of runs which, when combined, form a typical possibility of a present-day seismic test method. Tests numbers 1 and 2 are both biaxial independent random ground level tests, but they were created independently for the purpose of comparison. The same is true of floor level Tests 6 and 7.

The Test Matrix presented in Table III-1 includes, as Test No. 9, six biaxial sine beat tests. These tests consist of series of sine beats of 30 seconds total duration applied to each cabinet resonance found during the resonance searches below 33 Hz. The sine beat signals were designed to provide 10 cycles per beat with the peak acceleration amplitude set equal to the zero period acceleration (ZPA) of the floor level response spectrum. This required a 0.73g horizontal input and a 0.21g vertical acceleration input. One additional sine beat test was run at the frequency of peak response requirement from the floor level RRS, shown in Section 4.0. The horizontal and vertical command signals were developed independently such that no special phasing existed between them.

Test No. 10, listed in Table III-1, includes seven uniaxial continuous sine dwell tests. A sine dwell of 30 seconds duration was applied at each resonant frequency observed during the resonance searches below 33 Hz. In addition, one sine dwell was applied at the peak which occurred in the floor level RRS, shown in Section 4.0. The peak amplitude of the inputs was adjusted to be equal to the ZPA of the floor level RRS, when possible. Reduced amplitudes were required for several of the more severe resonances (see remarks in Table III-1 for amplitude utilized), in order to avoid immediate failure in the cabinet support welds.

3.4 Allowance for Cabinet Failure

At the start of the research testing program, it was clear that the test unit was to be subjected to a much more severe program than would normally be encountered during a standard seismic qualification test. Although there was no way to predict whether to expect test damage to the cabinet, prior to the start of the program, it soon became obvious that the test scope would eventually cause failures. For this reason, a procedure had to be formulated to take failures of the test unit into account.

The primary objective of the testing program was directed at recording the mechanical response of the cabinet. Since the mechanical response of the cabinet was initially considered to be typical, this response, as defined by resonance searches, was required to remain unchanged due to repair of failures.

During preliminary runs, required to develop the earthquake time histories, checks of the electrical monitoring circuits revealed damage to the wiring. Since these changes did not affect the mechanical response of the cabinet, the electrical checks were discontinued. At the same time, the interior panels were found to be loose and were repaired as previously described in Section 2.0. Upon completion of the preliminary setup runs, a comprehensive examination of the test unit revealed that several of the welds attaching the cabinet to the mounting plate were cracked. The cracked welds were removed and rewelded. Resonance searches were repeated, and the mechanical response was found to be essentially unchanged.

The earthquake time history tests were completed with no signs of cabinet damage. During the setup for the sine beat test, the welds to the mounting plate again cracked. The welds were repaired and the resonance searches were again checked. Since the mechanical response was again unchanged, the sine beat testing sequence was restarted. The remainder of the testing was completed with no further failures.

4.0 DEVELOPMENT OF EARTHQUAKE TIME HISTORIES

4.1 Ground Level Tests

Four independent synthetic time histories were generated to produce a 30-second full scale simulated seismic event at the table level on the simulator. The process was carried out in several steps which are described in the following paragraphs.

The basic full scale specifications for the earthquake tests are given in the form of the horizontal and vertical ground level generic response spectra shown in Figures 4.1 and 4.2, which are taken from Reference 6. Note that a ±3dB tolerance is allowed, and the Reg. Guide 1.60 spectra are given for comparison. Since Reference 3 usually requires an envelope of the RRS by the TRS, the present signals were designed to match the generic RRS, but to envelope the Reg. Guide 1.60 spectrum.

A " dummy" specimen of approximately the same weight as the cabinet was attached to the shake table and used to develop initial excitation (command) acceleration time histories. A signal was synthesized by combining six narrow band signals, each of which was filtered from a different frequency band of a random noise generator. The levels of each band were adjusted under successive trials until the TRS, as computed from the input acceleration signal (a_{1H}), sufficiently matched the RRS as given in Figure 4.1, for the horizontal axis SSE condition. A separate time history was then similarly generated for the vertical axis.

Subsequently, the "dummy" specimen was removed from the table, and the cabinet was installed in its place. Then, preliminary simulated earthquake runs were conducted to allow final adjustments and refinements of the command earthquake time histories. Each frequency band of the random signals was further adjusted until an optimum matching of the RRS by the TRS was achieved.

The next step in the production of the command signals was to sum all six channels into a single signal, and retape the sum onto a single channel of the analog tape. Accordingly, this signal formed the horizontal command displacement (x_{CH}) placed on channel 13. A similar, but completely

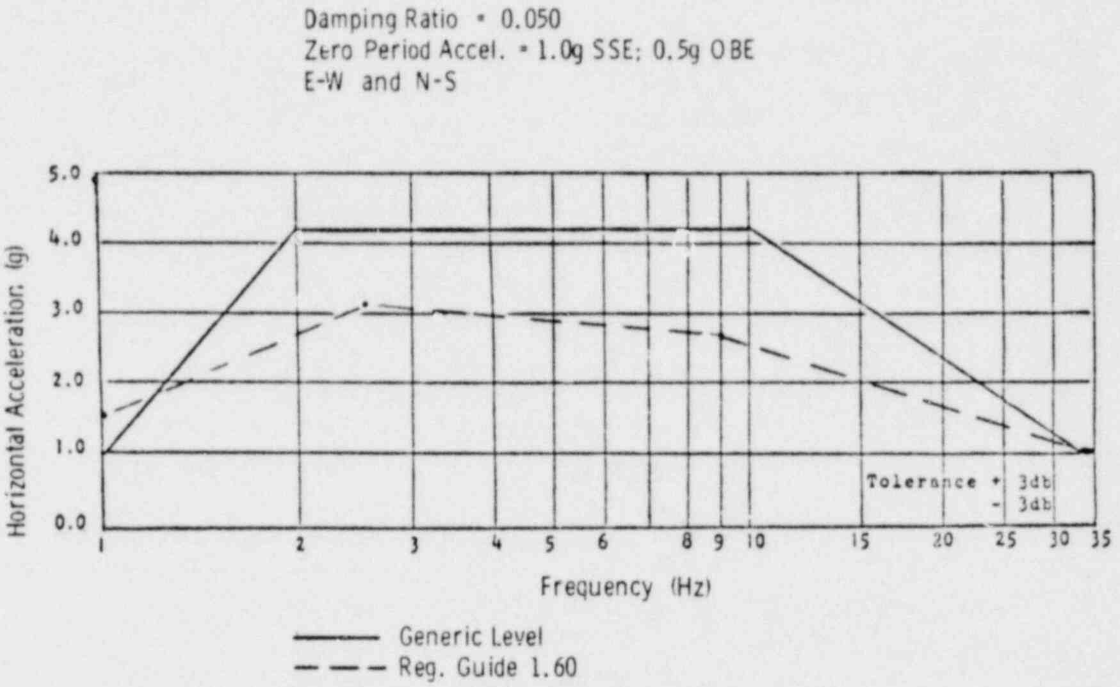

Damping Ratio = 0.050
Zero Period Accel. = 1.0g SSE; 0.5g OBE
E-W and N-S

Figure 4.1 Horizontal Ground Level Response Spectrum

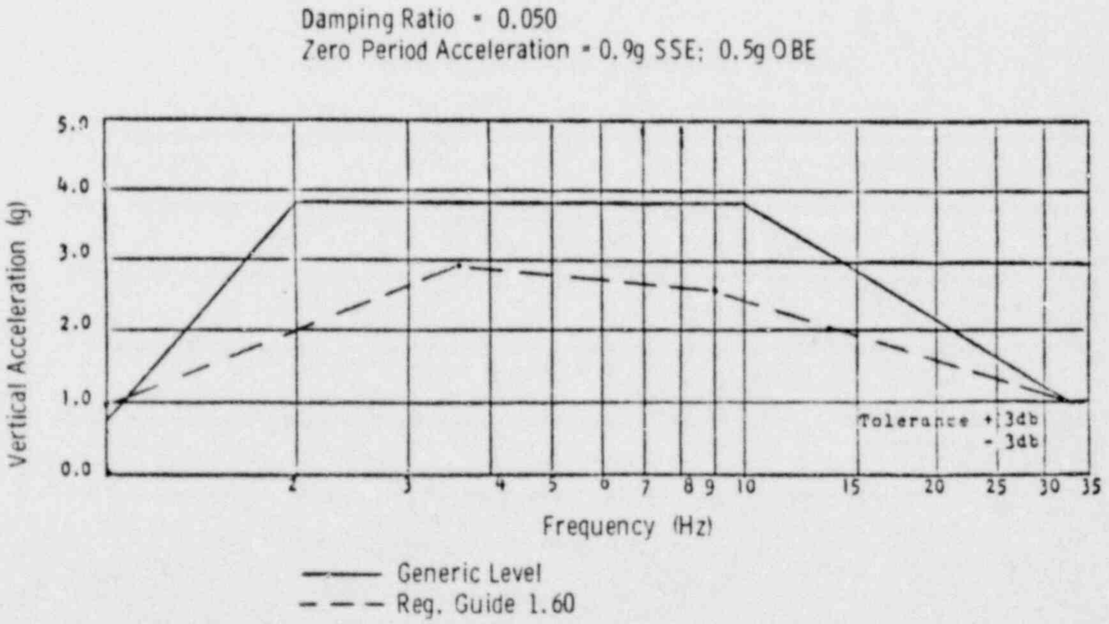

Damping Ratio = 0.050
Zero Period Acceleration = 0.9g SSE; 0.5g OBE

Figure 4.2 Vertical Ground Level Response Spectrum independent signal for vertical command acceleration (x_{CZ}) was synthesized and put on channel 14.

This process was then repeated for the other pairs of command signals until all four sets of time histories required for Tests numbers 1 and 2 were completed; see Table III-1. In order to form the dependent biaxial signals required for Test No. 3, the six vertical narrow band signals used for the two runs in Test No. 1 were readjusted to envelop the horizontal RRS when used as a horizontal input. In this way, following the same general procedure, the biaxial dependent command displacement signals were formed.

The development of the two sets of command signals, derived from an analog signal of an actual earthquake event, were performed in a similar manner. The analog signal was used instead of the random noise generator as a signal source for the filtering. The remainder of the procedure was the same. The actual earthquake used was the El Centro Earthquake of 1940 (Illinois Version - Ahmin). Our horizontal component was derived from the N-S component of the El Centro Earthquake. Our vertical component was derived from the E-W signal which was similar to the actual vertical signal. We were unable to use the actual vertical signal, as a defect was found in our copy of that trace.

4.2 Floor Level Tests

Four independent synthetic time histories were generated to produce 30-second full scale simulated seismic events. The signals were generated utilizing the method outlined for the ground level signals. The required response spectrum for which the floor level signals were shaped are shown in Figures 4.3 and 4.4. These signals were also utilized for the three uniaxial tests; see Table III-1.

Two sets of floor level command signals also were formed, based on the El Centro Earthquake and shaped to meet the RRS specified in Figures 4.3 and 4.4. The signals were generated as outlined for the ground level tests.

The various taped signal pairs produced by the processes described above were then reproduced on the same channels at a sufficient number of tape segments on the analog tape to provide control and recording capability for the required number of runs.

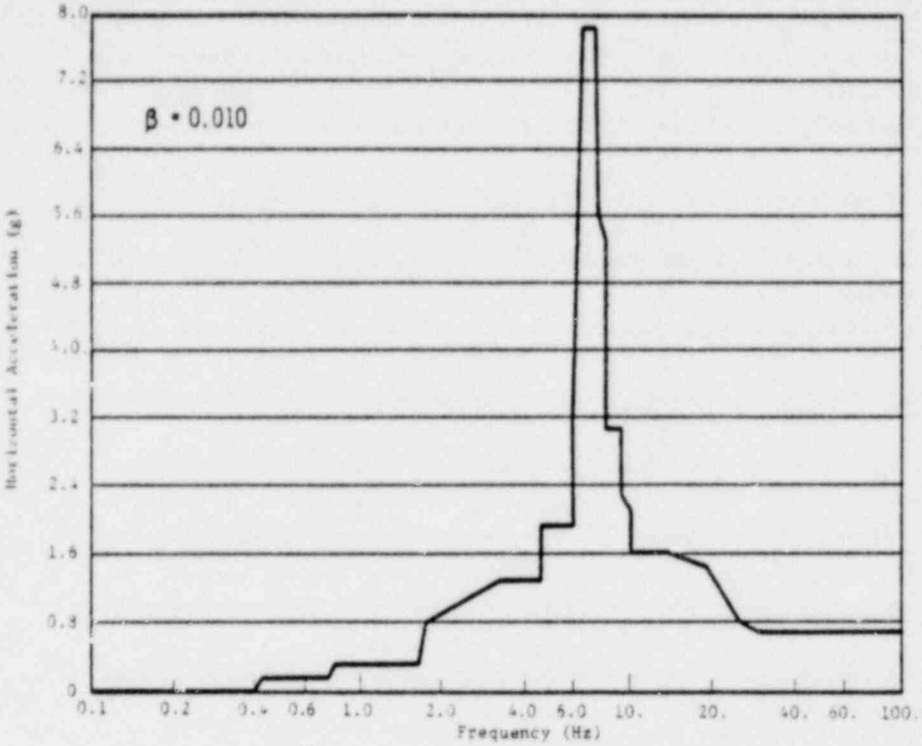


Figure 4.3. Horizontal Floor Response Spectrum

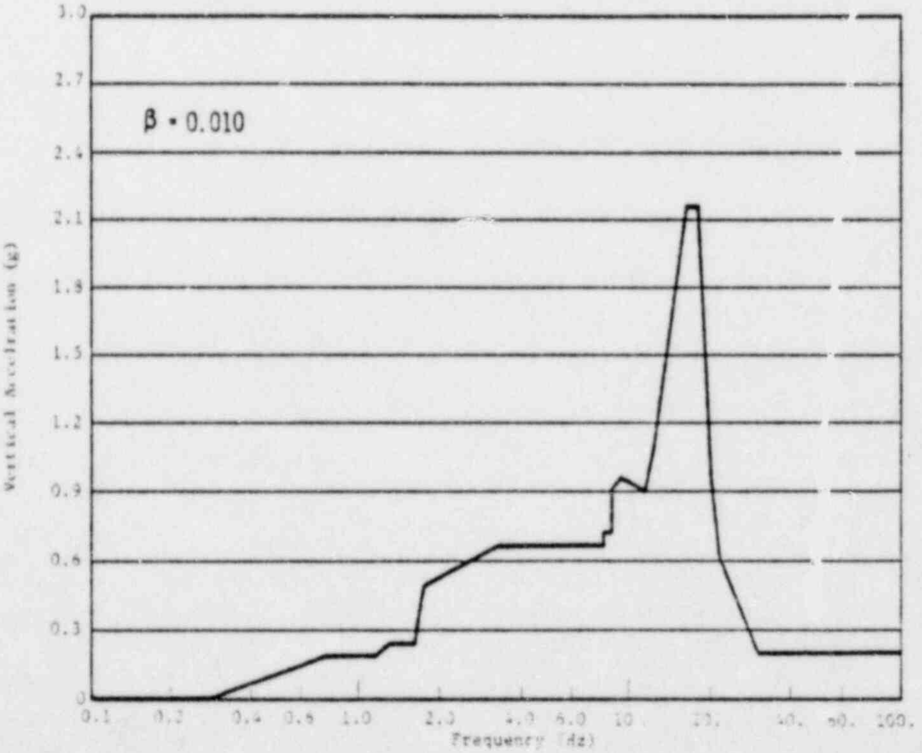


Figure 4.4. Vertical Floor Response Spectrum

5.0 RESULTS FOR RESONANCE SEARCH TESTS

The results of resonance search tests were sought as in any typical qualification test, to learn something about the basic harmonic behavior. Some differences between results of floor mounted and simulator mounted tests were observed.

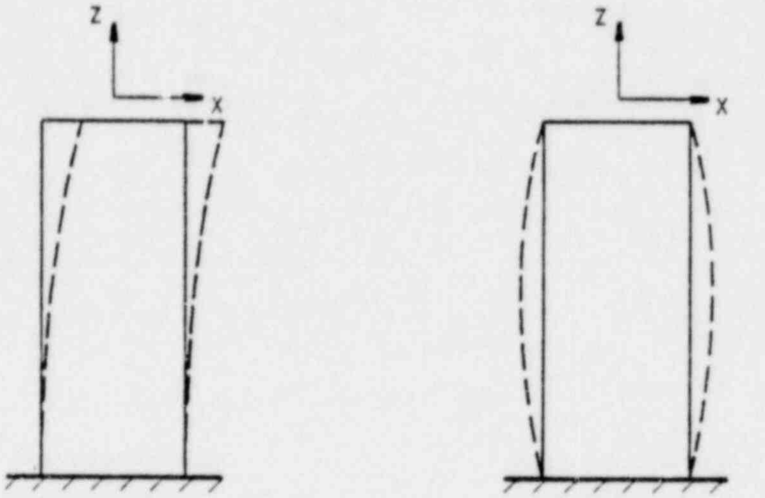
5.1 Floor Mounting

Figure 5.1 shows the general mode shapes of vibration for the first four modes observed during the floor mounted tests. The resonance frequencies and damping are given for the corresponding modes. No damping figure is available for the second mode since we had no accelerometers mounted on the side panels. Note that two modes were identified to occur dominantly along each horizontal axis of excitation.

Figures 5.2a and 5.2b illustrate the cabinet transfer function at the top, due to Y and X axis excitation for the floor mounted sweep tests. The cabinet response for a Y-axis input at the interior panel is shown in Figure 5.3 for the floor mounted condition. Figure 5.4 depicts the strain responses for X and Y axis inputs for the floor mounted resonance sweeps. Recall that for this test the ε_{4y} strain gage was in Location 1 (see Figure 2.3).

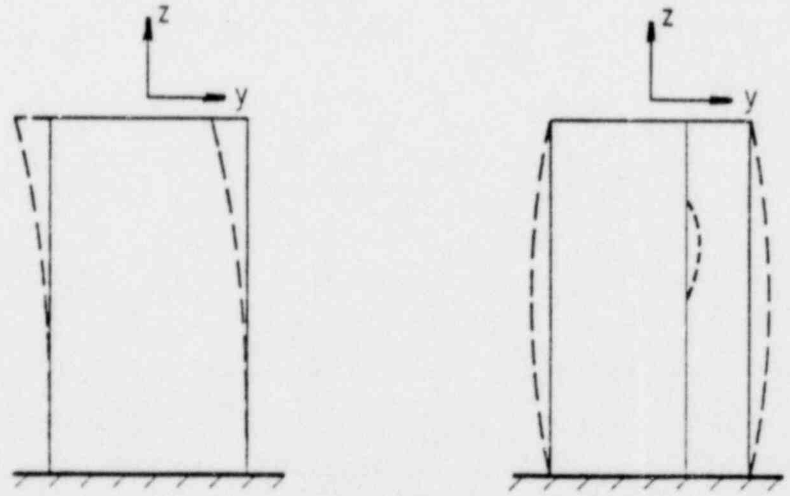
5.2 Earthquake Simulator Mounting

Figures 5.5 through 5.7 contain similar data for the simulator mounted test condition. The response magnitudes and resonance frequencies were found to have changed somewhat. The resonance frequency for the lateral bending mode in the X direction decreased from 11.7 Hz to 9.8 Hz. The side panel flapping mode, however, remained approximately constant at 16.4 Hz versus 16.5 Hz for the simulator mounted condition; see Figure 5.5b. For a Y-axis input, the fore/aft bending mode resonance frequency was observed to have changed from 19.1 Hz to 13 Hz; see Figure 5.5a. The interior panel mode was also changed from a single resonance at 31 Hz, to two resonances at 23 Hz and 27 Hz for a Y-axis input into the simulator mounted test condition; see Figure 5.6a. Figure 5.6b includes data for the three axes at the interior panel, due to an X-axis resonant sweep input. Figures 5.7a and 5.7b show the strain responses of the cabinet for Y and X inputs, respectively, for the simulator mounted sweep tests. Recall that for this test the ε_{4y} strain gage was mounted at Location 2 (see Figure 2.3).



FIRST MODE
LATERAL BENDING
11.7 Hz, $\xi = 0.041$

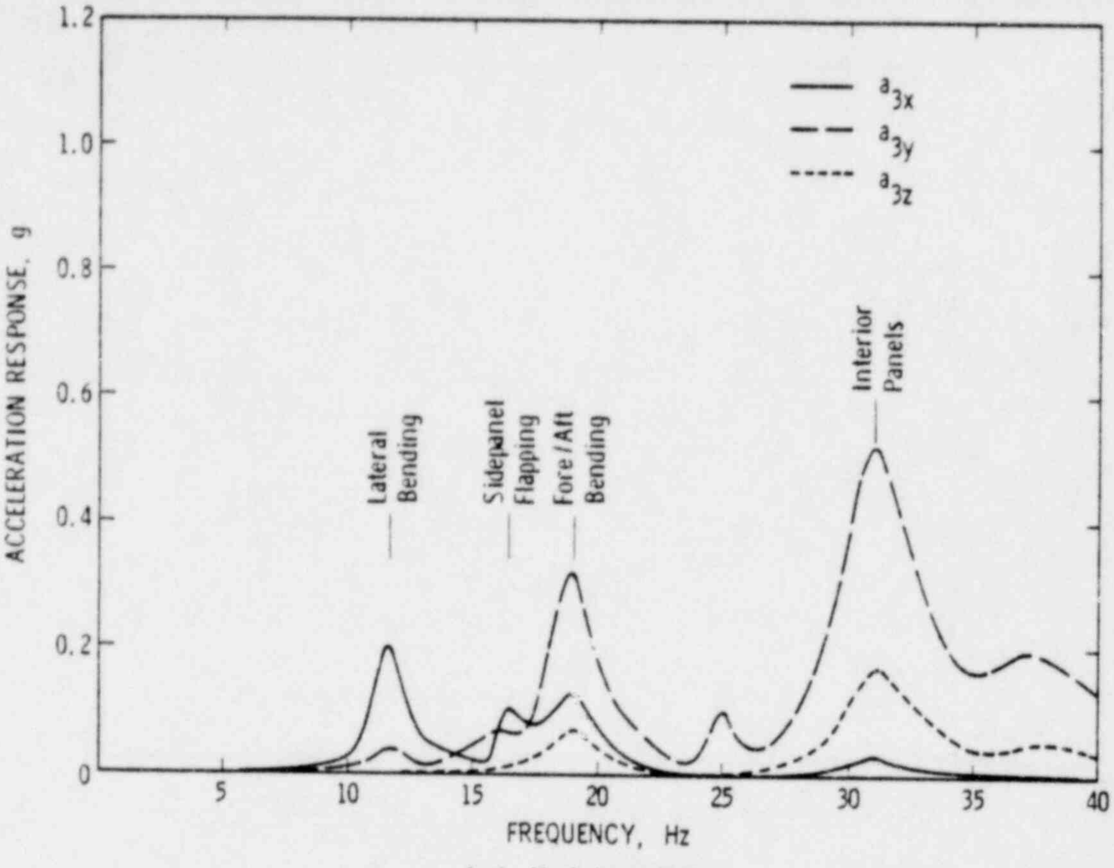
SECOND MODE
SIDEPANEL FLAPPING
16.4 Hz



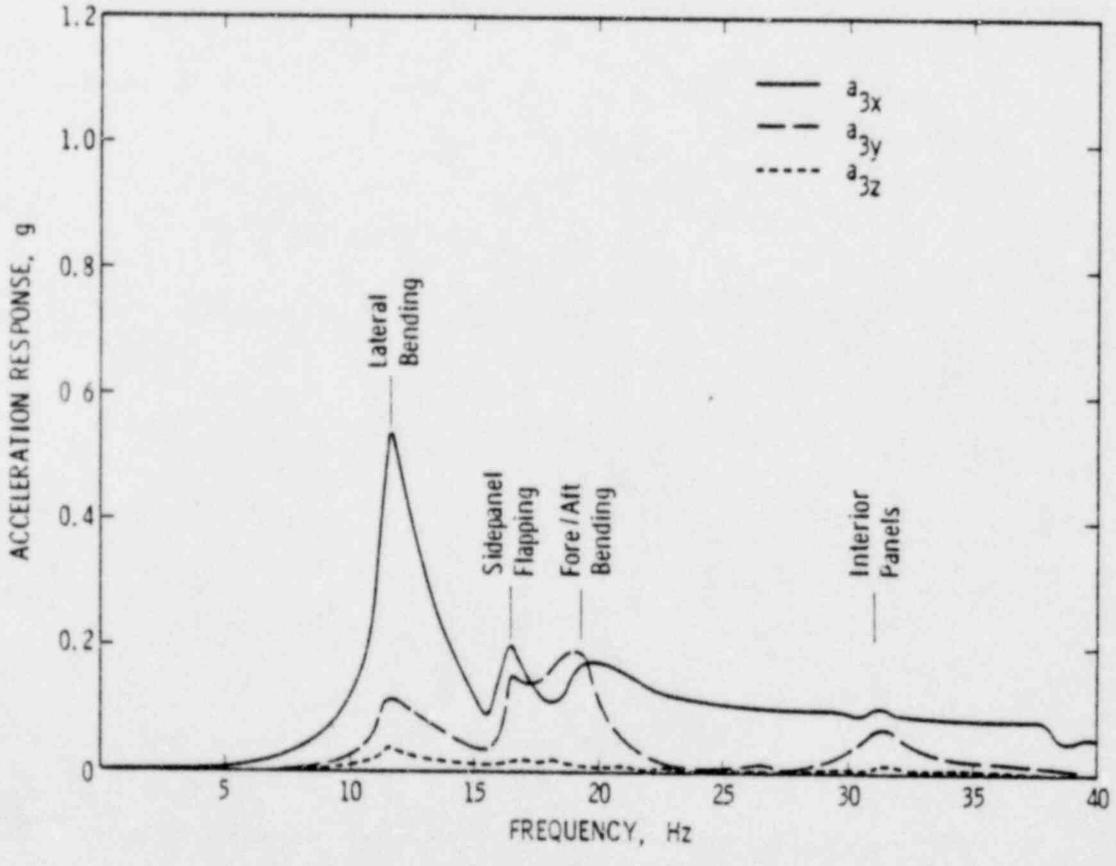
THIRD MODE
FORE/AFT BENDING
19.1 Hz, $\zeta = 0.042$

FOURTH MODE
FRONT, BACK, INTERIOR PANELS
31.0 Hz, $\zeta = 0.025$

Figure 5.1. Cabinet Natural Modes Below 35 Hz



(a) Y-Axis excitation



(b) X-Axis excitation

Figure 5.2. Top Acceleration Responses for Floor-Mounted Sweep Test

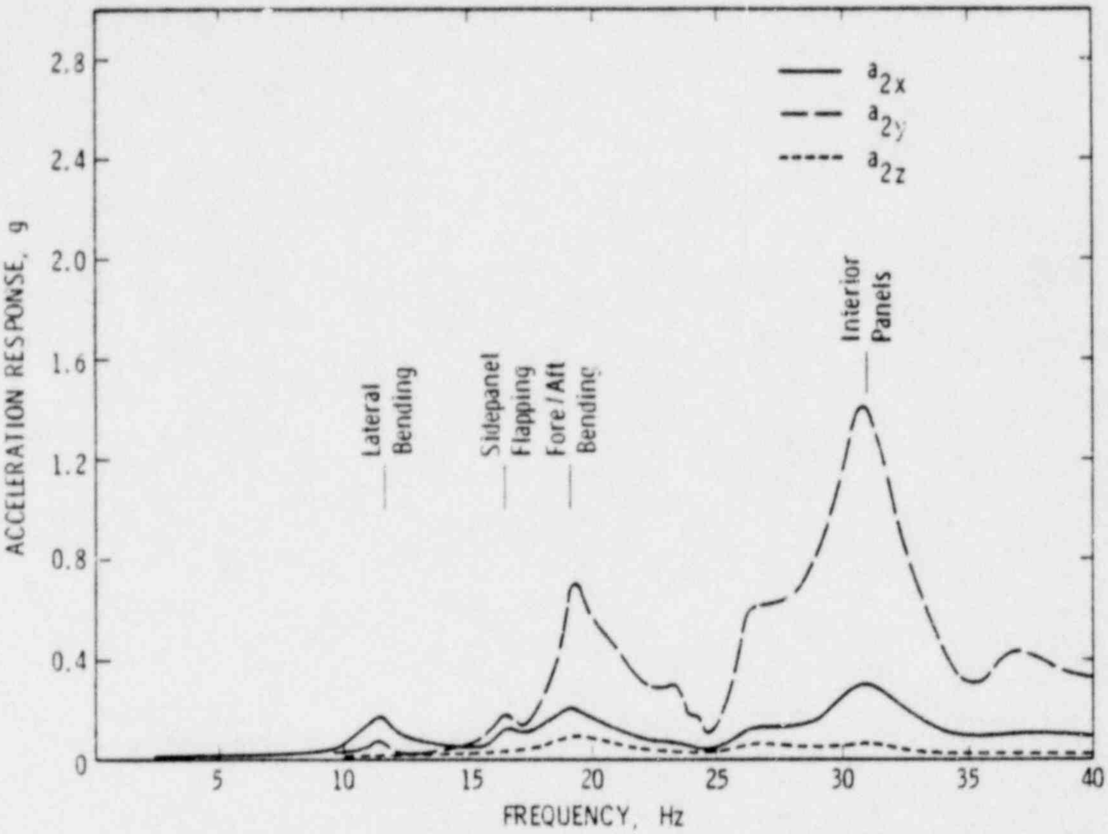


Figure 5.3. Interior Panel Acceleration Responses for Floor-Mounted Sweep Test - Y-Axis Excitation

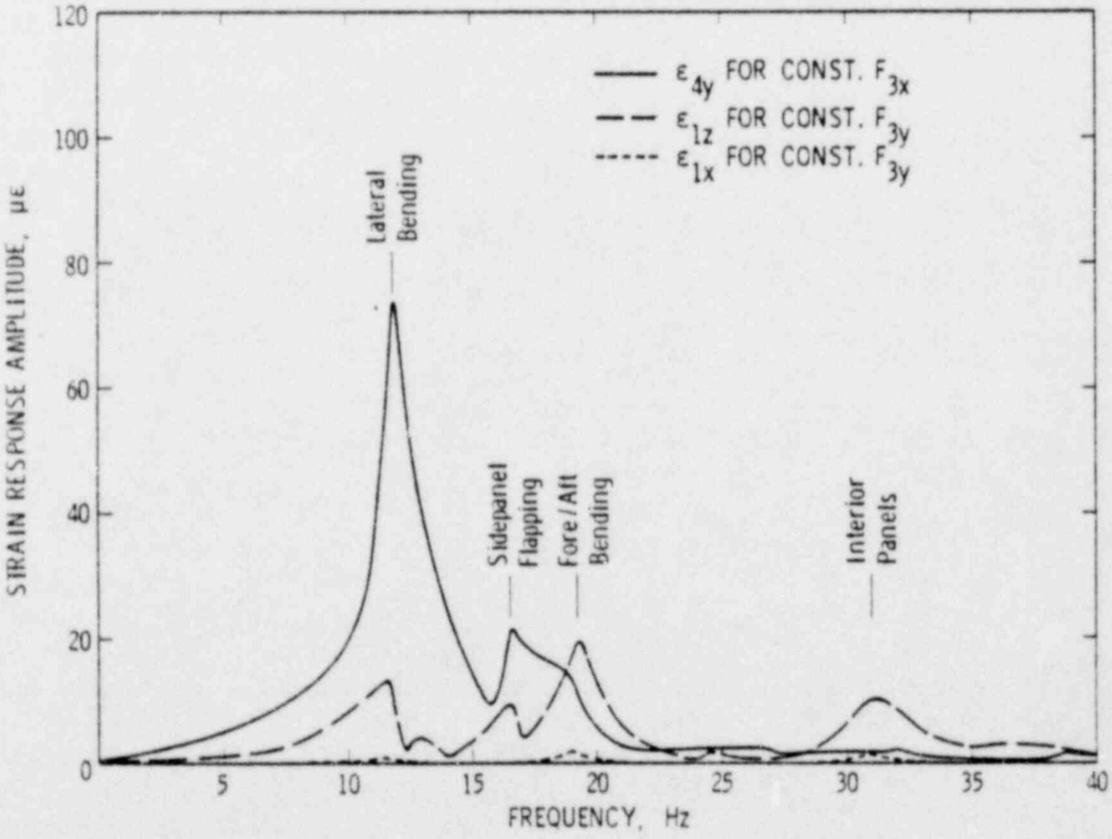
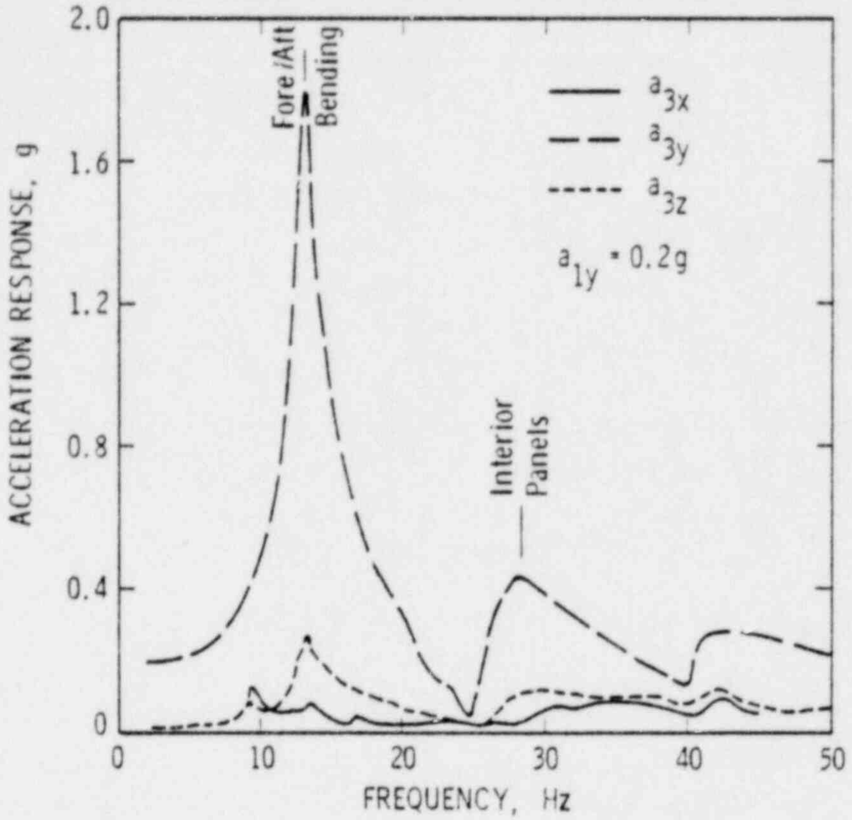
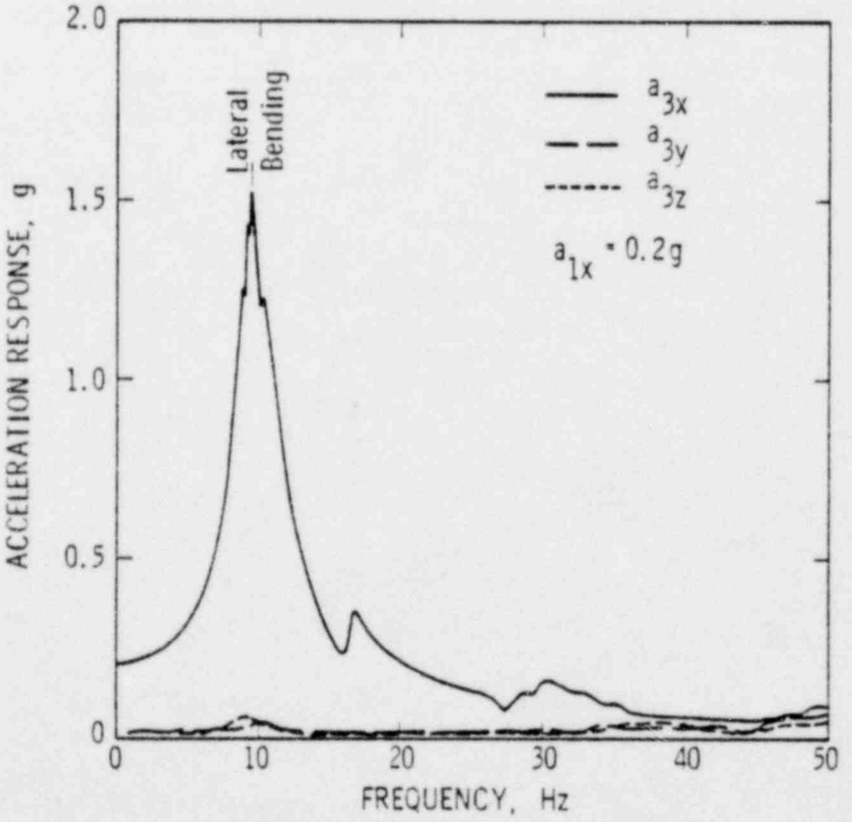


Figure 5.4. Strain Responses for Floor-Mounted Sweep Test

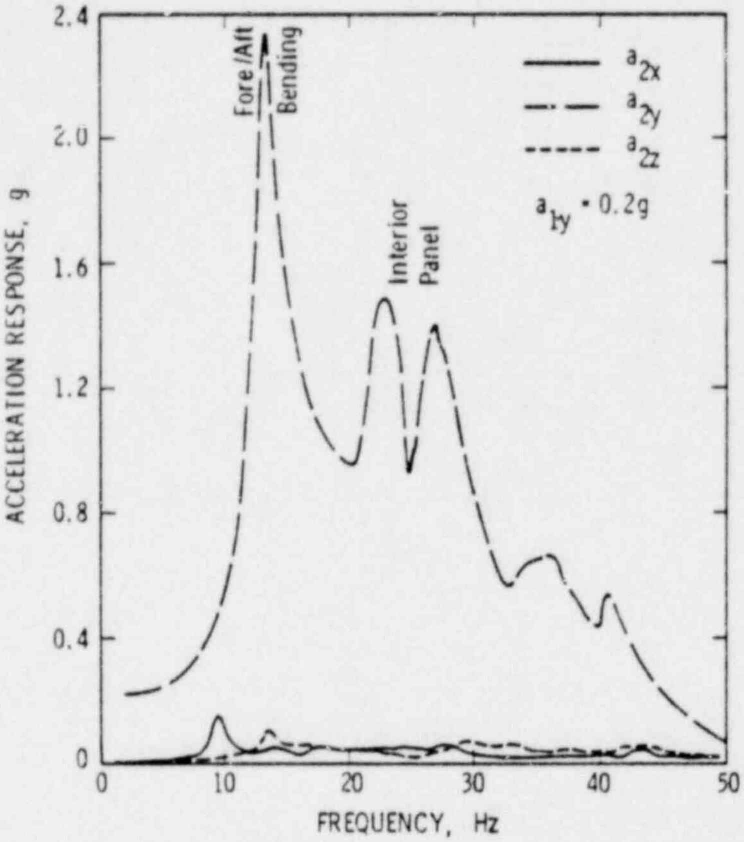


(a) Y-Axis excitation

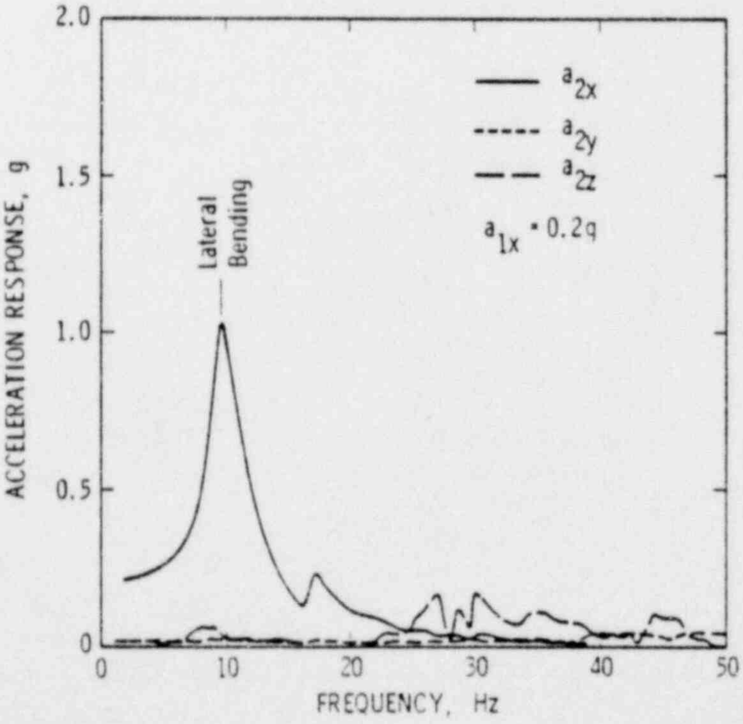


(b) X-Axis excitation

Figure 5.5. Top Acceleration Responses for Simulator-Mounted Sweep Test

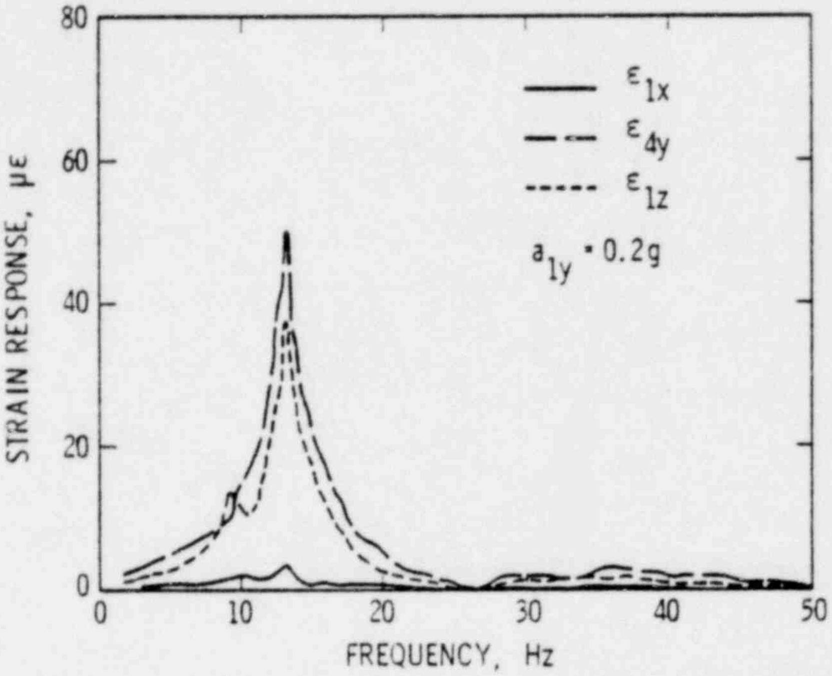


(a) Y-Axis excitation

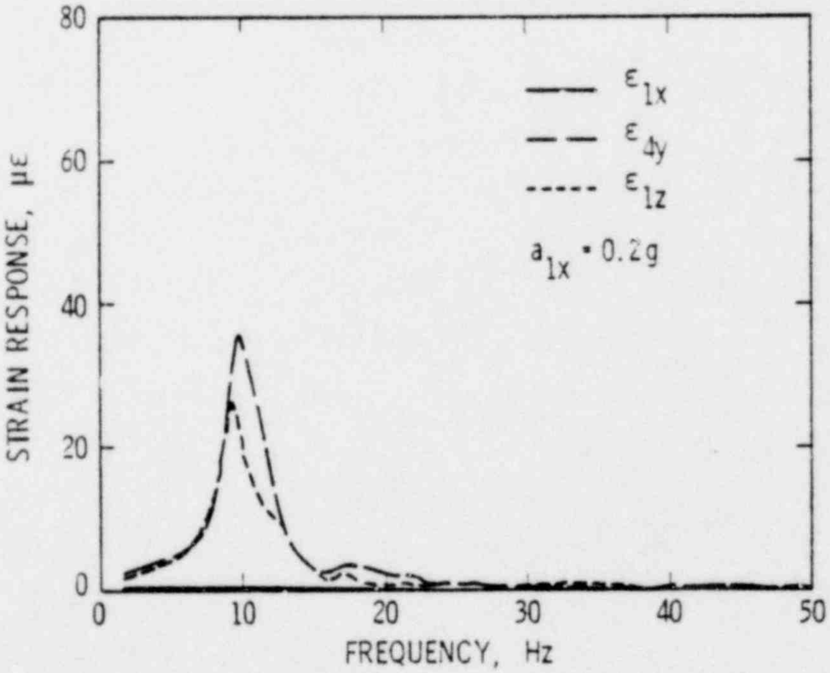


(b) X-Axis excitation

Figure 5.6. Interior Panel Responses for Simulator-Mounted Sweep Test



(a) Y-Axis excitation

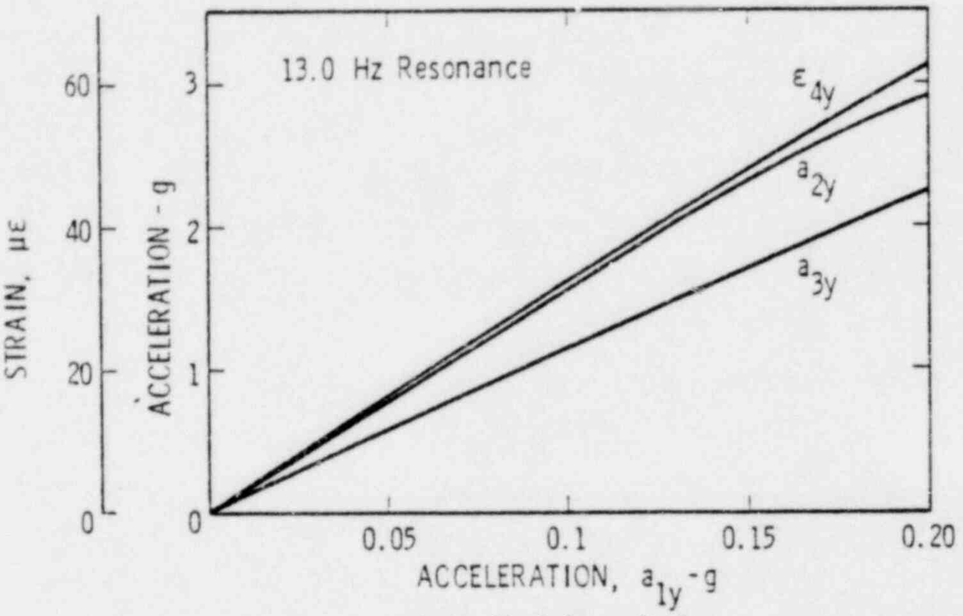


(b) X-Axis excitation

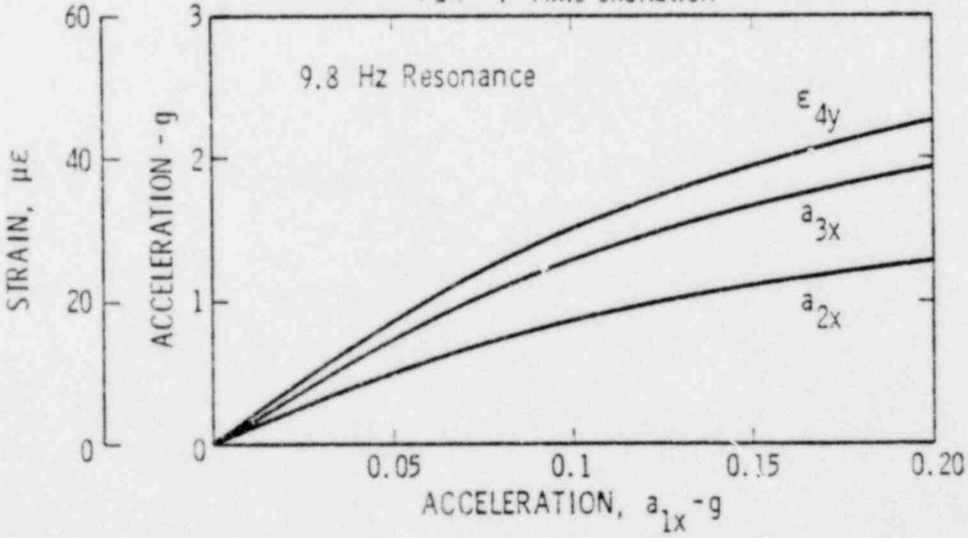
Figure 5.7. Strain Responses for Simulator-Mounted Sweep Test

Results for Z-axis excitation are not presented, as the cabinet was found to be nearly rigid along the vertical axis. Further discussion about the importance of the above changes in responses will be discussed later.

Finally, the results of a linearity check of the responses for two dominant modes are shown in Figure 5.8. Nonlinearity is evident for the Y-axis excitation, but is very significant for the X-axis excitation. Similar nonlinearities were found for the other modes as well. The influence of this behavior on test results will be noted carefully later.



(a) Y-Axis excitation



(b) X-Axis excitation

Figure 5.8. Transfer Function Characteristics

6.0 TYPICAL RESULTS FOR SIMULATED EARTHQUAKE TESTS

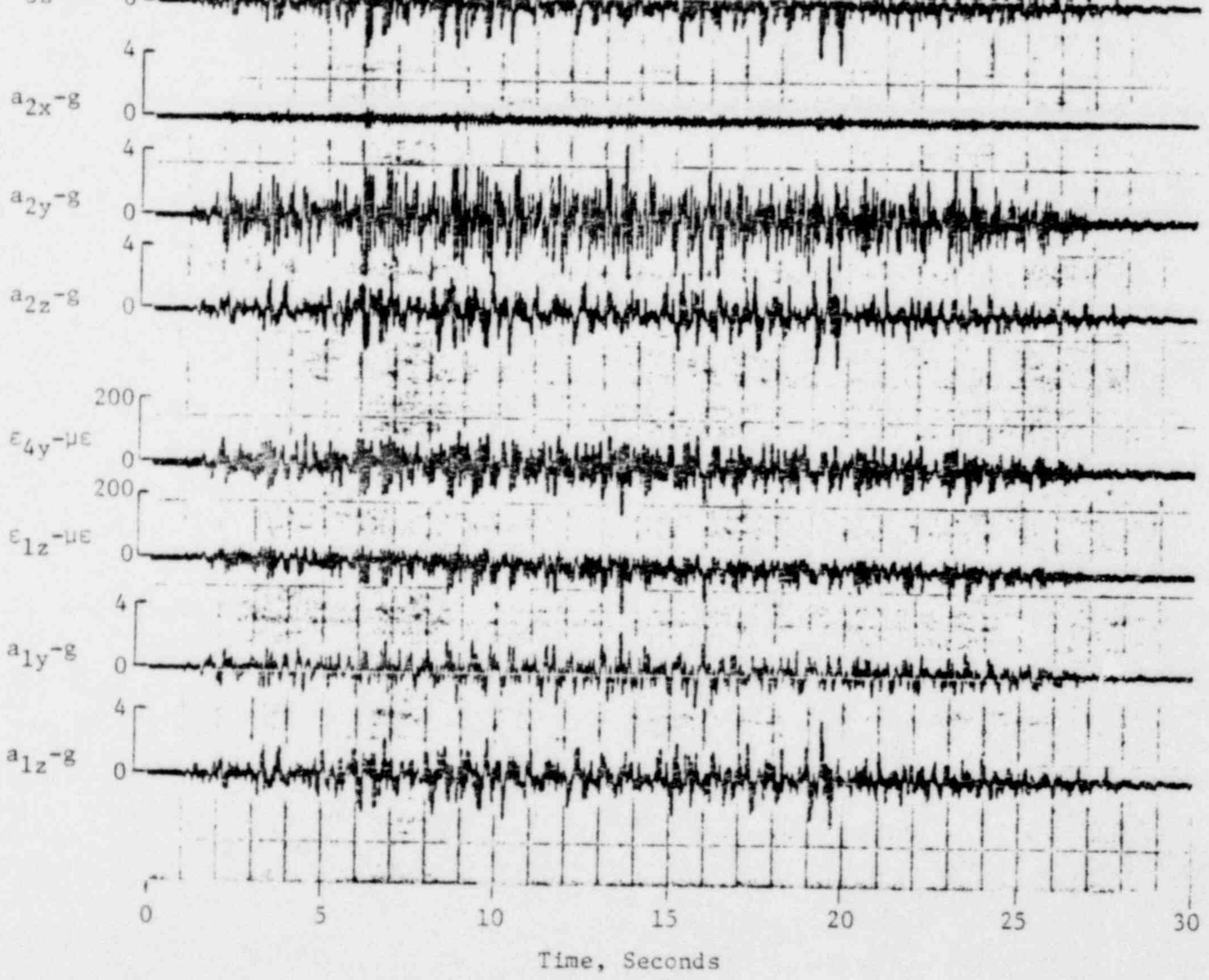
A selected set of typical preliminary results for simulated earthquake tests will be presented in this section. The results are displayed in the form of oscillograph time histories for responses at various specimen instrumentation locations, as well as comparisons between Required Response Spectra (RRS) and Test Response Spectra (TRS) for the simulator motion. Such data are generally required for seismic qualificaton tests, and are useful for obtaining an overall picture of the effects of the tests on the specimen. A much more detailed analysis of these and other data will be presented in Section 8.0.

When reviewing the data of this section, it is useful to refer occasionally to Figure 2.2, which identifies the transducer locations and orientations, and to Table III-1, which provides a more detailed identification of test type. Furthermore, only ten channels of the time history data are displayed in each case, in order to provide the optimum clarity of the results. One strain (ε_{1x}) and the transverse horizontal acceleration $(a_{1x}$ or $a_{1y})$ were, of course, recorded on tape, but were dropped from the display as being negligible. Furthermore, the command displacements $(x_{CH}$ and $x_{CZ})$, were also omitted as being of no consequence to the analysis of the excitation motion or the cabinet responses.

6.1 Ground Level Tests

Figures 6.1 through 6.4 show results for Test 1 which is a biaxial independent axis, random source test. Responses for both the Y-Z and the X-Z excitation orientations are given. Several general observations can be made from these data, and are also reflected in the results of subsequent tests.

A careful scrutiny of the a_{1z}, a_{2z}, and a_{3z} traces in Figures 6.1 and 6.3 shows that these accelerations are essentially identical, with only a slight amplification occurring toward the top of the cabinet. These results indicate that the cabinet was essentially rigid in the vertical direction, and that there was negligible cross-coupling between the horizontal and vertical responses for both orientations. Furthermore, there

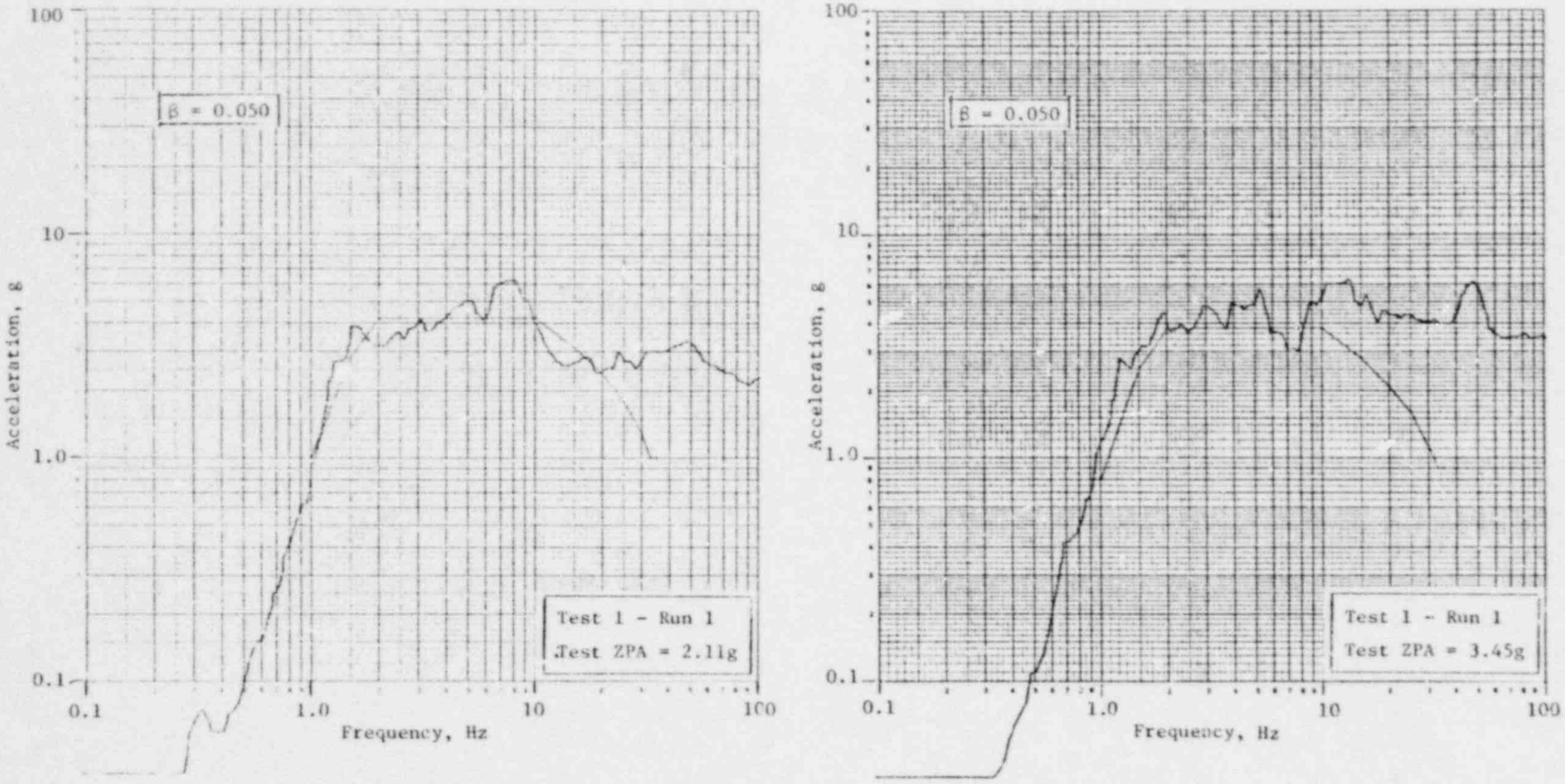


ε_{1x}, a_{1x} - Negligible

Test 1 - Run 1

FIGURE 6.1. RESPONSES FOR BIAXIAL INDEPENDENT RANDOM GROUND LEVEL TEST, YZ-EXCITATION

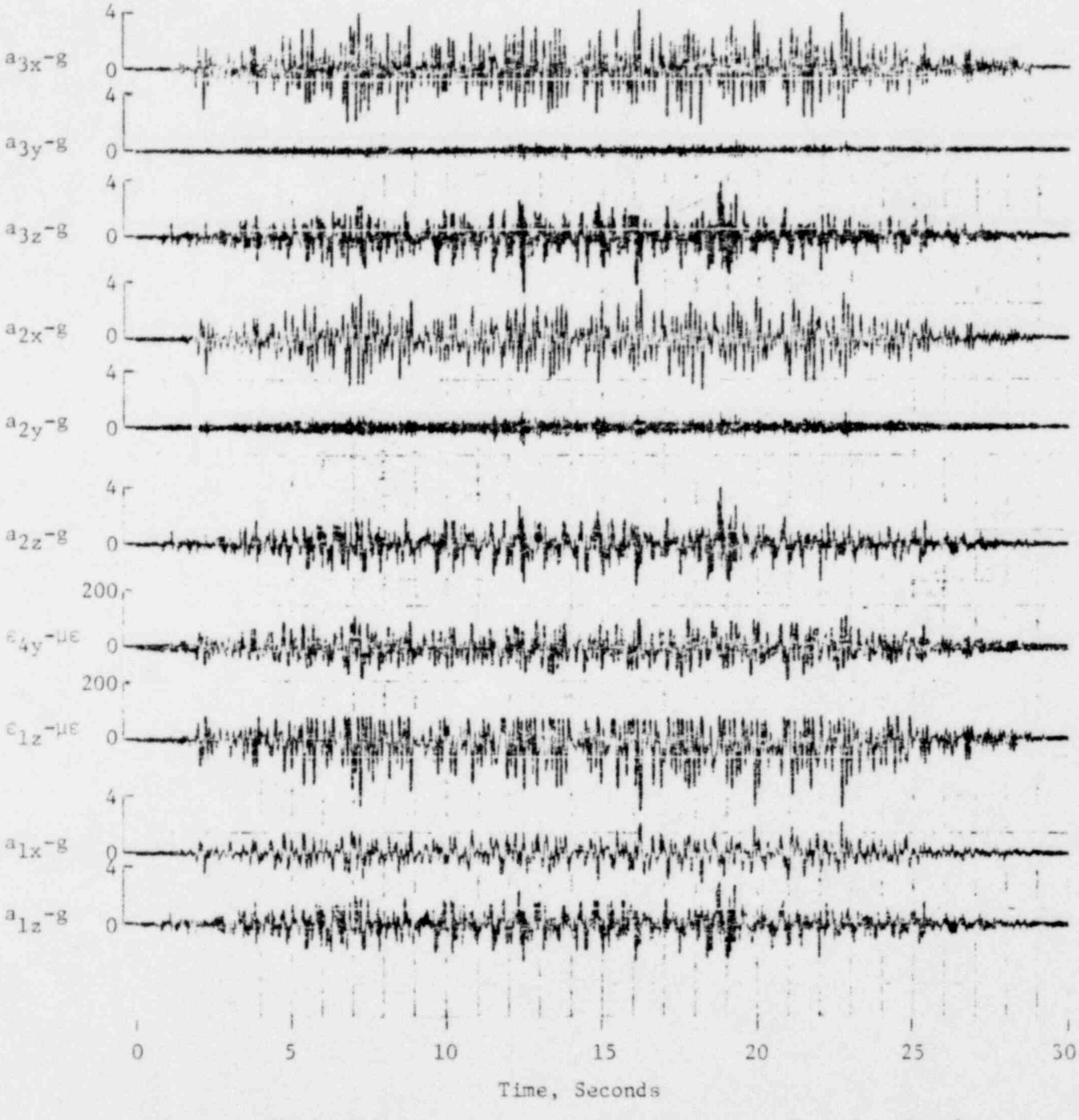
POOR ORIGINAL



a. Horizontal (a_{1y})

b. Vertical (a_{1z})

FIGURE 6.2. RESPONSE SPECTRA FOR BIAXIAL INDEPENDENT RANDOM GROUND LEVEL TEST, Y-Z EXCITATION

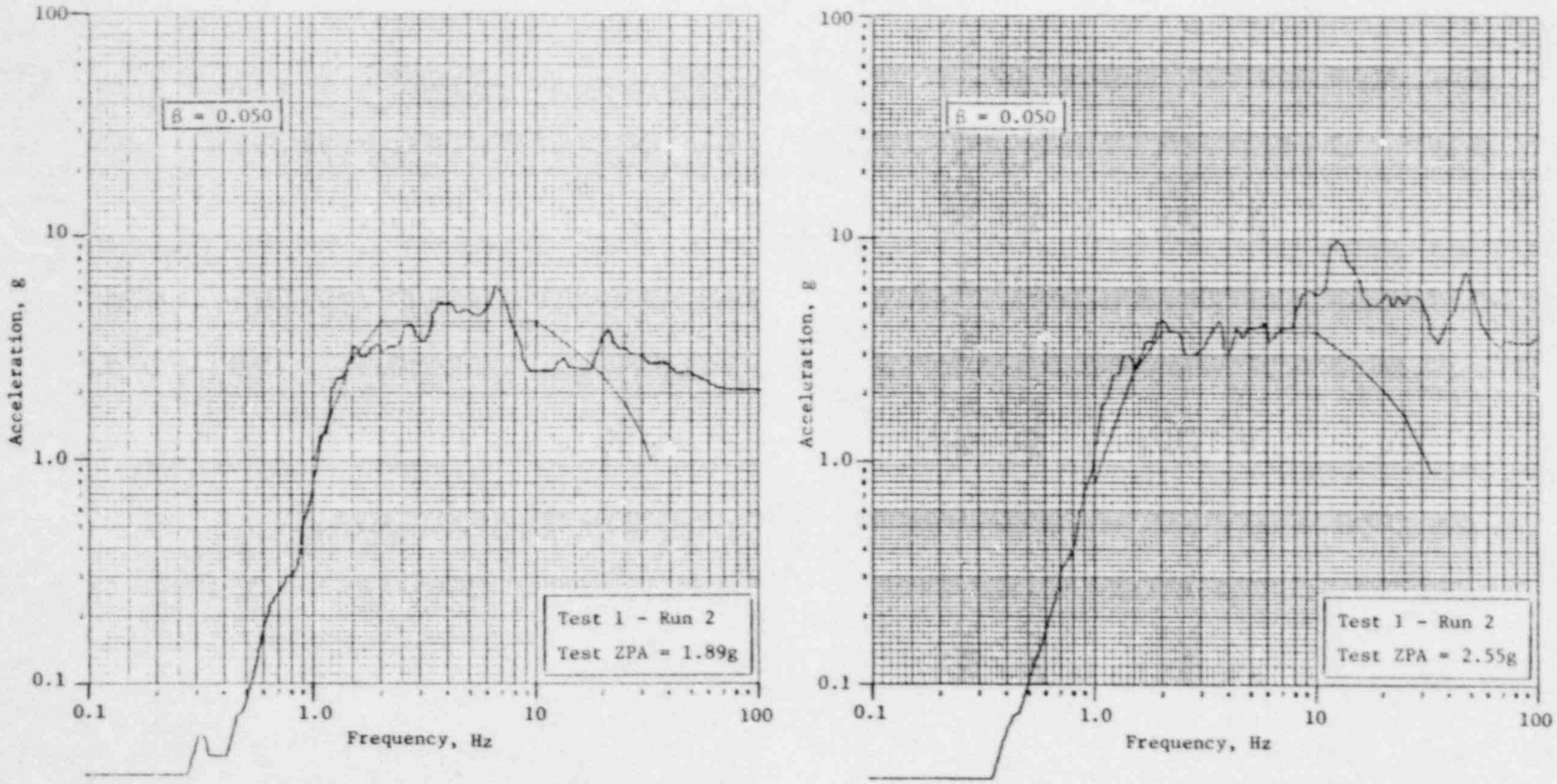


ε_{1x}, a_{1y} - Negligible

Test 1 - Run 2

FIGURE 6.3. RESPONSES FOR BIAXIAL INDEPENDENT RANDOM GROUND LEVEL TEST, XZ-EXCITATION

POOR ORIGINAL



a. Horizontal (a_{1x})

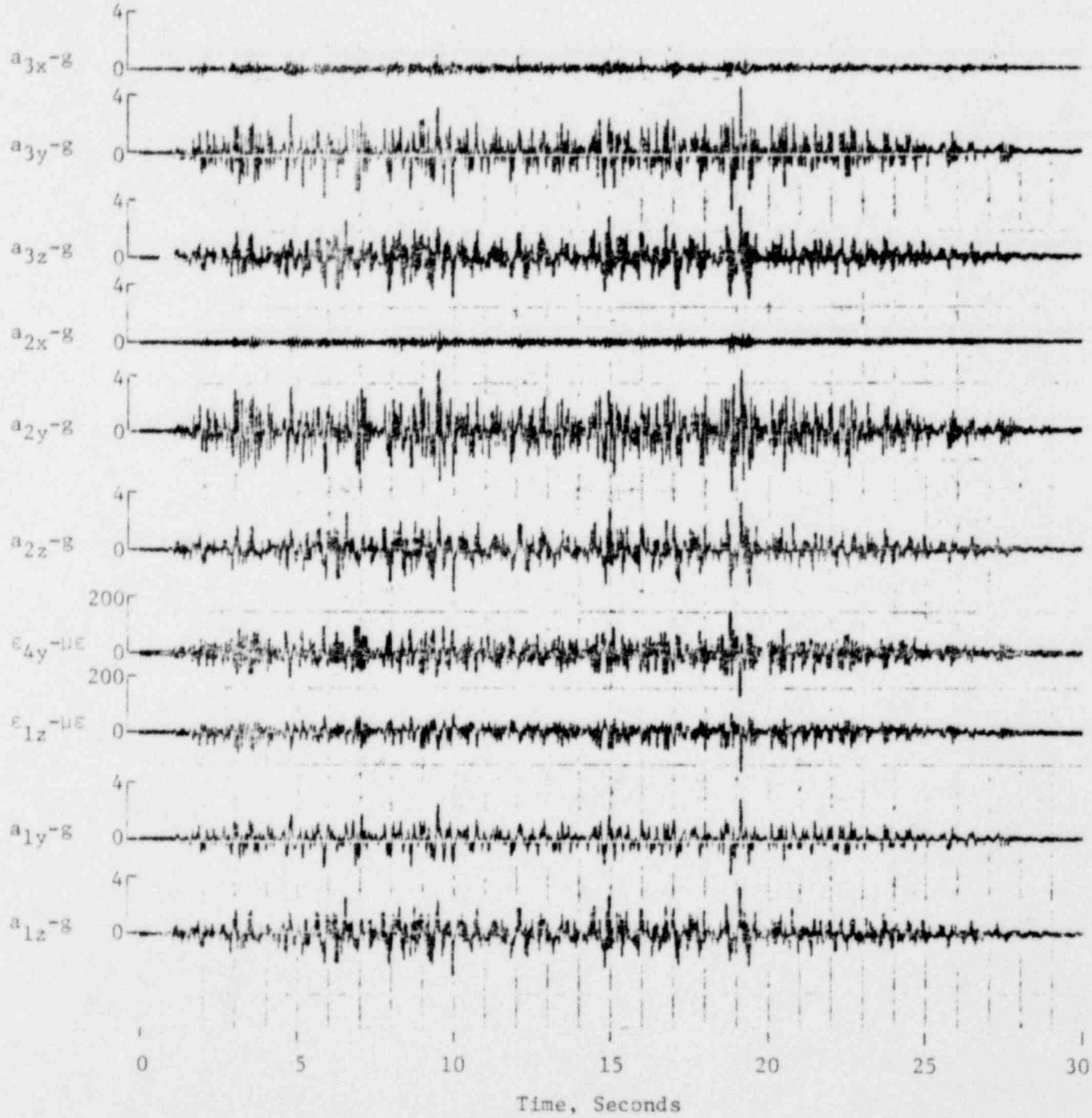
b. Vertical (a_{1z})

FIGURE 6.4. RESPONSE SPECTRA FOR BIAXIAL INDEPENDENT RANDOM GROUND LEVEL TEST, X-Z EXCITATION

is a similarity between the horizontal responses at a_2 or a_3 with the horizontal excitation at a_1, although a significant amplification of motion occurs from base excitation to the upper cabinet positions. Both of the latter observations are consistent with the transfer functions previously described in Section 5.2. Note also that the strain response ε_{1z} displays a strong, one-sided clipped nonlinearity. This type of response apparently results from the fact that the cabinet base is not welded on the X-direction sides. Thus, clipping occurs when the support frame relaxes contact with the base plate in one direction of the vibratory motion. This appears to occur above a threshold level of about +75 $\mu\varepsilon$ tension, and no corresponding limit exists for compression. Finally, note that only negligible responses occur at a_2 and a_3 in the transverse horizontal directions for each respective test.

Figures 6.2 and 6.4 show the respective response spectra for the table motion a_1. General matching of all response spectra was held to about ± 3 dB below 10 Hz, but higher levels were allowed at higher frequencies, where the test zero period accelerations (ZPA) generally is much higher than the specified ZPA. This particular type of apparent overtest at high frequency is typical for simulations produced on mechanical-hydraulic systems, and further attention to its consequences will be discussed in detail in Section 8.5. It should be mentioned that the matter of a ± 3 dB tolerance was typical in this case, since the RRS is a generic (i.e., all encompassing) specification. Many less severe specifications require that the TRS envelop the RRS at <u>all</u> frequencies. (Note by comparison to Figures 4.1 and 4.2 that the respective TRS's would indeed envelop the Reg. Guide 1.60 RRS's.) We assert that the conclusions of this report would not be altered if either set of tolerances were applied consistently. The vertical TRS (Figures 6.2b and 6.4b) indicate the presence of excessive excitation energy at about 12 Hz and 48 Hz. Further comment on the significance of this result will also be covered more in detail in Section 8.5.

Partial results for the biaxial <u>dependent</u> random ground level test (Test 3) are shown in Figures 6.5 and 6.6. Here, it can be seen from the similarity of a_{1y} and a_{1z} that the identical drive signal was used for each axis, and it corresponds to the z-axis excitation source for Test 1.

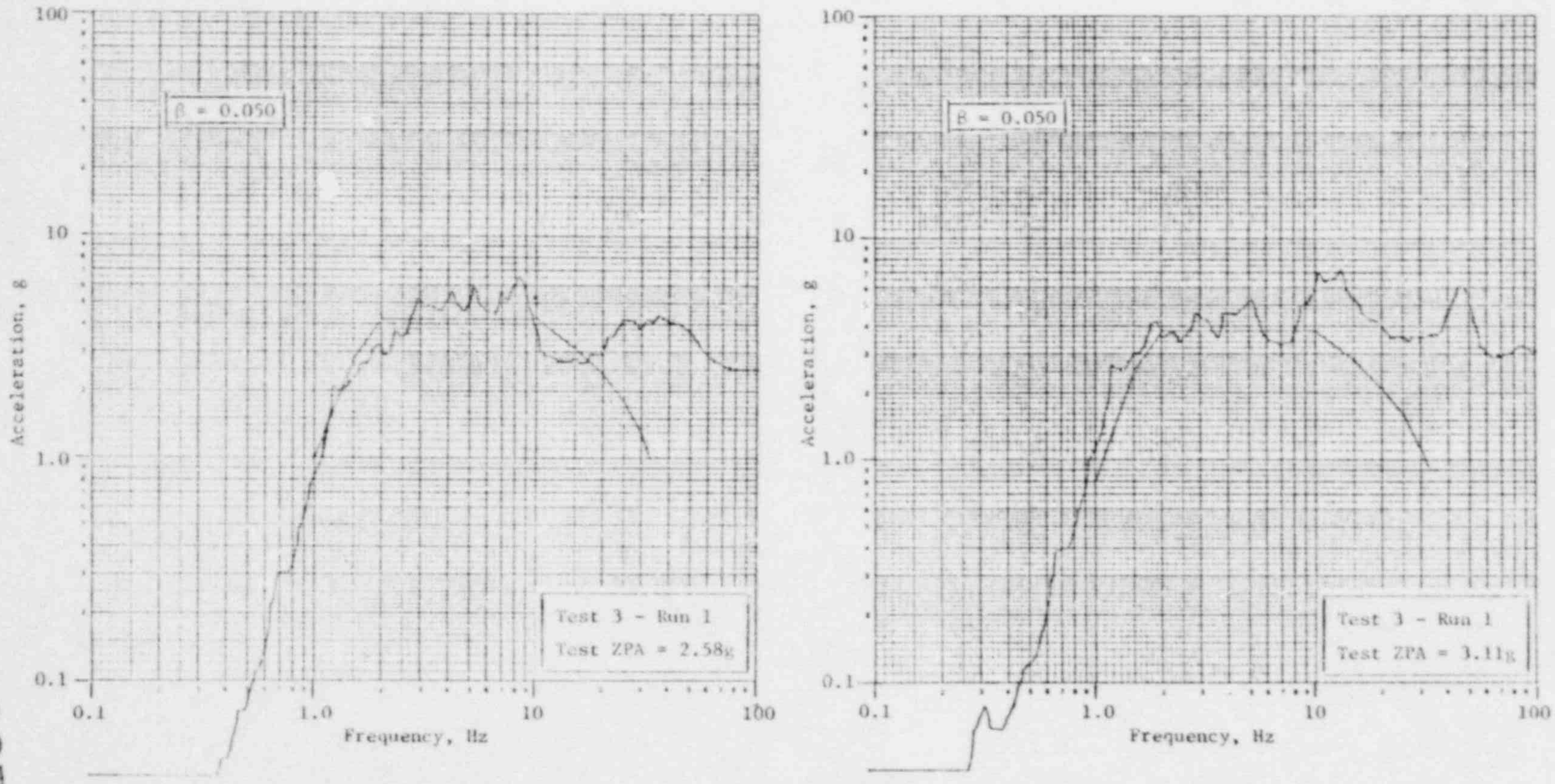


ε_{1x}, a_{1x} - Negligible

Test 3 - Run 1

FIGURE 6.5. RESPONSES FOR BIAXIAL DEPENDENT RANDOM GROUND LEVEL TEST, YZ-EXCITATION, PHASE 1

POOR ORIGINAL



a. Horizontal (a_{1y})

b. Vertical (a_{1z})

FIGURE 6.6. RESPONSE SPECTRA FOR BIAXIAL DEPENDENT RANDOM GROUND LEVEL TEST, Y-Z EXCITATION, PHASE I

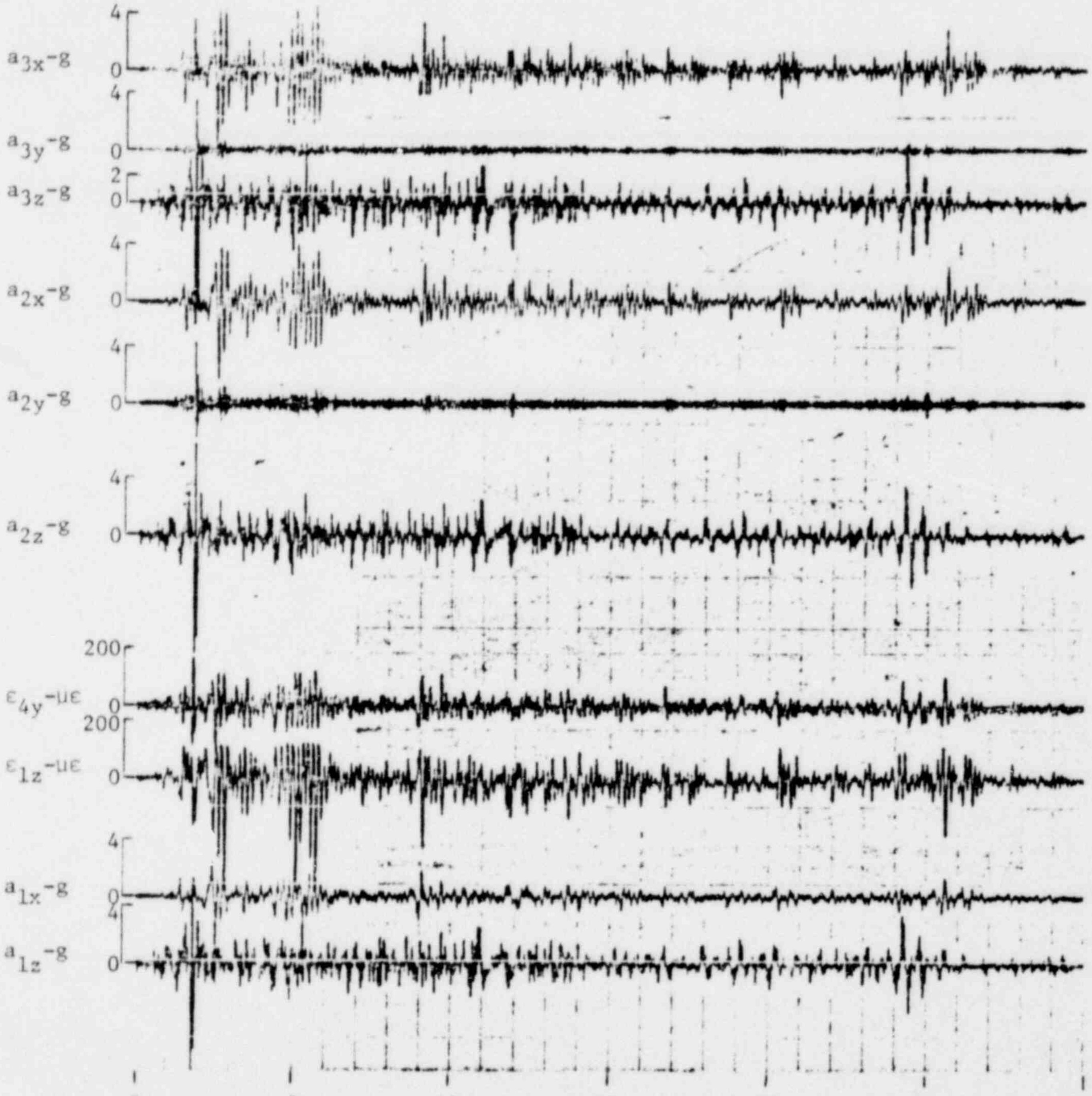
These results are typical of Runs 2, 3, and 4 of Test 3, although the upper cabinet responses are different, of course, for the respective horizontal orientations.

A final sample of ground level test data is shown in Figures 6.7 and 6.8, which were generated from the El Centro 1940 Earthquake source. Matching of the vertical TRS and RRS were particularly difficult with this source, as can be seen from Figure 6.8b. A large overtest is seen to occur. This apparently results from the large initial downward acceleration required in a_{1z} at about two seconds into the test. It is probable that velocity limiting of the vertical drive system occurs, so that this peak is more pronounced than is required, and the excessive buildup at 14 Hz, plus the excessive ZPA occur. A closer matching of this response spectrum probably could have been achieved with more attention given to the equalization process during the development of the command signal time histories for this test. However, this would have required significantly more test set-up time, and was not implemented in order to illustrate more vividly the discussion of excessive ZPA to be presented in Section 8.5.

6.2 Floor Level Tests

Similar test results for the floor level simulations are provided in this section. A greater variety of types of floor level tests were conducted (see Table III-1). However, all preliminary results in this section will be presented in a similar uniform manner, including time histories and response spectra for selected runs. This will be done for comparison purposes only, and would not, in general, be done for sine beat and/or sine dwell tests when performed individually.

Figures 6.9, 6.10, and 6.11, 6.12 show results for X-Z excitation runs, respectively, using the El Centro 1940 source and a random source (Test 5 and Test 6). In general, the floor level test is less severe (on an absolute scale) than the ground level tests previously described. However, this results merely because of the particular original choice of independent required response spectra (Figures 4.1 through 4.4), and one should not be too hasty in comparing the severities at this point. Much more will be developed on the comparison of test severities later.

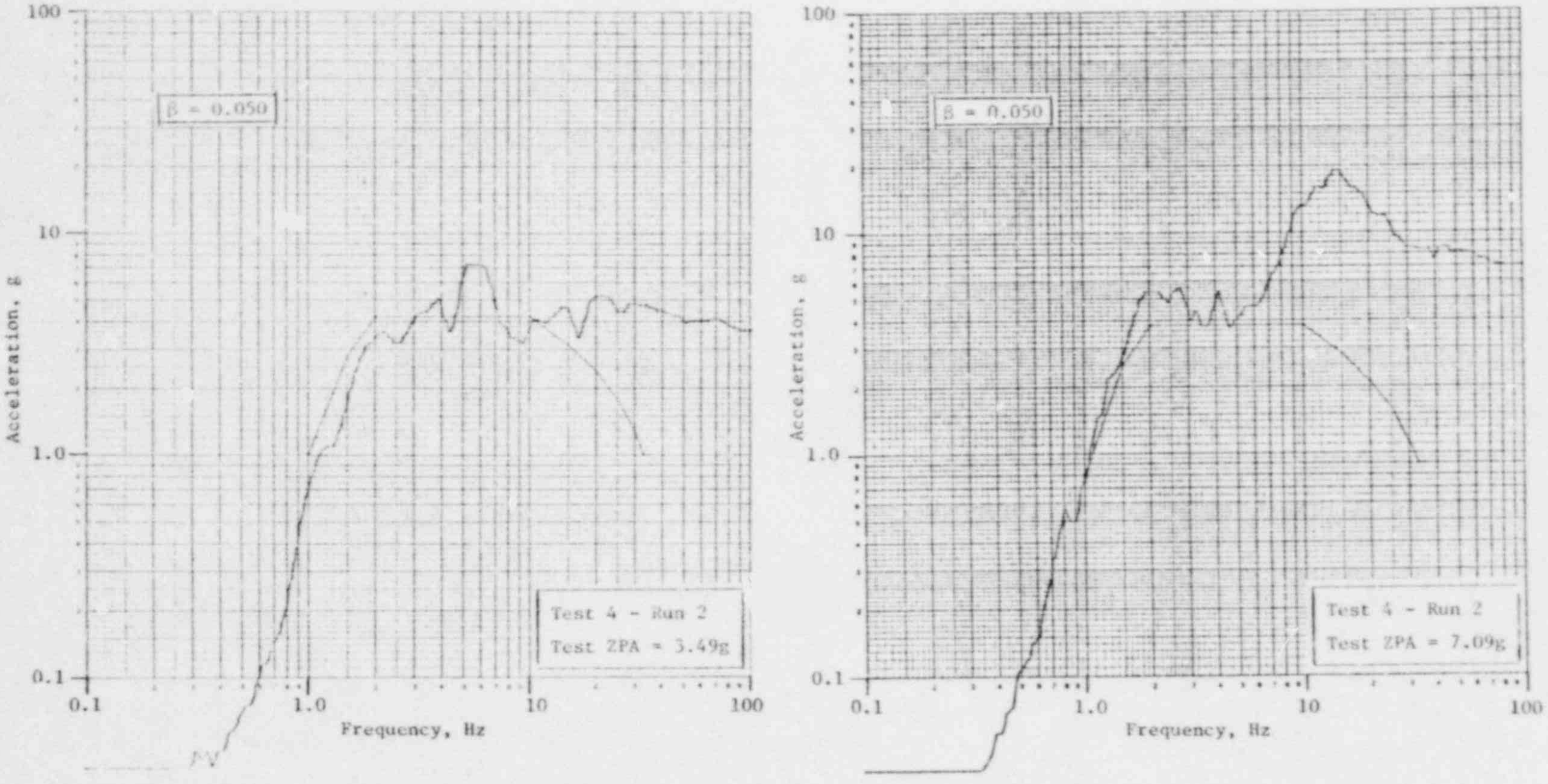


ε_{1x}, a_{1y} - Negligible

Test 4 - Run 2

FIGURE 6.7. RESPONSES FOR BIAXIAL INDEPENDENT EARTHQUAKE GROUND LEVEL TEST - XZ EXCITATION

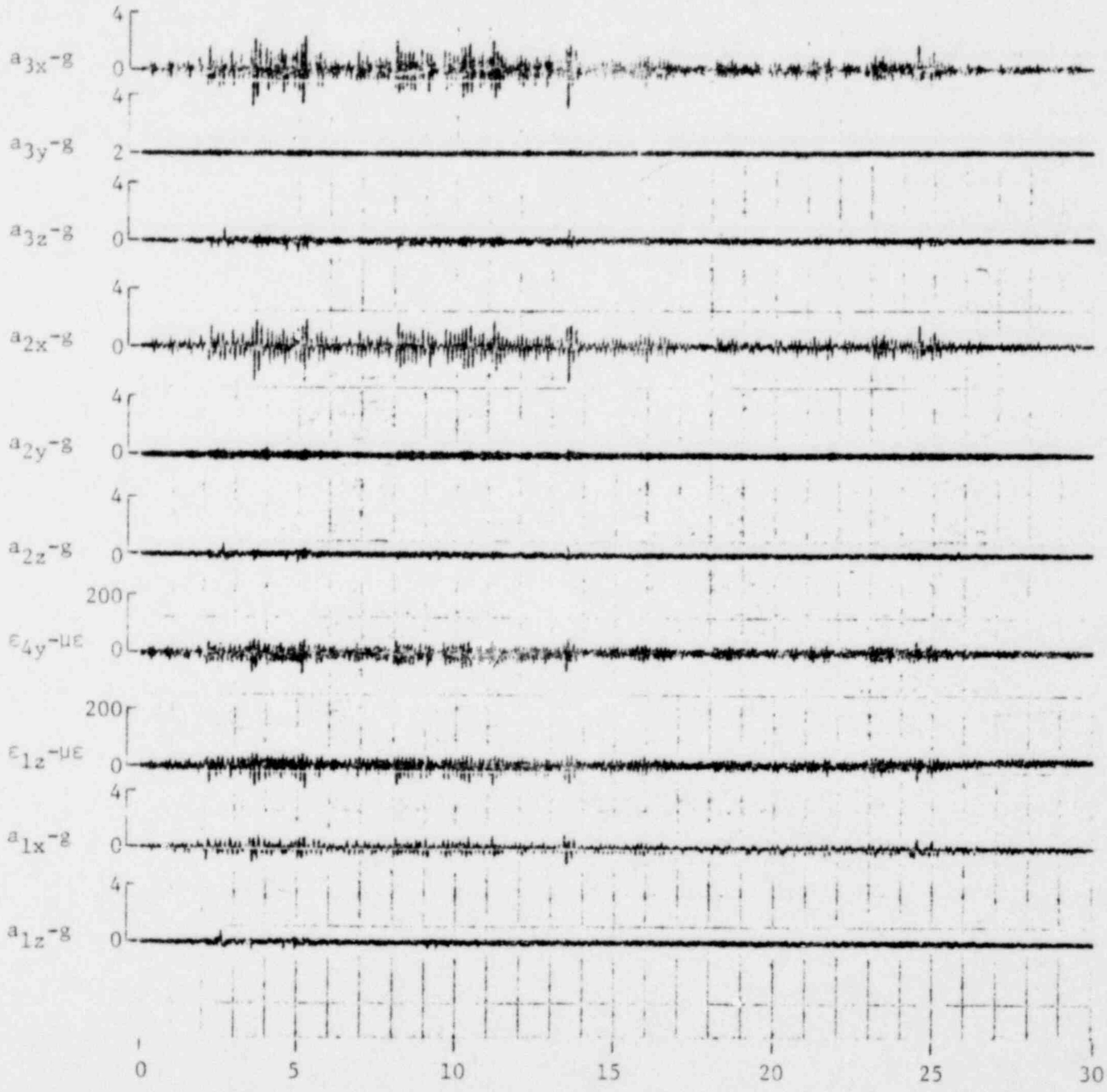
POOR ORIGINAL



a. Horizontal (a_{1x})

b. Vertical (a_{1z})

FIGURE 6.8. RESPONSE SPECTRA FOR BIAXIAL INDEPENDENT EARTHQUAKE GROUND LEVEL TEST, X-Z EXCITATION

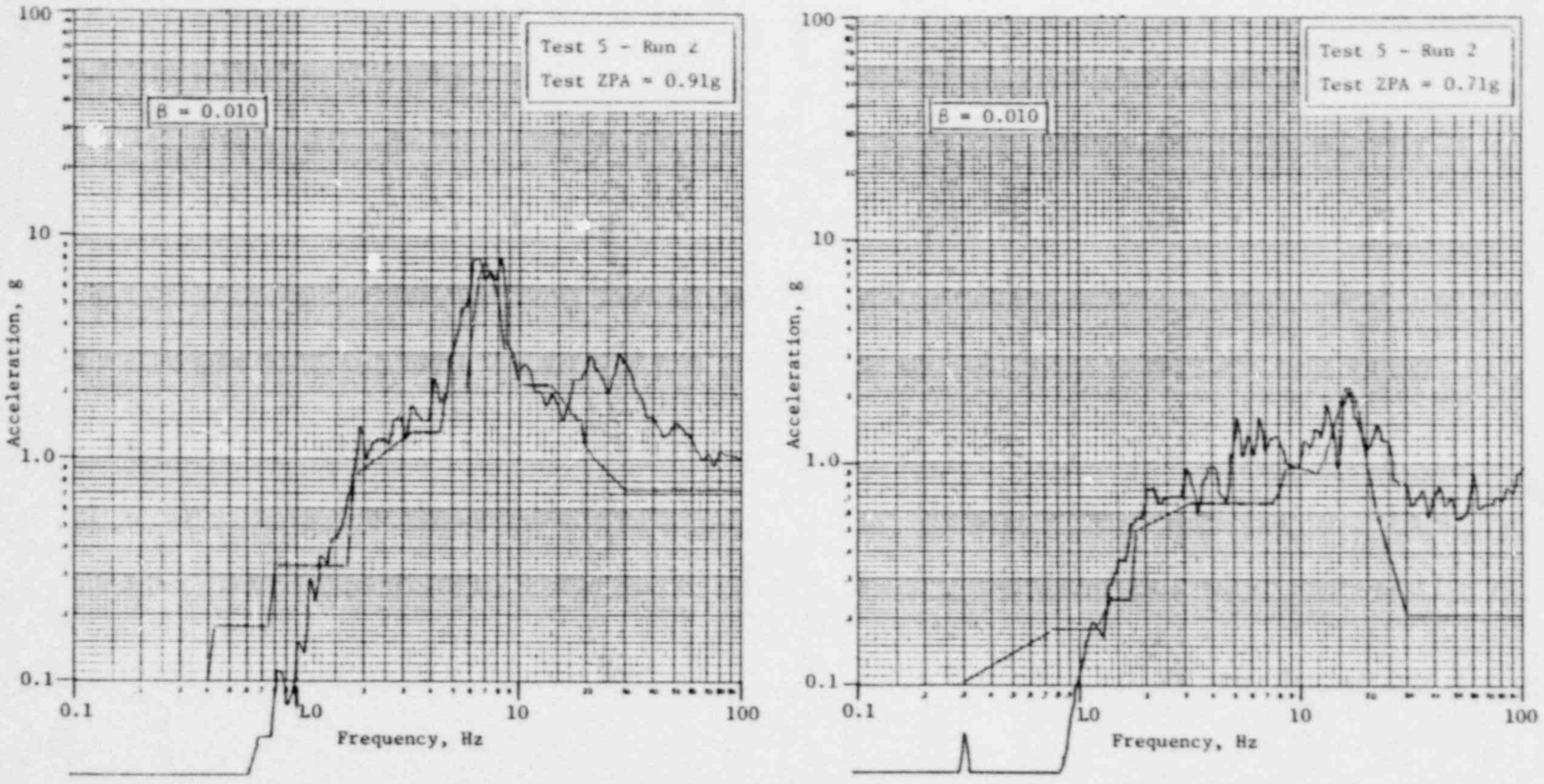


ε_{1x}, a_{1y} - Negligible

Test 5 - Run 2

FIGURE 6.9. RESPONSES FOR BIAXIAL INDEPENDENT EARTHQUAKE FLOOR LEVEL TEST - XZ EXCITATION

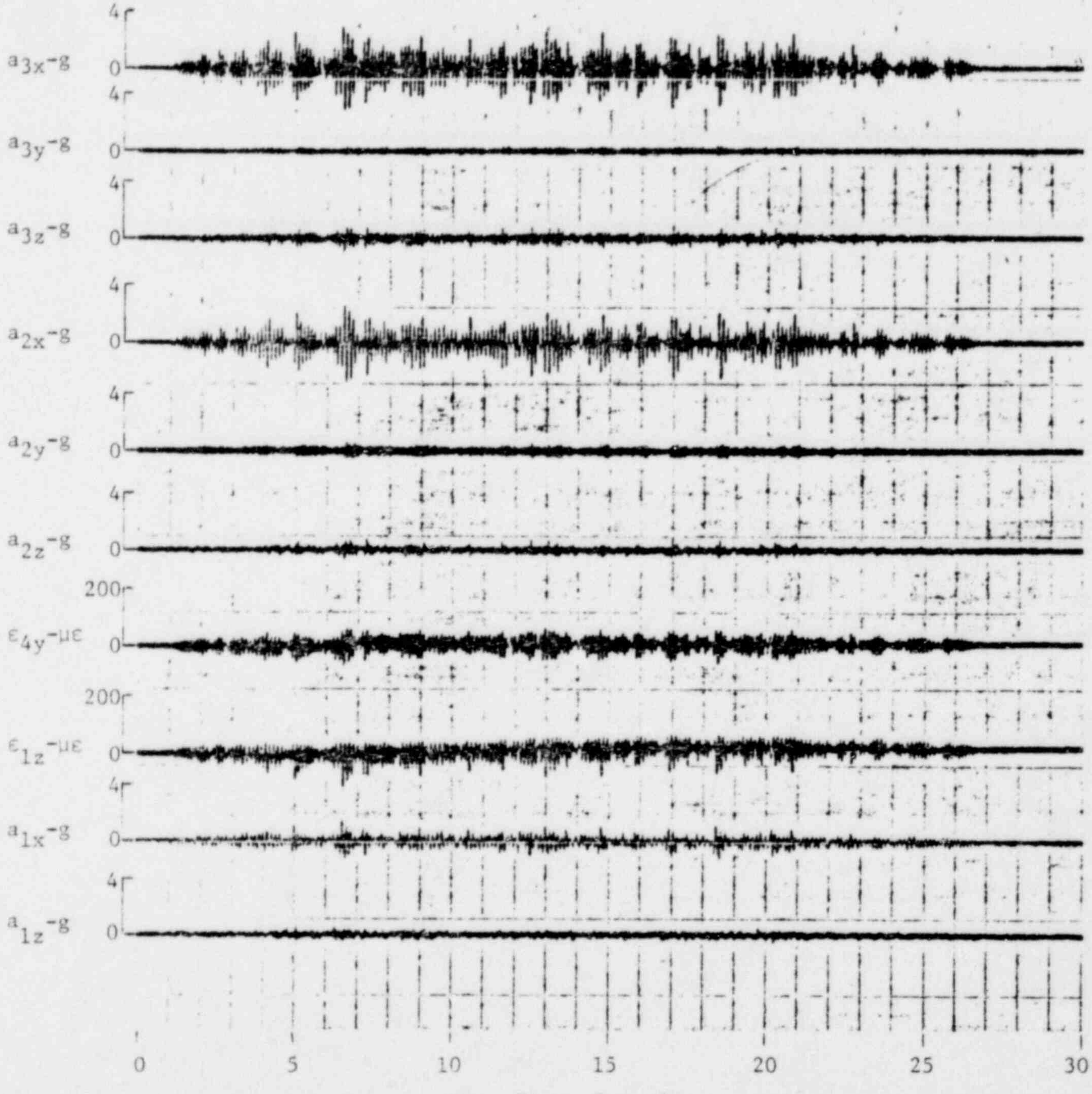
POOR ORIGINAL



a. Horizontal (a_{1x})

b. Vertical (a_{1z})

FIGURE 6.10. RESPONSE SPECTRA FOR BIAXIAL INDEPENDENT EARTHQUAKE FLOOR LEVEL TEST, X-Z EXCITATION

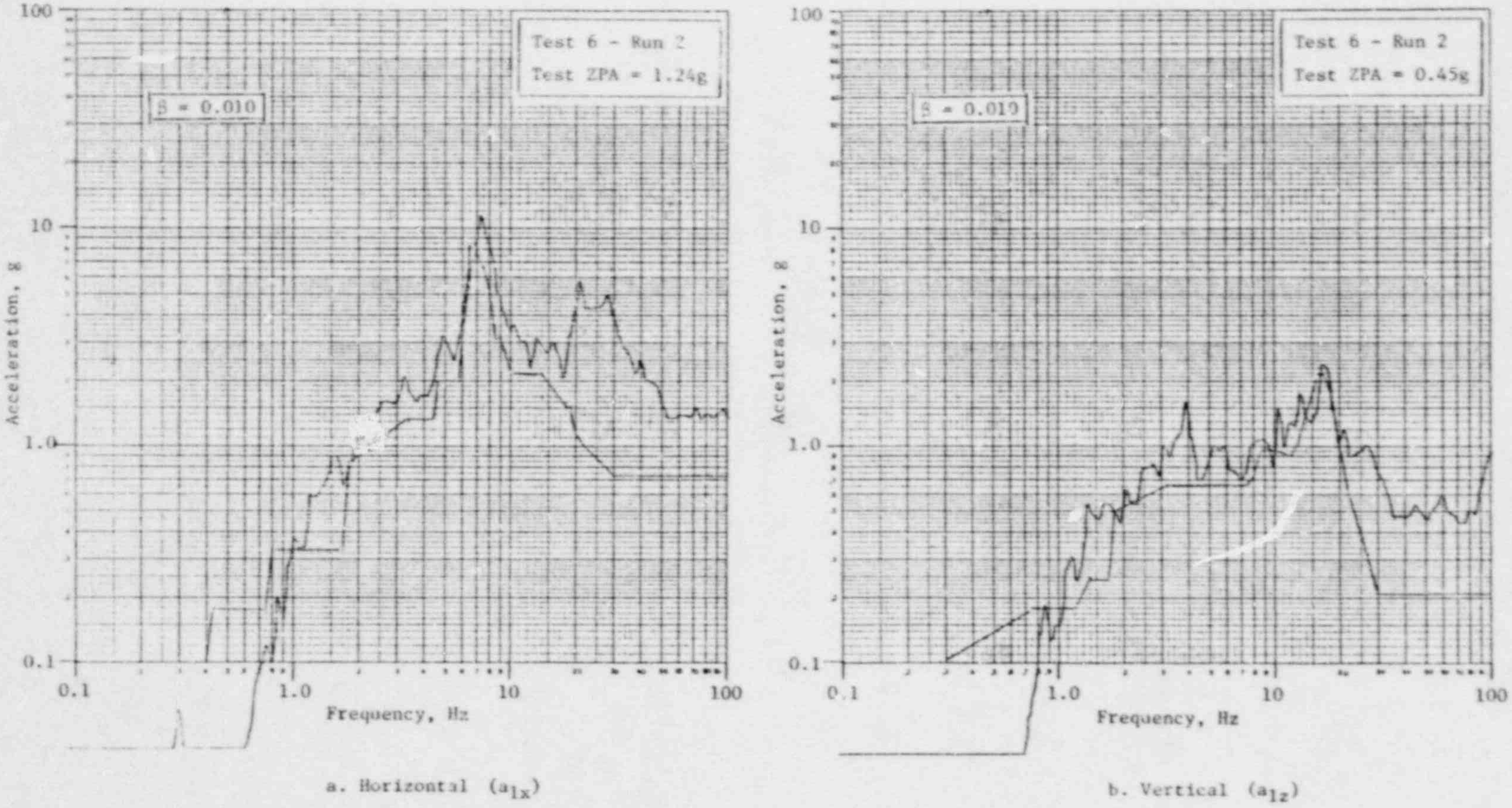


ε_{1x}, a_{1y} - Negligible

Test 6 - Run 2

FIGURE 6.11. RESPONSES FOR BIAXIAL INDEPENDENT RANDOM FLOOR LEVEL TEST - XZ EXCITATION

POOR ORIGINAL



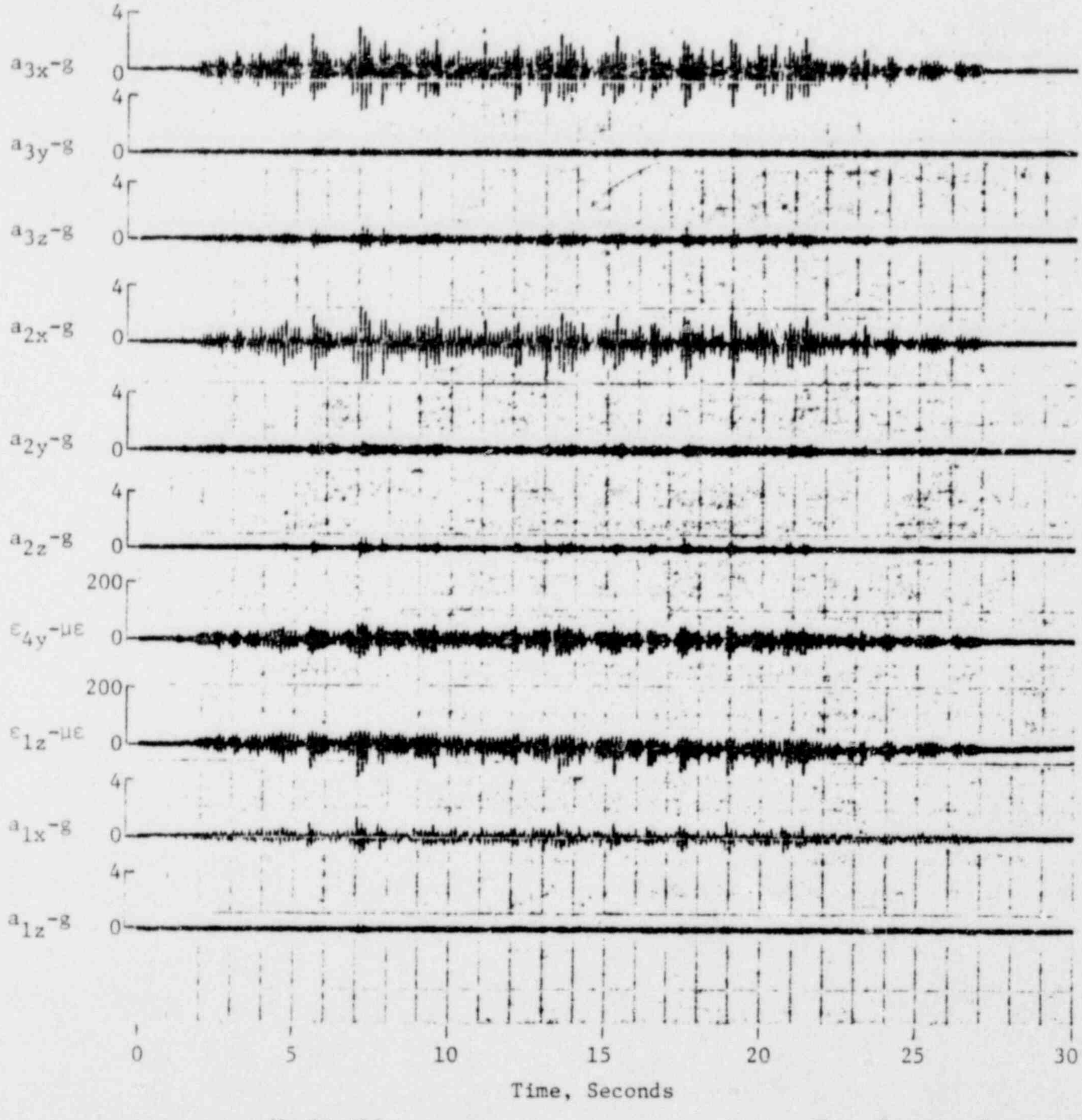
a. Horizontal (a_{1x})

b. Vertical (a_{1z})

FIGURE 6.12. RESPONSE SPECTRA FOR BIAXIAL INDEPENDENT RANDOM FLOOR LEVEL TEST, X-Z EXCITATION

It can be seen that the required vertical motion is quite small compared to the horizontal for these tests. Very little vertical response occurs at a_{2v} and a_{3v}. Furthermore, in Figures 6.13 and 6.14, when inspecting the results for Test 8 - Run 3 (which is a uniaxial random test using the same horizontal excitation source as Test 6 - Run 2), it is apparent that essentially the same test run has been applied. These results are also useful for demonstrating the repeatability of the simulator and data acquisition system.

Sample results for a sine beat run (Test 9 - Run 5) and a sine dwell run (Test 10 - Run 6) are shown respectively in Figures 6.15, 6.16, and Figures 6.17, 6.18. The response spectra of Figure 6.18 show that some vertical motion was present for the horizontal run, although it was relatively small, as can be seen from the a_{1z} trace in Figure 6.17. More importantly, the response spectra clearly show that a pure sinusoidal motion was not applied (i.e., response peaks occur at harmonics of the excitation). This type of result is typical for a motion produced by a hydraulic actuator, since harmonics are generated by friction in the actuator and in the table support system as well. The presence of the harmonics generally has no influence on the final outcome of a given test.



ε_{1x}, a_{1y} - Negligible

Test 8 - Run 3

FIGURE 6.13. RESPONSES FOR UNIAXIAL RANDOM FLOOR LEVEL TEST - X-EXCITATION

POOR ORIGINAL

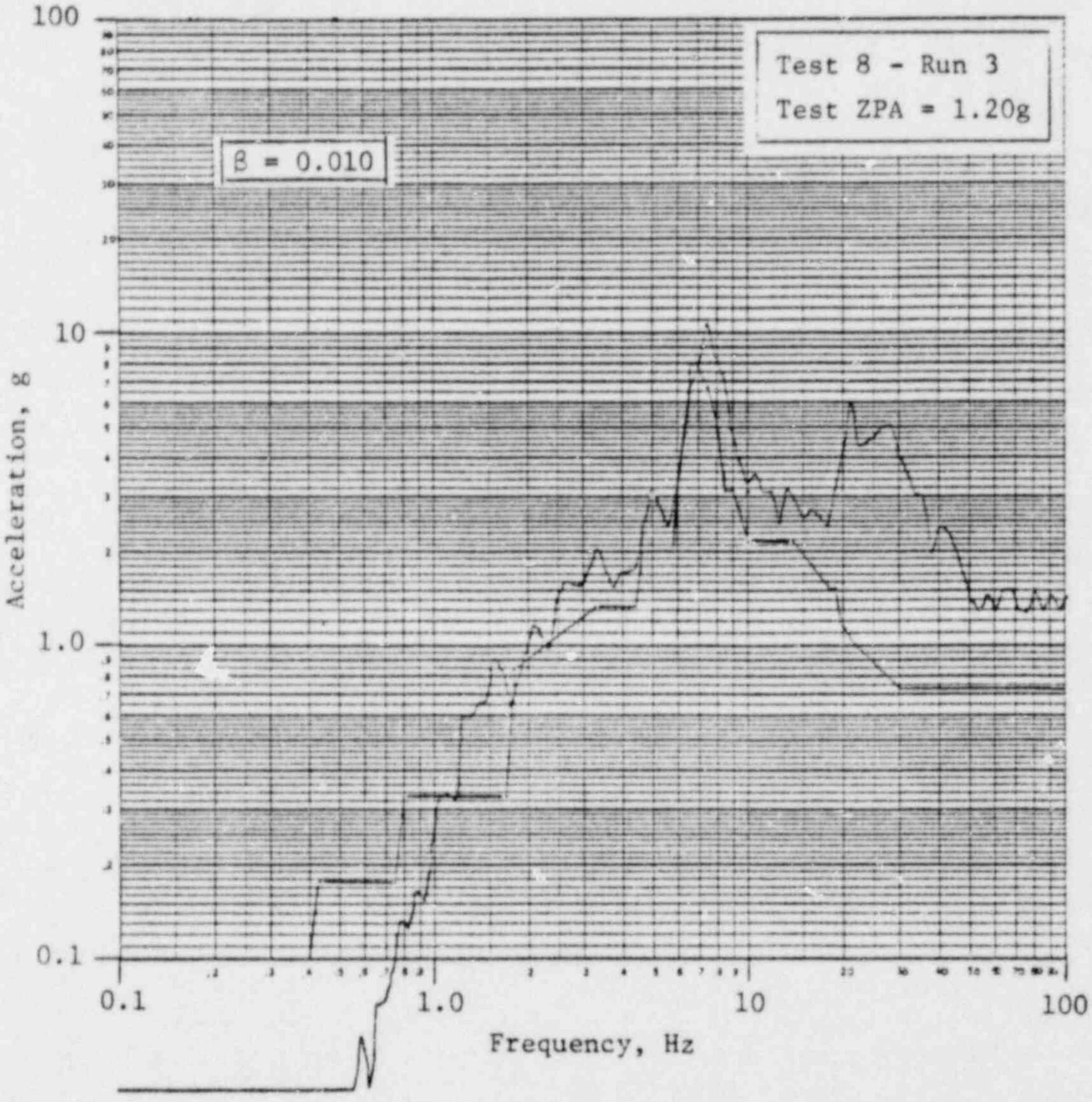
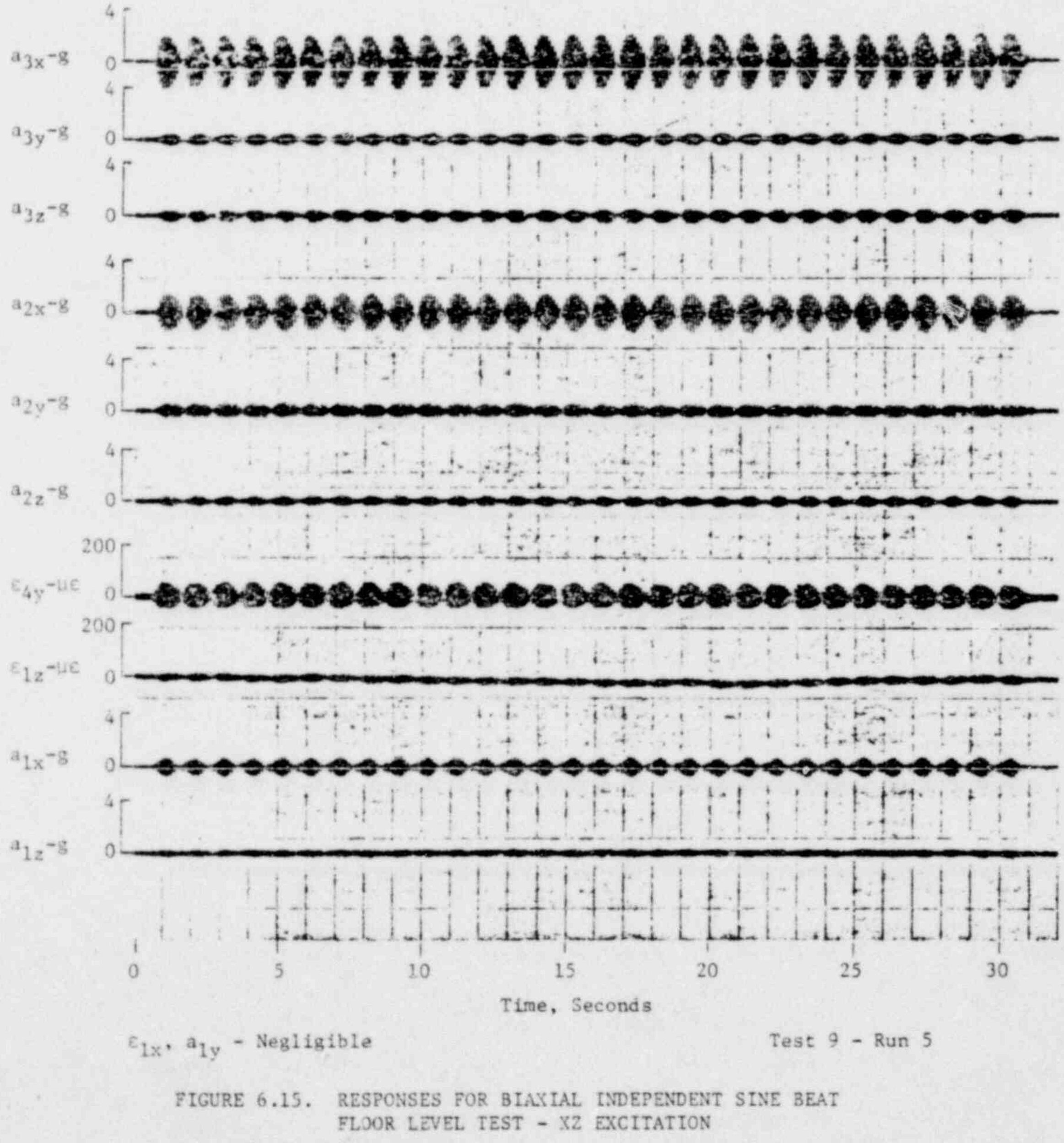


FIGURE 6.14. RESPONSE SPECTRUM FOR UNIAXIAL RANDOM FLOOR LEVEL TEST, X-EXCITATION (a_{1x})

POOR ORIGINAL

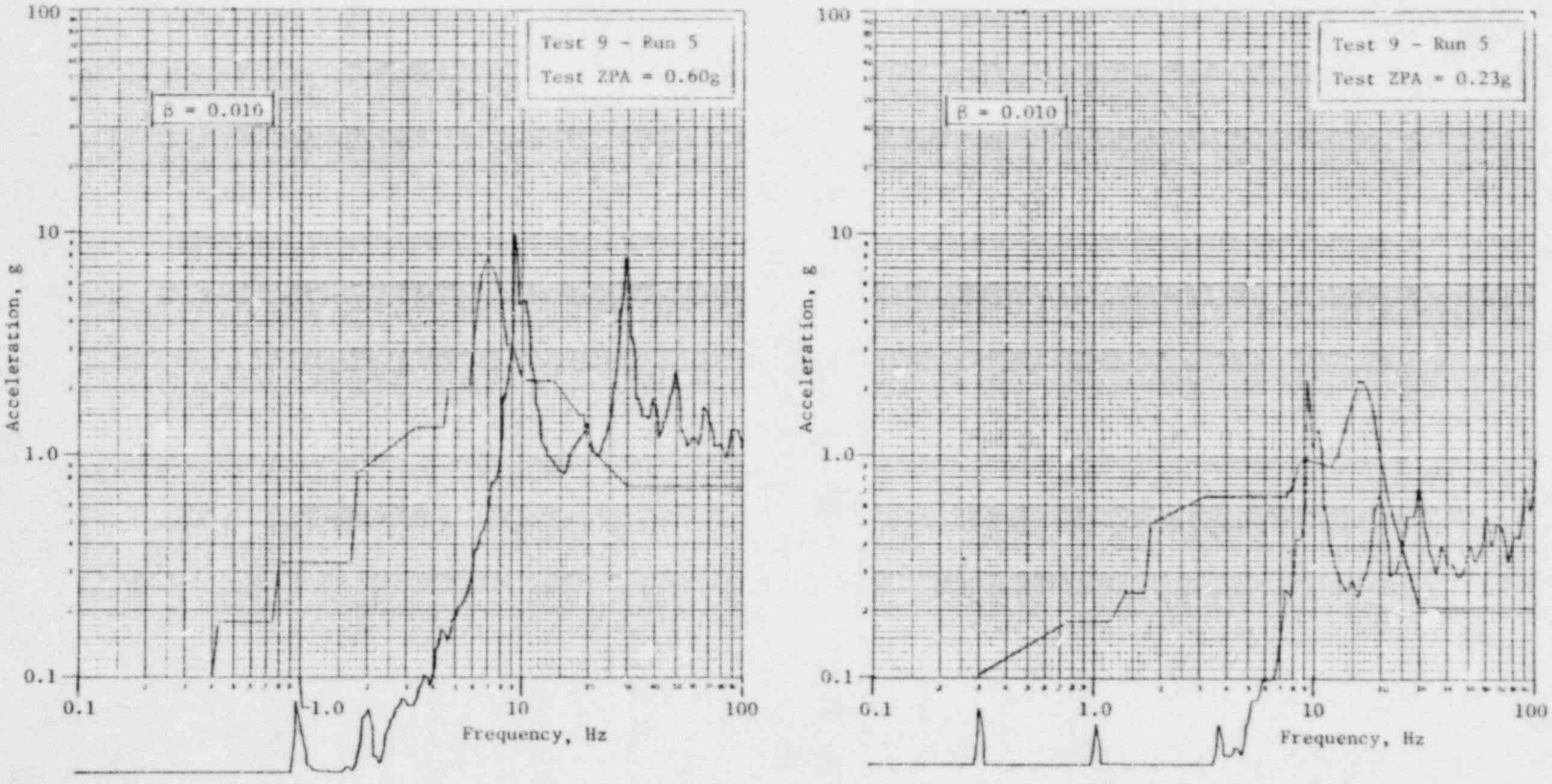


ε_{1x}, a_{1y} - Negligible

Test 9 - Run 5

FIGURE 6.15. RESPONSES FOR BIAXIAL INDEPENDENT SINE BEAT FLOOR LEVEL TEST - XZ EXCITATION

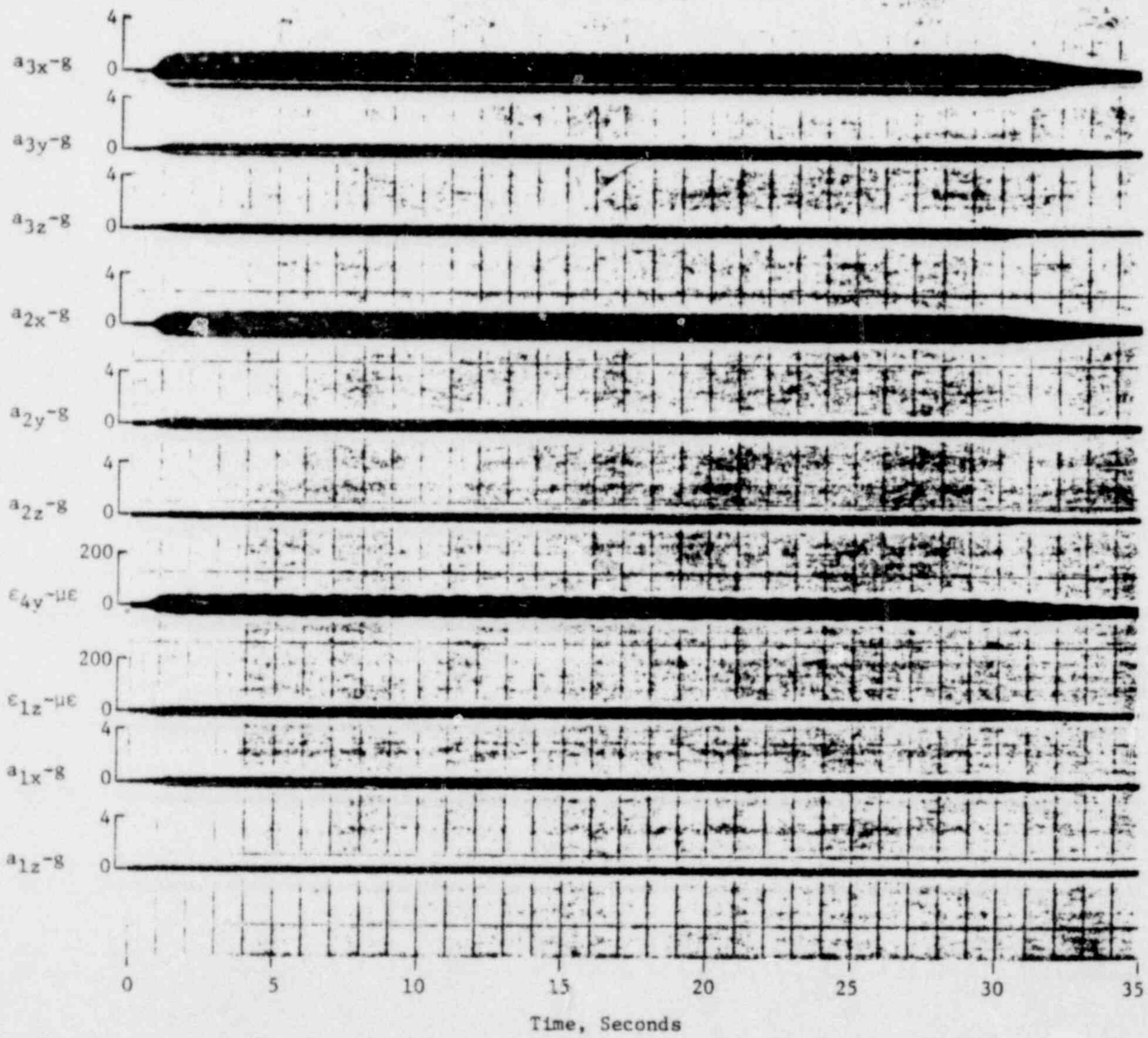
POOR ORIGINAL



a. Horizontal (a_{1x})

b. Vertical (a_{1z})

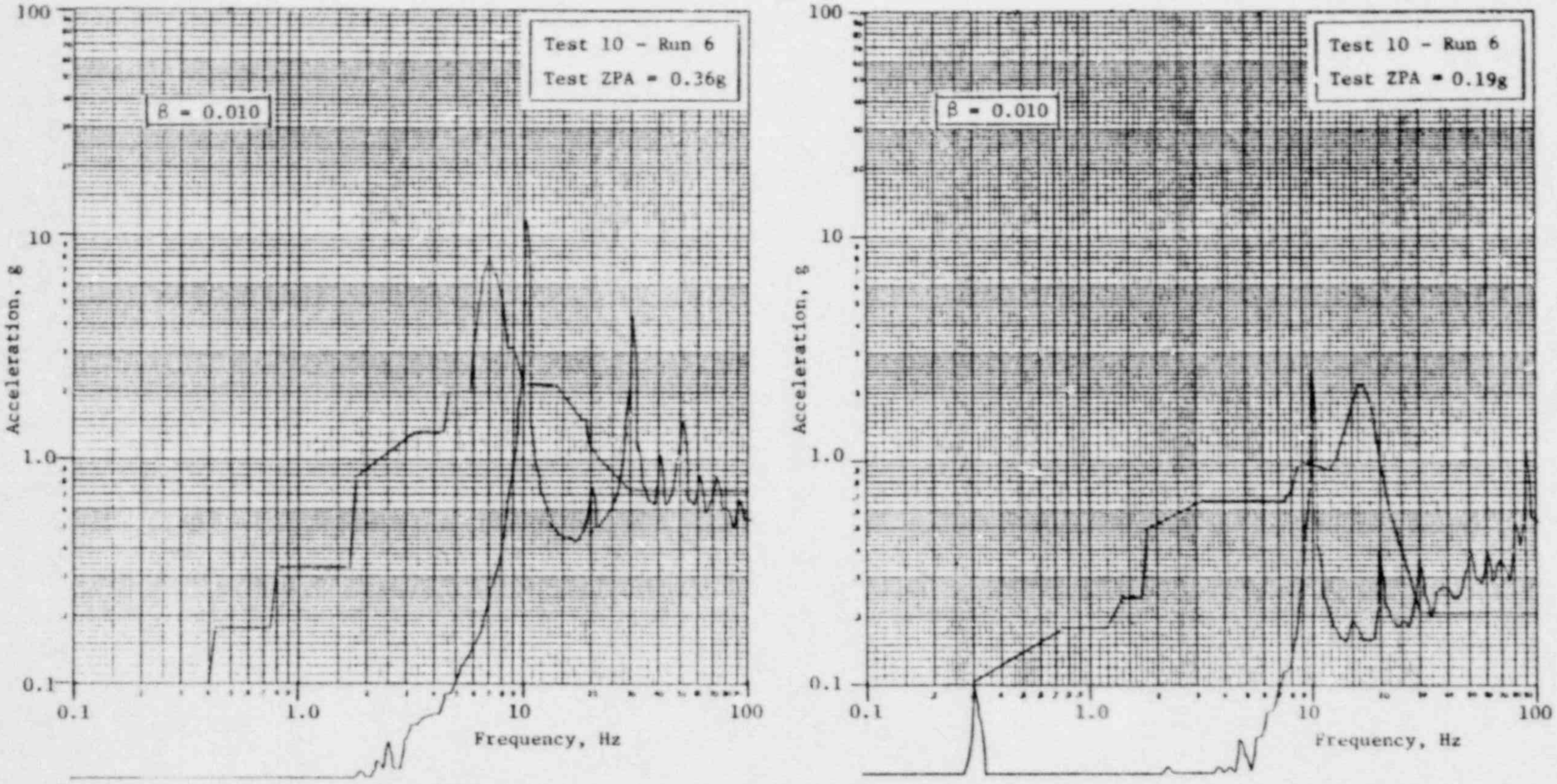
FIGURE 6.16. RESPONSE SPECTRA FOR BIAXIAL INDEPENDENT SINE BEAT FLOOR LEVEL TEST, X-Z EXCITATION



ε_{1x}, a_{1y} - Negligible

Test 10 - Run 6

FIGURE 6.17. RESPONSES FOR UNIAXIAL SINE DWELL FLOOR LEVEL TEST - X-EXCITATION



a. Horizontal (a_{1x})

b. Vertical (a_{1z})

FIGURE 6.18. RESPONSE SPECTRA FOR UNIAXIAL SINE DWELL FLOOR LEVEL TEST, X-EXCITATION

POOR ORIGINAL

7.0 DERIVATION OF DATA CORRELATION PARAMETERS

Up to this point, we have presented information about the test specimen and apparatus, procedures developed for the tests, and only sample preliminary data in a form which are part of the standard requirements for typical Class IE equipment qualification tests. In the remainder of this report, we will embark upon a detailed analysis of all of the data that has been acquired in order to meet the broad program research objectives outlined in Section 1.0. In order to provide a basis for the analysis, some mathematical background development is first appropriate. This background is developed in this section. The first development on response spectra contains no new information, but is presented in a form which is most useful to the problem at hand. The second development, which deals with test damage severity factors, contains significantly new concepts that have been formulated under this program.

7.1 Response Spectra Relationships

The development of this section is based on information provided in References 7 and 8, which can be consulted for more details. Here, we merely summarize several relationships in terms of the notation used in this study.

For a generalized structural system which is free at the top and excited at its base with a harmonic displacement x_{1h} of frequency ω_r at the r-th resonance frequency of the system, the relative displacement response amplitude u_{ir} at some upper point i can be written in terms of the following matrix equation

$$\left\{\frac{u_{ir}}{x_{1h}}\right\} = \left[\phi\right] \left\{\frac{q_r}{x_{1h}}\right\} \qquad (7\text{-}1)$$

where the left side is a column matrix, each element of which represents the transfer function of each point i when the system is excited at its r-th resonance. $[\phi]$ is a square matrix which relates physical coordinates u_{ir} to a set of generalized coordinates q_r, and $\{q_r/x_{1h}\}$ is a column matrix which consists of the set of generalized coordinates which describe the mode shape for the r-th mode of the structure. Equation (7-1) includes the assumption that the system is lightly damped, and the normal modes are sufficiently separated in frequency so that interaction does not occur.

If we concentrate on the absolute acceleration response of a single upper point ($\ddot{x}_i$) of the structure, we can write for the magnitude at the r-th resonance:

$$\left|\ddot{u}_{ir}/\ddot{x}_{1h}\right| \approx \left|\ddot{x}_{ih}/\ddot{x}_{1h}\right| = \phi_{ir} \sum_{j=1}^{N} \phi_{rj}\, m_j/(2\beta_r) \qquad (7\text{-}2)$$

where ϕ_{ir} and ϕ_{rj} are the indicated elements of the matrix $[\phi]$, m_j is the mass of element j of the structure, and β_r is the critical damping ratio for the r-th mode. The left side of this equation can easily be measured at a resonance frequency (such as for a_{2y}/a_{1y} in Figure 5.6a) and will be useful to us in a moment.

Now consider the same structural system excited by an earthquake transient acceleration $\ddot{x}_{1t}$. In this case, the generalized coordinates for the peak response in the r-th normal mode are given by

$$\{q_r^*\} = \frac{[\phi]^T\{m\}\,\ddot{x}_{1t}}{(\omega_r^2-\omega^2+i2\beta_r\omega_r\omega)} \qquad (7\text{-}3)$$

Furthermore, by definition of the response spectrum, we have

$$\left[\ddot{x}_{1t}/(\omega_r^2-\omega^2+i2\beta_r\omega_r\omega)\right] = S_d(\omega_r) \qquad (7\text{-}4)$$

where $S_d(\omega_r)$ is the relative displacement response spectrum value at ω_r for a single degree of freedom oscillator of light damping β_r, which is subjected to the same base transient acceleration $\ddot{x}_{1t}$. Thus, we have

$$\{q_r^*\} = [\phi]^T\,\{m\}\,S_d(\omega_r) \qquad (7\text{-}5)$$

and for a single mode which is an element of this vector, we have

$$q_r^* = \sum_{j=1}^{N} \phi_{rj}\, m_j\, S_d(\omega_r) \qquad (7\text{-}6)$$

Now recall that the actual physical peak transient response displacement at point i as a result of the r-th mode is given as

$$u_{it}^* = \phi_{ir}\, q_r^* = \phi_{ir} \sum_{j=1}^{N} \phi_{rj}\, m_j\, S_d(\omega_r) \qquad (7\text{-}7)$$

Furthermore, we can relate

$$S_d(\omega_r) \approx S_a(\omega_r)/\omega^2 \text{ and } \ddot{x}_{it}^* \approx u_{it}\,\omega^2 \qquad (7\text{-}8)$$

where $S_a(\omega_r)$ is the absolute acceleration response spectrum for the single degree of freedom Oscillator. Thus, combining Equations (7-2) and (7-8) into Equation (7-7), we have

$$\ddot{x}^{*}_{it} = 2\beta_r \left| \ddot{x}_{ih}/\ddot{x}_{1h} \right| S_a(\omega_r) \tag{7-9}$$

or in terms of the notation used for the instrumentation identified in Section 2.2,

$$a^{*}_{it} = 2\beta_r \left| H_{i1}(\omega_r) \right| \hat{a}_{1r} \tag{7-10}$$

where $\hat{a}_{1r}$ is the value for the acceleration response spectrum at ω_r, and $H_{i1}(\omega_r)$ is the acceleration transfer function for the structure at ω_r under harmonic excitation.

In words, Equation (7-10) allows one to calculate the peak absolute acceleration at point i by using the value $\hat{a}_1$ at the frequency (ω_r) of the absolute acceleration response spectrum $S_a(\omega)$ which has been computed for the base transient. Note that the computation must be for a damping value of β_r, which also must be valid for the mode of the structure being investigated. Also, one must include the magnitude of the harmonic transfer function $\left| a_{ih}/a_{1h} \right|$, which can be measured during a resonance search.

If the structure is governed by one dominant mode in the frequency range of interest, then Equation (7-10) is sufficient for prediction of the peak acceleration response. However, if more than one mode influences the response, then the most likely peak response can be obtained by

$$a^{*\,p}_{it} = \left[\sum_r \left(2\beta_r \left| a_{ir}/a_{1r} \right| \hat{a}_{1r} \right)^2 \right]^{\frac{1}{2}} \tag{7-11}$$

that is, an SRSS peak response. These relationships will be useful for correlating the mechanical behavior of the cabinet in a later section. Note in doing this, that different applications of the equation must be performed in each the Y and X directions, since the cabinet has different response characteristics along each axis. Furthermore, the above relationships have been developed for acceleration responses. Of course, they are also applicable to strain or any other type of response, providing that the appropriate transfer function has been determined under harmonic excitation.

7.2 Development of Test Severity Factors

One of the major objectives of this program has been the development of some means of comparing the severity or damage potential of various seismic qualification tests. The basis for this comparison will be developed in this section. However, it is first necessary to introduce other concepts which will be used as ingredients for the severity factors. We start with a discussion of time-average responses in systems subjected to nonstationary random processes. The general basis for this development has been given in Reference 9, and has been applied, in part, previously to the problem of seismic response of liquid slosh in a cylindrical tank in Reference 10.

We consider the response at point 2x of a linear system subject to an excitation at point 1x by a nonstationary random process having the nonstationary power spectral density $G_{1x}(\omega,t)$. We can predict the nonstationary response power spectral density as

$$G_{2x}(\omega,t) = \left|H_{2x1x}(\omega)\right|^2 \; G_{1x}(\omega,t) \tag{7-12}$$

where $H_{2x1x}(\omega)$ is the linear harmonic transfer function for the system. If we now consider earthquake or simulated earthquake type transients, we will also average these quantities over the duration T_e of the transient. Thus, we can write the time-averaged relationship as

$$\bar{G}_{2x}(\omega) = \left|H_{2x1x}(\omega)\right|^2 \; \bar{G}_{1x}(\omega) \tag{7-13}$$

Now we consider classes of excitation transients in which all samples have the identical normalized time average power spectral density shape (as a function of frequency), but the magnitude is proportional to the time-average mean square of the acceleration. Note that this type of transient classification is consistent with the general nature of earthquake ground motion transients, and in fact, is analogous to the response spectrum envelope curves specified by the NRC RG 1.60. Thus, we can write

$$\bar{G}_{1x}(\omega) = \bar{G}_{k1x}(\omega) \; \bar{a}_{1x}^2 \tag{7-14}$$

where $\bar{G}_{k1x}(\omega)$ is the normalized power spectrum for a given type of transient k (i.e., k = 1 may denote earthquake ground level, k = 2 may denote earthquake floor level, k = 3 sine beat, etc.). Furthermore, $\bar{a}_{1x}$ is the time average RMS value for the acceleration. We now substitute Equation (7-14) into (7-13), integrate over frequency and take a square root to obtain

$$\bar{a}_{2x} = A_{k2x}\, \bar{a}_{1x} \tag{7-15}$$

where

$$A_{k2x} = \left[\int_{0}^{\infty} \left| H_{2x1x}(\omega) \right|^2 \; \bar{G}_{k1x}(\omega)\, d\omega \right]^{\frac{1}{2}} \tag{7-16}$$

Thus, A_{k2x} is a constant for a given response point on a given specimen or structure, and for a given class (k) of excitation. Then, Equation (7-15) states that the RMS time average response acceleration is proportional to the RMS time average excitation acceleration. This assertion will be checked with the data obtained from the present experiments.

We are now in position to develop relationships for a test severity factor D. It is recognized that RMS vibration levels are useful for determining effects of sustained vibration on failure such as fatigue. However, it is also recognized that peak acceleration levels are useful for determining the occurrence of threshold type failures, such as fracture or opening of electrical relays. Furthermore, time duration of exposure must play a role in damage that will occur. Therefore, on the basis of physical reasoning alone, we define a damage or severity factor according to

$$D = a^{*}\, \bar{a}\, T_e \tag{7-17}$$

It is recognized that this is only one possible way that the definition could be postulated. That is, each term might appear with some exponent (or fractional exponent). However, this is a detail which must be left to future work. With the present development, we will provide at least a means of <u>relative</u> comparison of severity. Thus, it can be seen that with this relationship, we can define excitation severity

$$D_{1x} = a_{1x}^{*}\, \bar{a}_{1x}\, T_e \tag{7-18}$$

and response severity

$$D_{2x} = a_{2x}^{*}\, \bar{a}_{2x}\, T_e \tag{7-19}$$

and the ratio D_{2x}/D_{1x} is a measure of the tendency of a structure to amplify or attenuate the severity of the excitation. It is, therefore, desirable to obtain a relationship between the excitation and response severity so that this characteristic of the structure can be determined.

We assert that for a given type (k) of transient excitation process, the ratio of peak value to time average RMS value is a constant. That is, for a sine dwell longer than about six seconds,

$$a^*/\bar{a} \approx 1.414$$

and for stationary Gaussian random process,

$$a^*/a \approx 3.0 \quad \text{at 99.9\% probability.}$$

For a nonstationary earthquake type transient at ground level, the ratio should be even greater than 3.0. At this point, we simply assert that the value can be considered constant at a given probability level, without determining its exact value. Thus, for a given type of process (k), we have

$$(a_{1x}^*/\bar{a}_{1x})_k = B_k$$

Now, for linear systems, the response has the same probability distribution as the input, hence

$$(a_{2x}^*/\bar{a}_{2x})_k = (a_{1x}^*/\bar{a}_{1x})_k = B_k \tag{7-20}$$

Now, if we square Equation (7-15) and multiply by B_k as expressed by Equation (7-20) as well as multiply by T_e, we have

$$D_{k2x} = A_{k2x}^2 \, D_{k1x} \tag{7-21}$$

where

$$D_{k2x} = (a_{2x}^* \, \bar{a}_{2x} \, T_e)_k \tag{7-22}$$

$$D_{k1x} = (a_{1x}^* \, \bar{a}_{1x} \, T_e)_k \tag{7-23}$$

and the latter accelerations are understood to have occurred for a given type of process (k). Hence, Equation (7-21) says that for linear systems, the A_k provide a measure of the tendency for a structure to amplify or attenuate the input damage severity. For nonlinear systems, Equation (7-21) must assume some more complex form.

We now have a basis for computing the severity of a given run (j) for a given type of test (k). For a test which includes several runs, the total severity becomes

$$D_k = \sum_j D_{k_j} \tag{7-24}$$

The above discussion has ignored the existence of cross coupling of responses between input axes, as well as the possibility of multiple independent simultaneous excitations. These problems can probably be handled on an SRSS basis, and are left to future work. The present cabinet specimen can be analyzed with the expressions as developed. At this point, it is more important to use the correlations with experimental data obtained to determine whether plausible relationships result.

8.0 ANALYSIS OF CORRELATED RESULTS

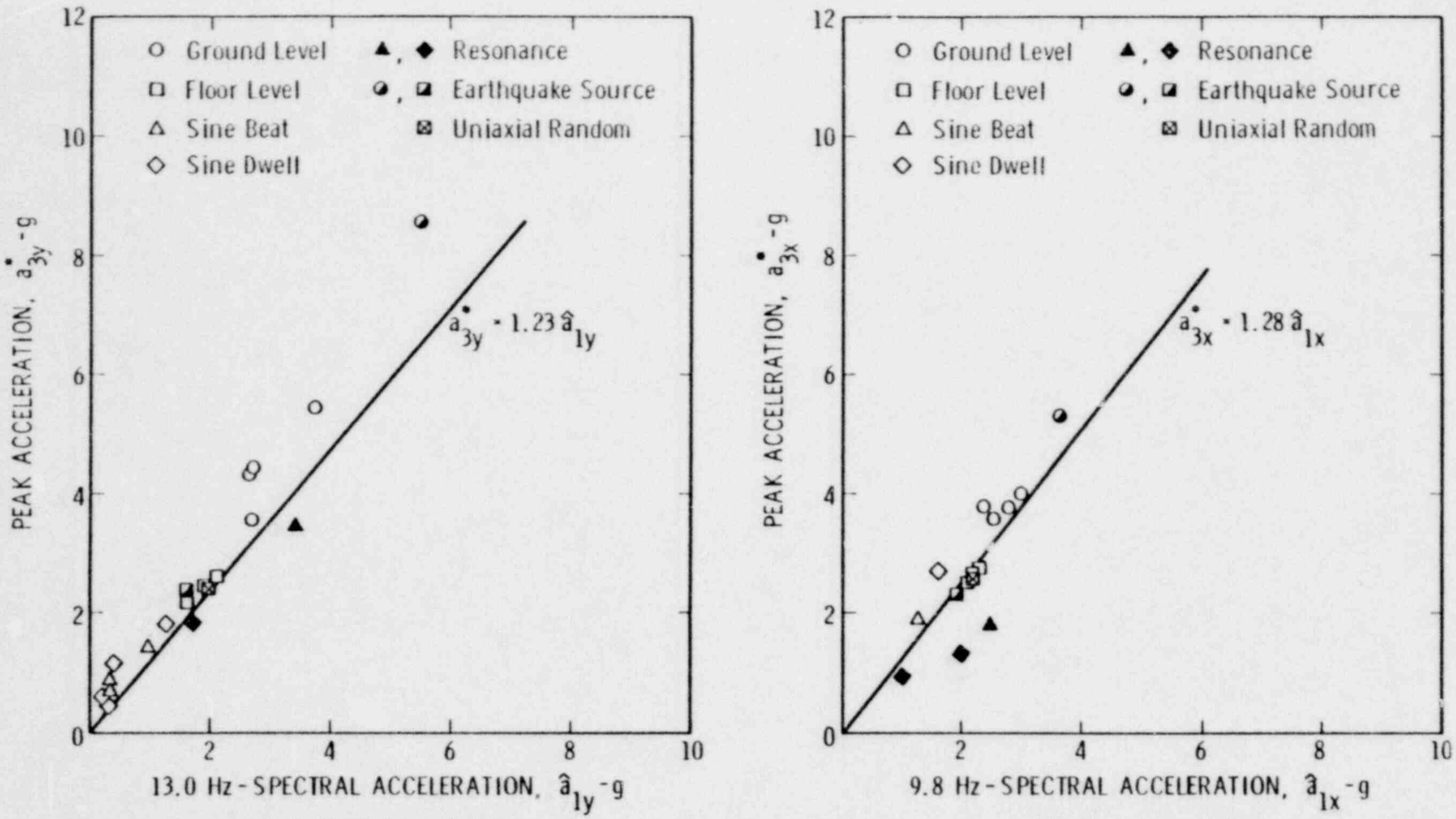
Having acquired all data from the series of representative seismic qualification tests, and outlined the preceding mathematical background development, we now develop an analysis of the data which forms the real meat of the results for this program. Discussions will be presented for a series of topics which fall under the original objectives outlined in Section 1.0.

8.1 Mechanical Behavior of Cabinet

It is first appropriate to establish the general dynamic behavior of the cabinet. Certain aspects of its response characteristics have already been noted in Section 5.0, i.e., transfer functions for harmonic excitation, and in Section 6.0, i.e., sample response time histories. Herein, we investigate certain response data from all runs in a form which allows an initial comparison of the peak and RMS values for individual test runs.

Most of the responses at various locations are governed by one dominant mode, so that a comparison of measured and predicted responses can be obtained by applying Equation (7-10) repeatedly. First, actual measured peak values a_i^* are plotted against peak spectral values $\hat{a}_{1r}$ of the excitation response spectrum at the appropriate resonance frequency. Then, predicted peak values are developed by using the same spectral values $\hat{a}_{1r}$, a damping value of $\beta_r = 0.05$, and the transfer function $H_{i1}(\omega_r)$ at resonance, as presented in the data of Section 5.2. Note that for these correlations, all floor level response spectra for the excitation a_1 had to be recomputed at a damping value of $\beta = 0.05$ (since initially, values for all floor level tests were computed at $\beta = 0.01$). Also, the measured damping for the cabinet modes were slightly different from 5% in some cases, but this was considered negligible. It can be seen that the resulting comparison determines the validity of applying Equation (7-10) to prediction of cabinet responses, as well as provides a basis for comparing peak responses for individual runs of all tests.

Figures 8.1a and 8.1b show results for the peak responses at the cabinet top for Y-excitation and X-excitation, respectively. Experimental data for the various test runs are labeled in separate categories,



(a) Y-Axis excitation (b) X-Axis excitation

Figure 8.1. Peak Acceleration Responses at Cabinet Top

as indicated by the symbol key on each figure. This includes a separate notation for runs which utilize the earthquake source, identify the uniaxial random test run for the respective excitation direction, or emphasize those sine beat and sine dwell runs which are applied at a resonance frequency. Finally, the appropriate numerical form of Equation (7-10) and its associated theoretical line are presented in each case.

It can be seen from these figures that the experimental data, in general, do form a single correlation line, but it is somewhat different from the predicted one in each case. Furthermore, there is a significant separation of the results for the sine beat and sine dwell resonance runs from the rest of the data, except at the lowest amplitude. In fact, the resonance points tend to fall below the predicted line in each case. The deviation is more pronounced for X-excitation, than for Y-excitation. Much of this behavior can be attributed to the nonlinearity in the response, as was described in the transfer functions in Figures 5.8. The values of $H_{31}(\omega_r)$ at 13.0 Hz and at 9.8 Hz, respectively, represent the slopes of the a_{3y} and a_{3x} curves at an input value of $a_{1x} = 0.10g$. These slopes diminish for larger amplitudes at resonance, and demonstrate that their use in Equation (7-10) would provide a better correlation with the experimental data which resulted in excitation of larger responses at resonance. At the same time, however, the tests which include a more random or earthquake type of motion were not affected by the nonlinearity, as also were not those sine beat and sine dwell tests which were applied at a frequency off resonance, regardless of the severity of the test. In general, the actual measured peak value correlation line tends to be higher than that predicted by Equation (7-10).

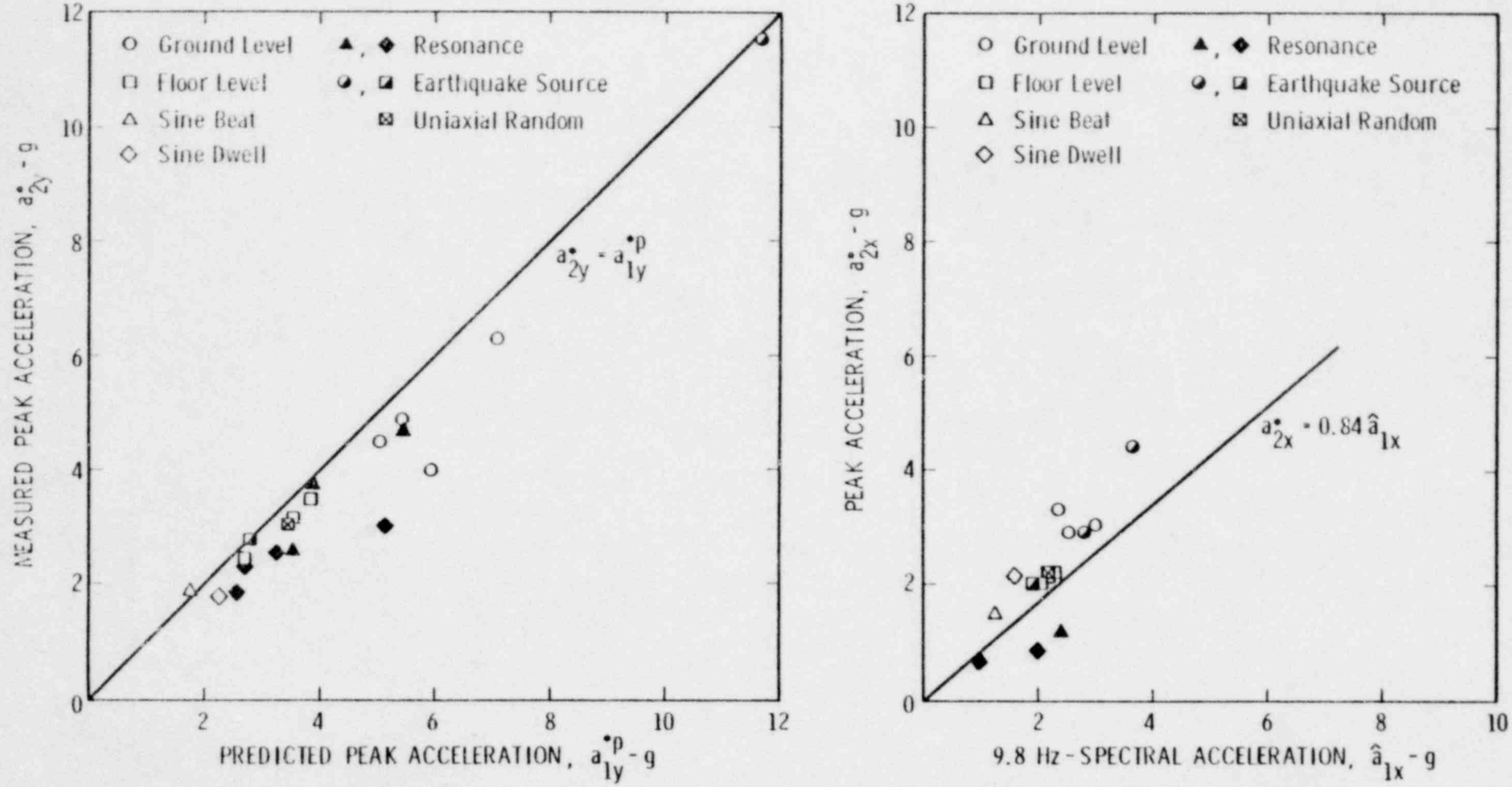
Figures 8.1 provide a measure of the severity of peak responses for the various tests. Of course, the peak spectral value $\hat{a}_{1y}$ or $\hat{a}_{1x}$ provides a measure of the ability of each input transient to excite the respective cabinet mode. Likewise, $\overset{*}{a}_{3y}$ provides an indication of the peak severity for the response point a_3. In view of these assertions, it would appear that on an absolute basis, the individual ground level test runs were the most severe, and the severity of other runs fell below in an order according to their positions in the plots. However, at this point, the information can be misleading, since the sine dwells at resonance were conducted at significantly reduced amplitudes, as was explained in Section 3.3. Thus, a better total basis for comparison will be given in the next section, in terms of the severity factors developed in Section 7.2.

A similar set of data is presented for the cabinet interior panel response a_2, in Figures 8.2. However, the response for X-axis excitation in Figure 8.2a is now influenced by three modes, one each at 13.0 Hz, 23 Hz, and 27 Hz. In this case, the predicted correlation line is based on the use of Equation (7-11). Experimental values are plotted at corresponding points as well. It can be seen that even more deviation occurs than for the single mode case; values for sine beat and sine dwell tests at resonance still deviate the most.

Finally, another set of data influenced only by single modes is presented for the strain ε_{4y}, in Figures 8.3. The behavior here appears to be similar to that described for the top acceleration a_3. That is, the order of the points is similar. This result simply says that the strain at the cabinet base and the cabinet top acceleration are similarly correlated, while the interior panel acceleration a_2 is not. This result is consistent with previous observations of transfer function data.

In view of all of the above data, it appears that the general form of Equation (7-10) is valid for predicting the results observed, but its accuracy is very sensitive to slight nonlinearities. Furthermore, transfer function values at the smallest amplitudes appear to be most useful in these equations, when applied to random type excitation, regardless of the severity of the tests. This conclusion may not be valid if such tests had produced more bending motion of the cabinet. The consequences of this statement will be explored further in Section 8.5.

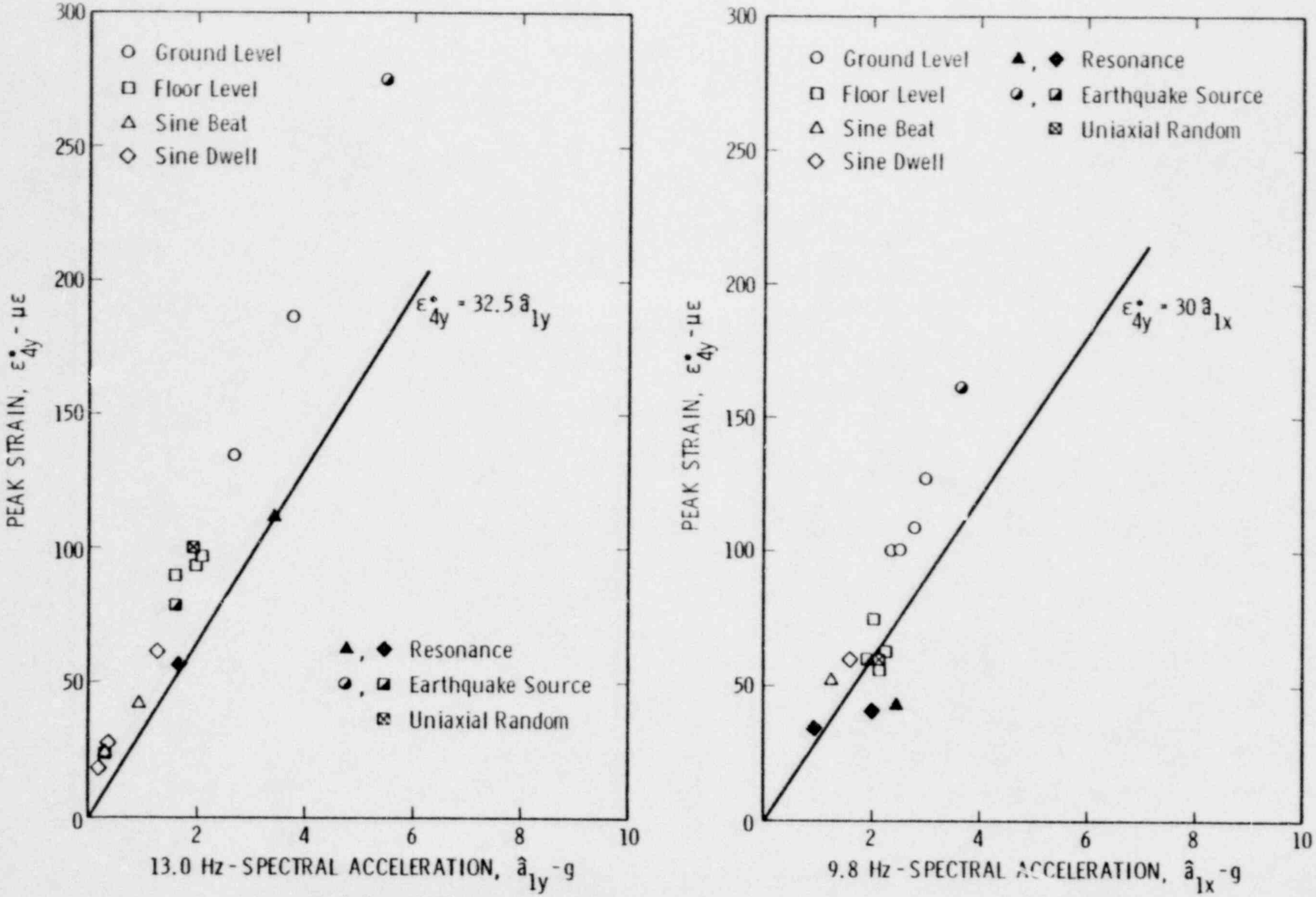
A second type of comparison is now considered, in the form of time-average RMS responses for individual runs. This, in effect, produces evidence which supports the validity of Equation (7-15) as applied to specific excitation orientations and individual test runs. Data correlations are presented for responses at those points whose peak values were discussed above. They appear in Figures 8.4 through 8.6. Several observations should be made about these data. In Figures 8.4 and 8.5, the rigid body line



(a) Y - Axis excitation

(b) X - Axis excitation

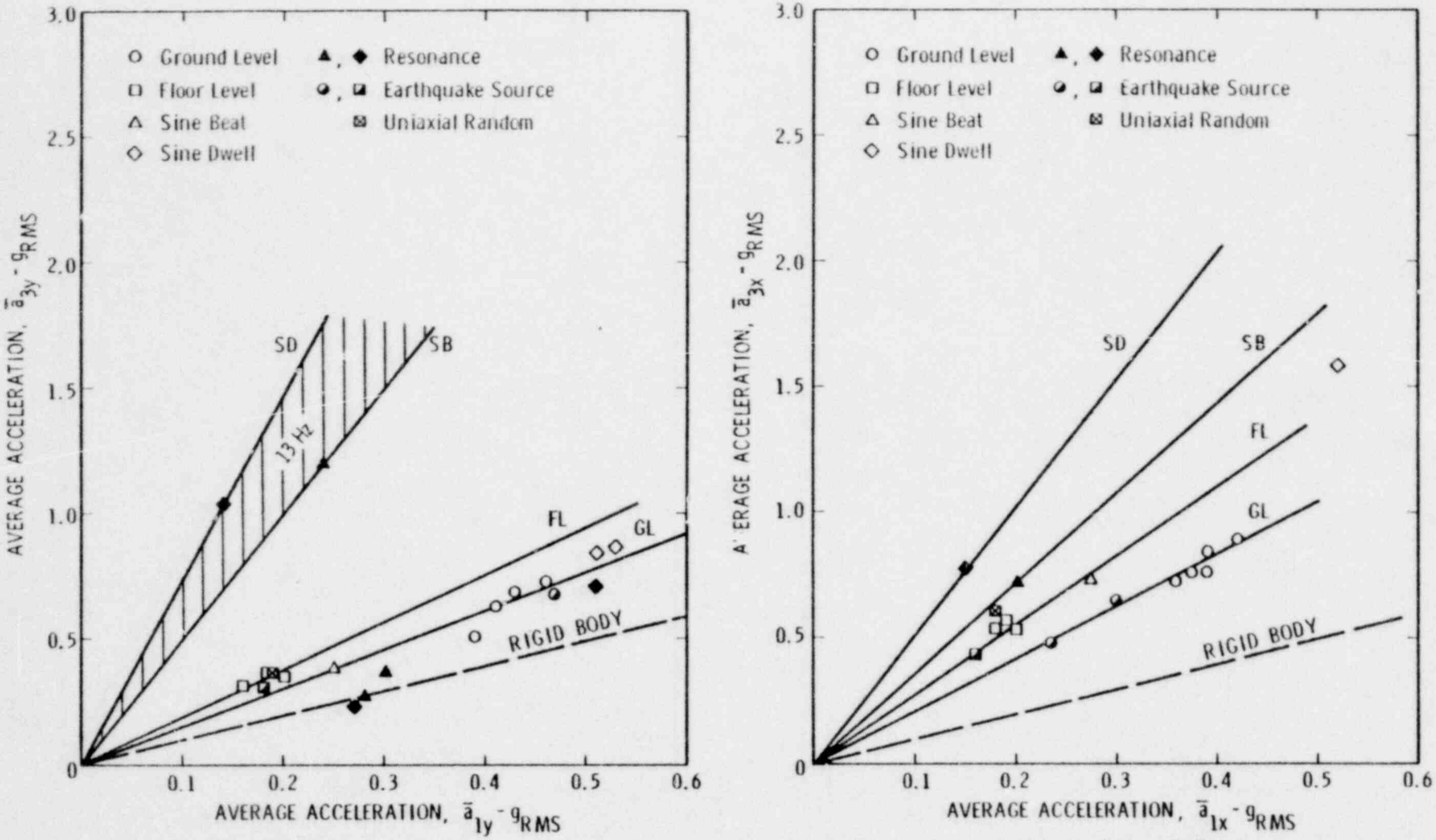
Figure 8.2. Peak Acceleration Responses at Cabinet Interior Panel



(a) Y-Axis excitation

(b) X-Axis excitation

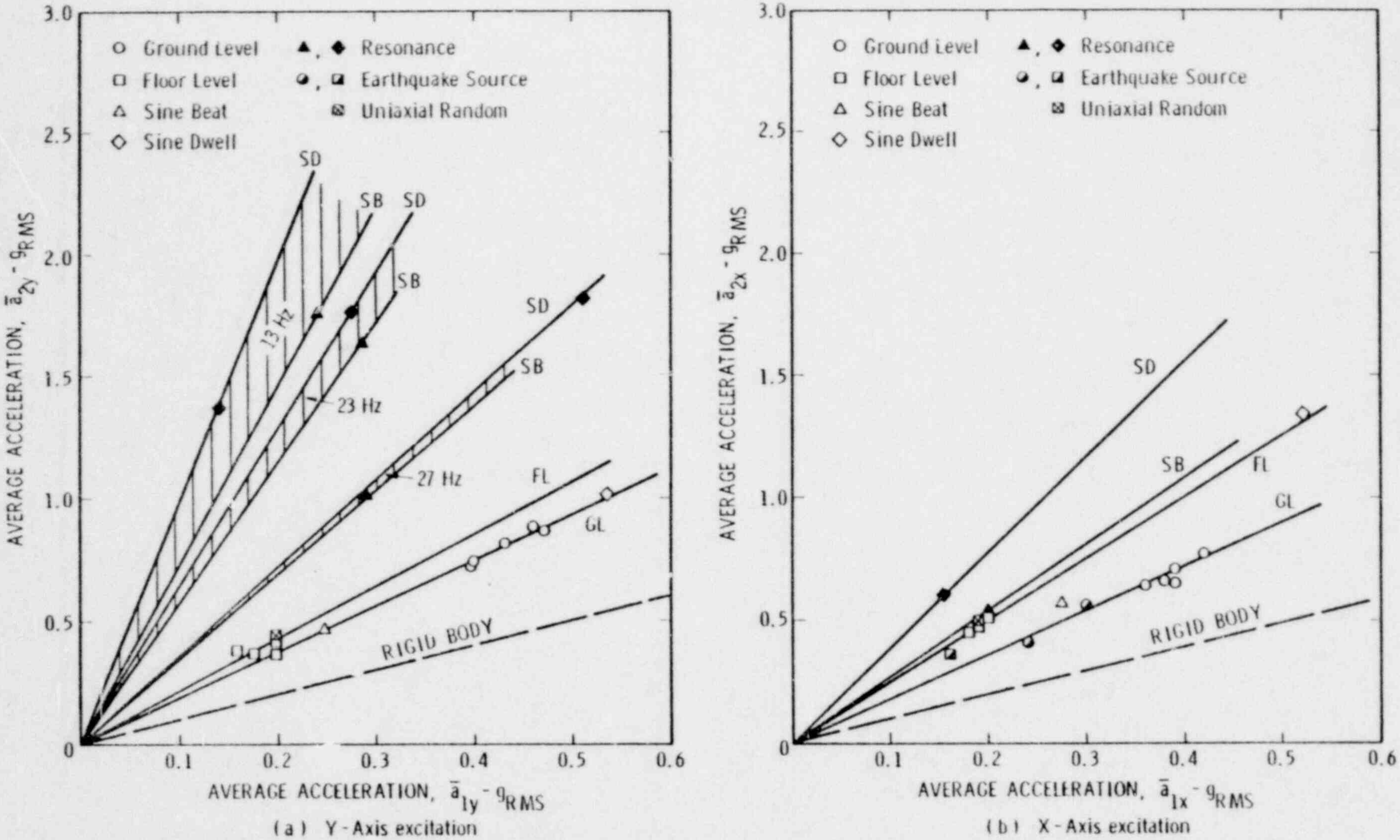
Figure 8.3. Peak Strain Responses at Cabinet Base



(a) Y-Axis excitation

(b) X-Axis excitation

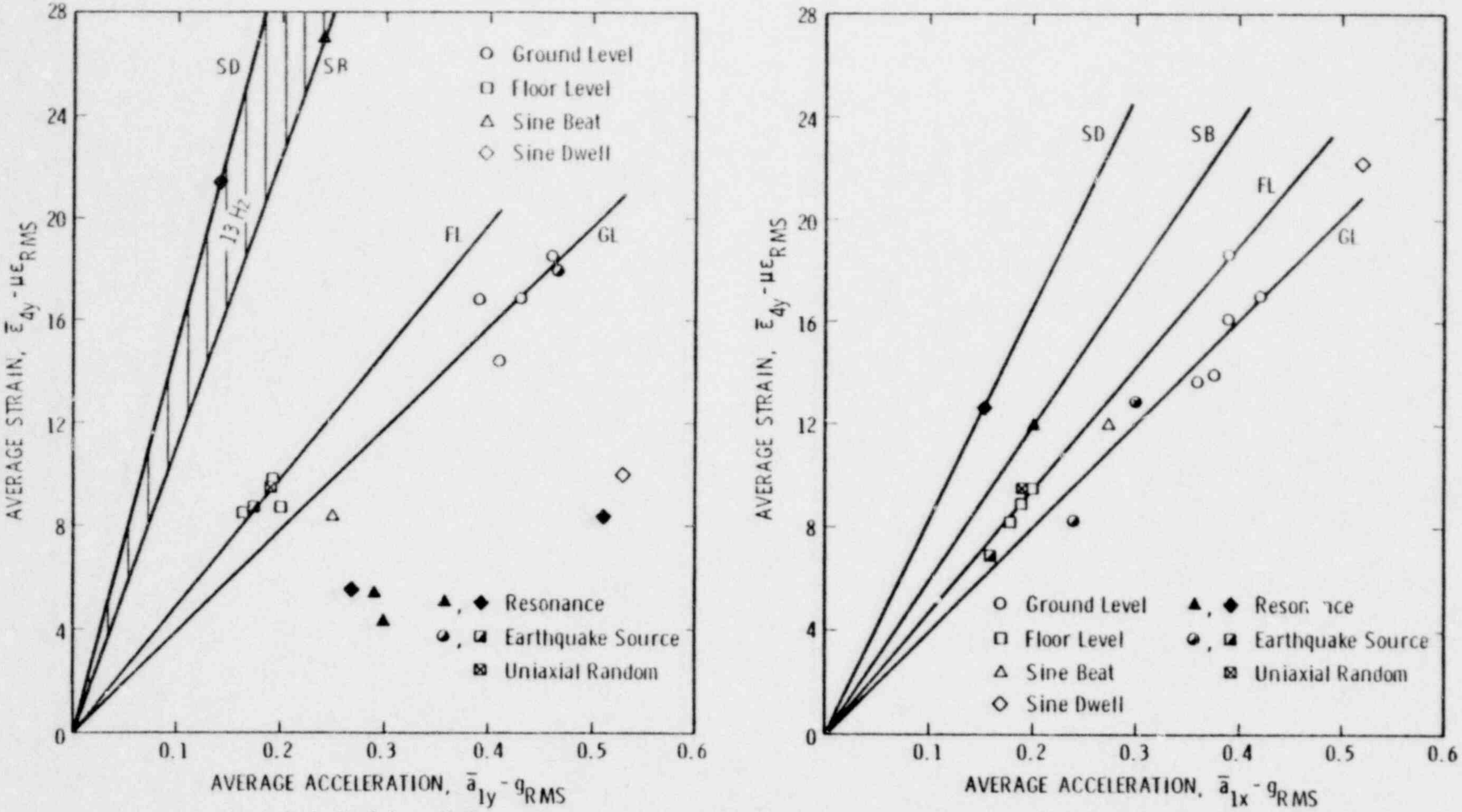
Figure 8.4. Time-Average Acceleration Responses at Cabinet Top



(a) Y-Axis excitation

(b) X-Axis excitation

Figure 8.5. Time-Average Acceleration Responses at Cabinet Interior Panel



(a) Y-Axis excitation

(b) X-Axis excitation

Figure 8.6. Time-Average Strain Responses at Cabinet Base

represents equal acceleration response and excitation. Any points above this line represent an amplification over rigid body response. Individual straight lines have been drawn through certain types of test runs, i.e., ground level, floor level, sine beat, and sine dwell. Note that all data for ground level (GL) and floor level (FL) tests based on random or earthquake sources, respectively, fall on common lines. On the other hand, data for sine beat (SB) and sine dwell (SD) runs widely differ, depending on the corresponding frequency relative to a resonance. As indicated by the cross-hatched areas in Figures 8.4a, 8.5a, and 8.6a, similarities exist between sine beat and sine dwell runs which excite a common resonance. Furthermore, the slopes of these data are much higher than those of the other type test runs, which are somewhere between resonance and rigid body motion.

The slopes of the individual lines of these figures clearly represent values for the A_{k3y} and A_{k3x} constants in Equation (7-15). This being so, it can be seen that there is an increasing severity of response per unit excitation, as one passes from ground level tests to floor level tests, to sine beat and sine dwell tests at resonance. The latter two types of tests are much less severe when applied off resonance, as can be seen for results of this type of test run also. It is recognized that the above correlation has been established with rather limited data. More data needs to be acquired at intermediate test levels in order to establish these curves more accurately. However, several such additional runs were made for the ground level tests in the X-direction (see Figures 8.4b, 8.5b and 8.6b), and the straight line correlation is reasonably established.

We assert that all indicated curves could readily be established similarly, and that the sine beat and sine dwell curves at resonance would include significant decrease of slope at higher amplitudes because of the nonlinearity which has previously been discussed.

Finally, it may be observed that the strain curves of Figure 8.6 are similar in pattern to those of the top acceleration in Figure 8.5. This result is consistent with the observation on peak values, that both are an indication of overall bending in the cabinet.

All of the above results are extremely important in establishing a comparative basis for severity of various seismic qualification tests, as will now be demonstrated. Furthermore, there are even more far-reaching implications of these results for use in the development of improved specifications for qualification tests, as will be demonstrated in subsequent sections.

8.2 Comparison of Severity for Various Tests

The severity factors developed in Section 7.2 will now be used as a basis for comparison of all of the qualification tests defined in Table III-1. In this regard, it must be recalled that each complete test is comprised of two or more test runs. Therefore, excitation severity factors for each separate run were computed by the use of Equation (7-18) and response severity factors were computed by Equation (7-19). The total respective input and response severity factors for each complete test were then obtained by using Equation (7-24). Thus, data for ten different representative qualification tests (which were defined in Table III-1) were developed. In this development, it must be recalled that some of the sine dwell runs were performed at reduced levels, as has previously been explained in Section 3.3. For the latter cases, the full level results of these runs were estimated by a linear scaling up of the excitation and response values to full test requirements. This will result in a conservative estimate for the present system, which suffers reduction in response at higher levels.

Final results of the above computations are given in Table VIII-1. Excitation damage severity is given by ΣD_1, while response damage severities are given for three example response points a_2, a_3, and ε_{4y}. These absolute excitation and response severity factors for each test are useful only for a qualitative comparison of one test with another. The most useful comparison can be made in the last three columns, where the ratios of the damage factors are given. Here, it can be seen that all ground level tests, regardless of absolute level, fall within a small range of this ratio (i.e., 1.6 to 2.04 for the accelerations a_2 and a_3). The floor level random and earthquake tests are the next most severe with a range of 4.99 to 6.36 for the same accelerations. For a_2 the sine beat test is about twice as severe, while the sine dwell test is again twice as severe as this. Similar quantitative comparisons can be made for each response parameter of consequence.

Several general conclusions can now be made by studying the results in Table VIII-1, along with results that have been presented in Figures 8-1 through 8.6. The effects of using different random samples for various tests which match the same response spectra are very small. Furthermore, the absolute damage severity can be used as a gage whether a sufficiently identical matching of the response spectrum has been achieved in the two cases. For example, from the values for ΣD_1, it can be seen that both the dependent random (Test 3) and the independent earthquake (Test 4) ground level tests were more severe than Tests 1 and 2, but all four tests fit the same category as seen from the severity factor ratios for all ground level tests. The fact that the inputs were more severe resulted from an overmatch of the response spectrum for Test 4, and the additional exposure to two more runs in Test 3. By looking at the results for individual runs in Figures 8.1 through 8.6, it is clear that whether one uses an earthquake source or random source, all points fall near the same correlation lines, so that the choice of motion source is immaterial. The uniaxial random floor level test (Test 8) appears to be of similar severity as the independent axis tests (Tests 5, 6, and 7). This conclusion must be qualified, however, since these tests required very little vertical excitation and there was negligible cross-coupling between the axes of the cabinet structure.

At this point, it must be emphasized that the above results have been obtained for a single specimen of electrical equipment, although it is thought to be representative of such equipment in general. Therefore, one must be very careful in generalizing the above conclusions. Obviously, additional work must be performed to provide a better understanding of the generality of the results.

One might also ask how the entire above described approach can be useful estimating the effects of different types of tests on another piece of equipment? One general approach is now described in a sequence of required steps. There are two essential ingredients that are required for the estimation; (1) the detailed test specification for the different tests, and (2) the linear transfer functions for the specimen. The steps of the procedure to be applied to each test to be compared, are as follows:

TABLE VIII-1. COMPARISON OF DAMAGE SEVERITY
FOR SEISMIC QUALIFICATION TESTS

Test No.	Test Type	A ΣD_1	D ΣD_2	B ΣD_3	F $\Sigma \varepsilon_{4y}$	E $\Sigma D_2/\Sigma D_1$	C $\Sigma D_3/\Sigma D_1$	G $\Sigma D_{\varepsilon 4y}/\Sigma D_1$
1	BIRG	131.7	258.5	268.2	119780	1.96	2.04	910
2	BIRG	170.9	345.3	326.8	165880	2.02	1.91	971
3	BDRG	285.2	488.8	496.5	245220	1.71	1.74	860
4	BIEG	263.8	524.9	421.1	209700	1.99	1.60	795
5	BIEF	9.5	54.0	52.0	32800	5.67	5.46	3452
6	BIRF	14.8	75.9	73.7	43370	5.14	4.99	2938
7	BIRF	10.7	58.2	68.0	37034	5.45	6.36	3467
8	URF	13.8	82.7	73.6	39880	5.99	5.33	2825
9	SB	50.7	585.8	237.2	149120	11.56	4.68	2944
10	SD	46.2	977.3	521.7	261586	21.13	11.28	5657

B - Biaxial
I - Independent Axes
D - Dependent Axes
R - Random Source
E - Earthquake Source

G - Ground Level
F - Floor Level
U - Uniaxial
SB - Sine Beat
SD - Sine Dwell

(1) Obtain transfer functions for the equipment specimen for response locations that are significant with respect to potential failure. This can be done by resonance search tests or by analytical development.

(2) Develop a test time history for the appropriate excitation. In the case of the specification including a required response spectrum, compute the TRS such that it matches or envelops the RRS.

(3) Compute the time average power spectrum $\bar{G}_{1x}(\omega)$, the normalized power spectrum $\bar{G}_{k1x}(\omega)$, and the RMS excitation acceleration $\bar{a}_{1x}$, all associated with the developed time history.

(4) Compute the constants A_{k2x} by means of Equation (7-16).

(5) Calculate the time-average RMS response $\bar{a}_{2x}$ by means of Equation (7-15).

(6) Estimate peak values of response a^{*}_{2x} by using Equation (7-10). Transfer function values $H_{2x1x}(\omega_r)$ and peak spectral values $\hat{a}_{1xr}$ obtained from the TRS are required ingredients.

(7) Compute the damage severity factor by means of Equations (7-18), (7-19), and (7-24).

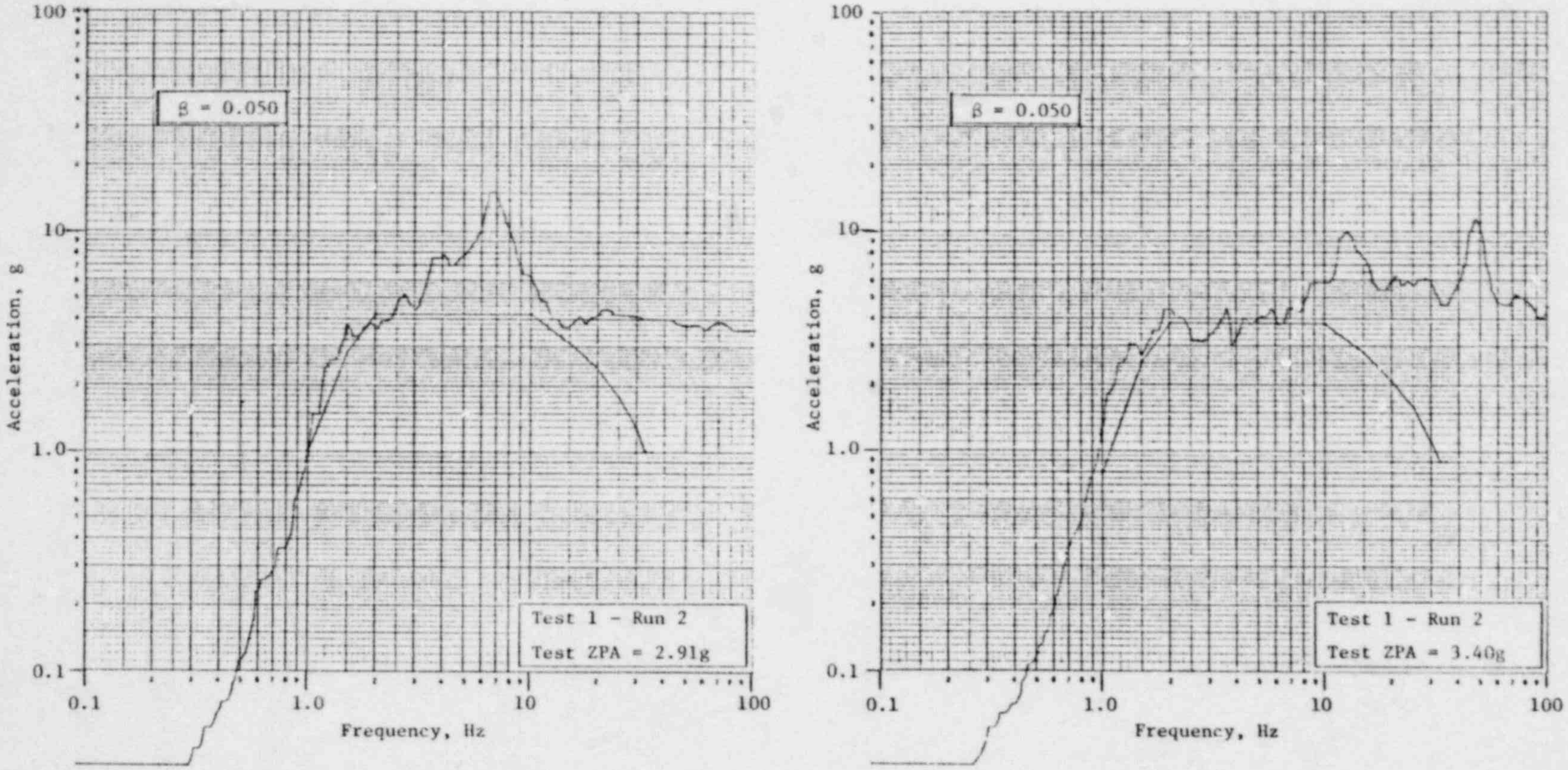
The above procedure is applied to each type of test to be considered. The results then allow a determination of which test is more severe. Thus, it can be used as a design tool, or may also be used as a basis for comparing the severity of previously-conducted tests on equipment that is already in operation, with predicted results for tests whose specifications are based on more recent criteria.

8.3 Floor Versus Simulator Natural Modes

The results of the resonance search tests in Section 5.0 have demonstrated that some differences in modal response may be experienced between floor mounted tests and simulator mounted tests. These differences occur because of dynamic interaction between the specimen and simulator, whose impedance is large, but can never be infinite. The immediate question is, what influence this difference may have on the outcome of a given qualification test? The results of the present study indicate that the outcome of a ground level test, in which the input motion is sufficiently broad to encompass any shifts in the resonances, would be influenced very little. On the other hand, in a floor level test where a concentrated energy exists (such as in the present tests), the results may vary considerably, depending on whether the shifted resonance has the proper relationship relative to the excitation energy. In the latter case, one should consider running resonance searches with both a floor mounting and on the simulator, and if differences exist, the excitation motion (i.e., response spectrum of the simulator) should be modified so that the concentrated energy of the excitation will match the resonance for the simulator mounting. In this way, the correctly amplified responses will be achieved in the specimen, although they will occur at a somewhat different frequency. It should be obvious that a similar type of adjustment should be made for a sine beat or sine dwell test.

8.4 Component Excitation

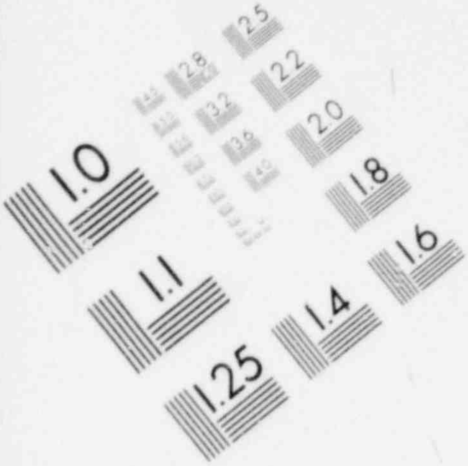
In electrical cabinets, it is not unusual to qualify the cabinet structure with only dummy components attached. During the procedure, it is then necessary to provide sufficient measurements so that subsequent qualification of the components can be performed on an individual basis. The usual procedure involves development of a new test response spectrum from the motion that was measured on the cabinet at the appropriate mounting point during qualification of the cabinet itself. Examples for the present ground level test (Test 1 - Run 2) are given in Figure 8.7. These spectra are based on the response signal a_2 at the interior panel of the cabinet. They should be compared with Figure 6.4, which gives the original input response spectra for this particular test. As one would expect, there has been some amplification of the motion and, in particular of the ZPA, at the response point. However, there is a large amplification at about 6 Hz (Figure 8.7a), and no apparent amplification at the known resonance of 9.8 Hz, as one might expect. These differences obviously can affect the required RRS for subsequent tests on components attached at this point. This apparent discrepancy led to further investigation which relates to whether or not the enveloping of an RRS by the TRS (as required by Reference 3) is a sufficient condition for defining the various tests being considered. More on this matter will be discussed in the following section.



a. Horizontal (a_{2x})

b. Vertical (a_{2z})

FIGURE 8.7. RESPONSE SPECTRA AT INTERIOR PANEL BIAXIAL INDEPENDENT RANDOM GROUND LEVEL TEST, X-Z EXCITATION



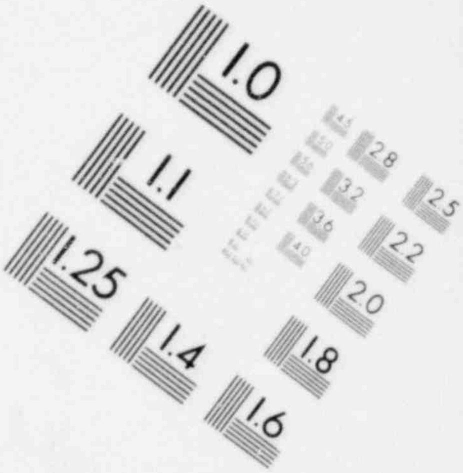
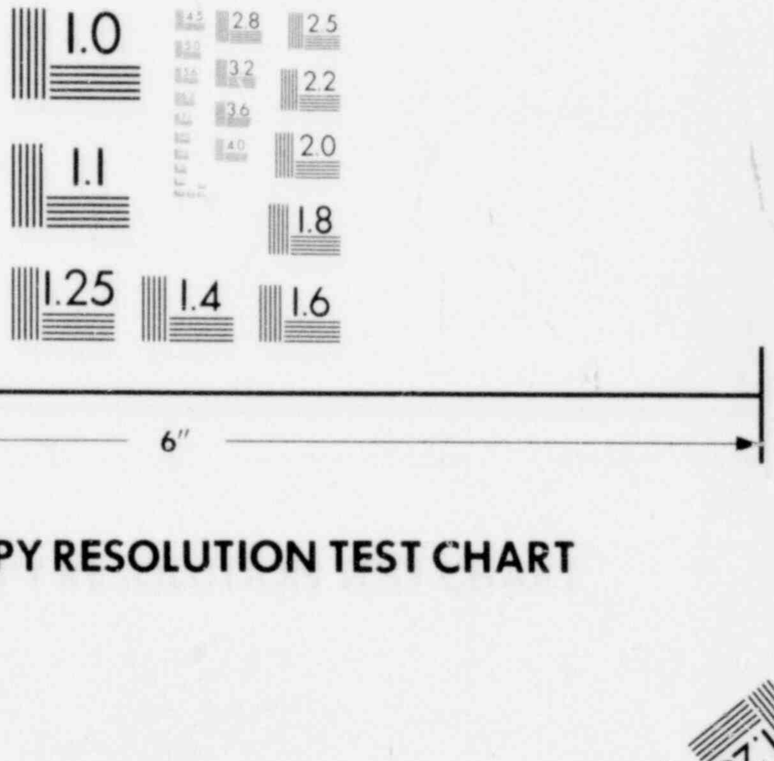
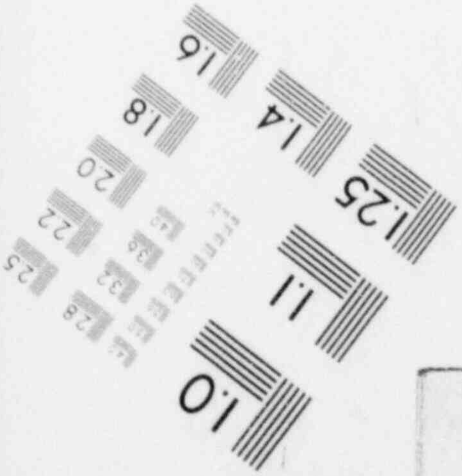
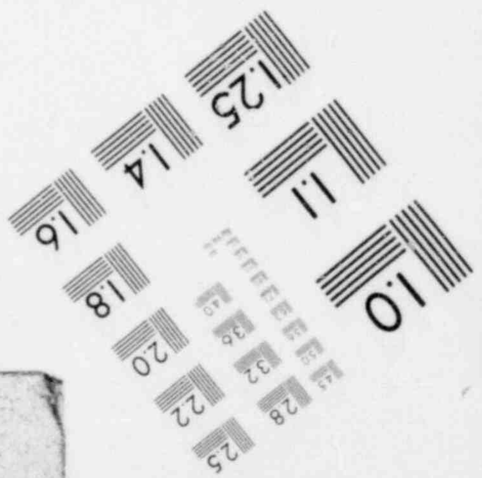


IMAGE EVALUATION TEST TARGET (MT-3)



MICROCOPY RESOLUTION TEST CHART

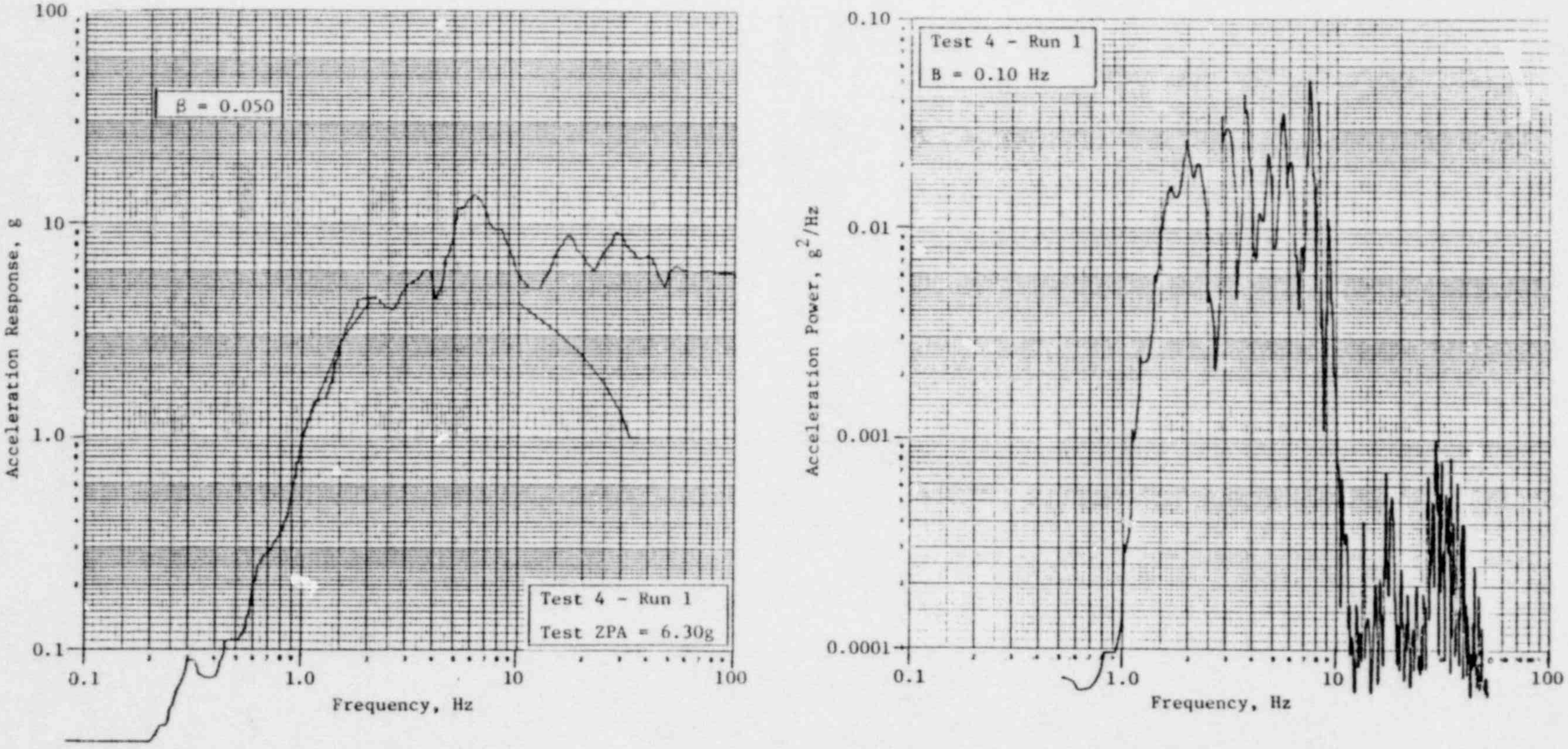




8.5 Effect of Excessive ZPA

The apparent discrepancy just described leads directly to another problem area, a determination of how an excessive test ZPA influences the results of a qualification test. The presence of the excessive ZPA results from a lack of sufficient matching of the TRS with the RRS, a procedure which at times can be quite time-consuming. It can also result from the presence of resonances in the simulator shake table system itself, so that no amount of effort can remove the effects. Thus, in the test lab it is not unusual to have the excessive ZPA occur. This has been ascertained from discussions with personnel of various test labs as well as published evidence.(4,11,12) Most test specifications based on the guidelines described in Reference 3 simply require that a TRS envelop the RRS, and no maximum may be given. Of course, one might expect that an unlimited ZPA cannot be condoned, as the large peak excitation must eventually produce an overly conservative test. As long as no failure occurs, one may not be concerned with this. However, if a failure does occur, how can one argue that it did or did not result from the excessive ZPA? Furthermore, can the presence of the excessive ZPA produce other problems which may invalidate a test in other ways than overconservatism? The latter consequence will be discussed first, as it relates back to the discussion of Section 8.4.

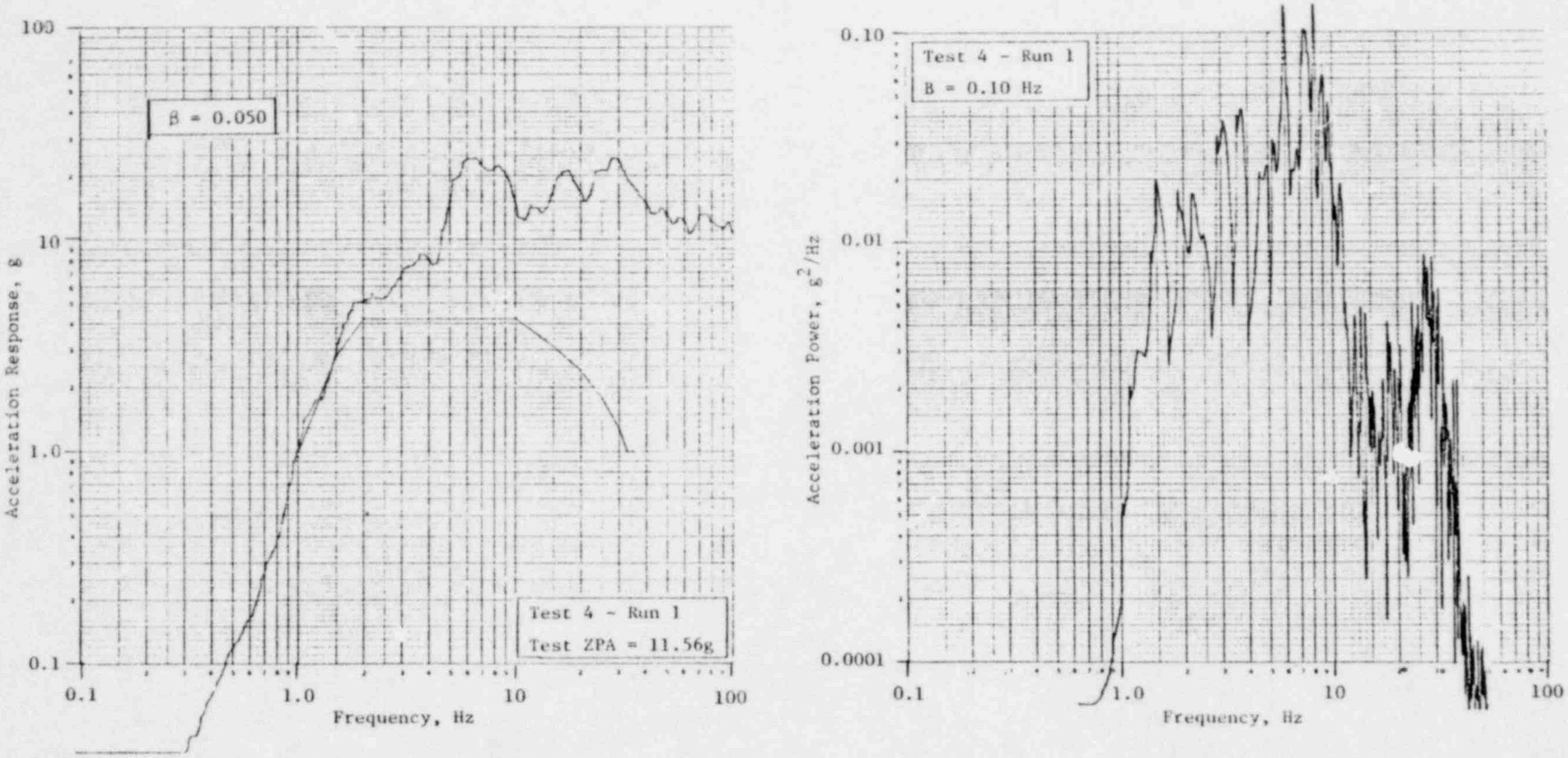
In the present work, the earthquake derived ground motion test (Test 6) appears to be the most severe with respect to excessive ZPA. Therefore, some additional analysis of excitation and response signals for Run 1 of this test will be developed. Figures 8.8a and 8.9a show response spectra for the excitation a_{1y} and interior panel a_{2y}, respectively for this run. It can be seen that significant motion amplification occurs at a_{2y}, but it does not give the appearance of excitation of any dominant modes. Recall that a similar observation was made for the response a_{2x} in Figure 8.7a. At this point it was becoming obvious that less modal amplification of the response was occurring than one might expect. This seemed peculiar, for the presence of the first mode at 13.0 Hz for the Y-excitation, and 9.8 for the X-excitation, surely should be strongly felt in the response for the required motion. Note that the RRS has approximately an amplification of 4 to 1 over the ZPA at these frequencies.



a. Response Spectrum

b. Time-Average Power Spectrum

FIGURE 8.8. PARAMETERS WHICH DESCRIBE GROUND ACCELERATION (a_{1y}), Y-Z EXCITATION



a. Response Spectrum

b. Time-Average Power Spectrum

FIGURE 8.9. PARAMETERS WHICH DESCRIBE INTERIOR PANEL ACCELERATION (a_{2y}), Y-Z EXCITATION

On the other hand, the test ZPA of the response in Figure 8.9a is 11.56, while the actual input ZPA in Figure 8.8a is 6.3. The actual amplification was less than 2 to 1.

The above observations suggest that less energy was included in the excitation near the 13.0 Hz frequency than may be appropriate. In order to demonstrate this, time average acceleration power spectral densities were run for the excitation a_{1y} and the response a_{2y}, and are shown respectively in Figures 8.8b and 8.9b. From Figure 8.8b it can be seen that, indeed, very little energy exists above 9 Hz in the excitation. It is not surprising then to note in Figure 8.9b that there is no significant energy in the a_{2y} response at any of the 13.0, 23, or 27 Hz frequencies, compared to that below 9 Hz. The power spectra clearly confirm the suspicion that an insufficient excitation of the structural modes has occurred, even though the TRS severely envelops the RRS for the excitation in Figure 8.8a. This result is enormously important! That is, in spite of the fact that an apparent overtest has been indicated according to the present criteria required by Reference 3, in fact, an undertest has occurred, insofar as response in these modes is concerned. The discovery of this discrepancy occurred just near the end of the present program, so that further analysis of the data could not be performed.

In view of the above discovery, it is immediately obvious that the adequacy of the presently-accepted test criteria is in question, and requires immediate attention to resolve the discrepancy. Although the ZPA's indicate that an adequate, and in fact, excessive maximum peak response has occurred, the distribution of lesser peaks will not necessarily be adequate. At this point it appears that it may be necessary to use some combination of response spectrum and time-average power spectrum to assure that both the correct peak values and the correct frequency distribution of the excitation energy have been developed properly. Furthermore, the question of overconservatism of the ZPA and its effects on the test is so interrelated to this discrepancy, that its resolution must be developed jointly in additional work. It may very well be that the discovery of the discrepancy outlined in this section is the single most important result of this entire research program!

9.0 SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

A series of brief conclusions and, in some cases, associated recommendations will be provided in this section. The order presented bears no significance to the relative importance of each item.

A plausible method has been developed for comparing the severity of various types of seismic qualification tests. The use of the severity factor method as a design or development tool should be given careful consideration. At the same time, additional research work should be performed to determine the utility of the method to various types of nuclear power plant equipment. Both analytical and experimental efforts are in order to determine whether the exact postulated form of the severity factor may need modification, as well as whether it should be incorporated into guidelines for conduct of qualification tests.

It has been demonstrated that some differences in resonance behavior may be encountered during floor mounted tests and simulator mounted tests. Consideration should be given to adding floor level resonance searches for those cases that may be influenced by simulator compliances. For subsequent simulator mounted tests, widening of the response spectrum to include the entire range of resonance frequency shift is recommended.

An extremely important discrepancy has been revealed in the use of matching or enveloping an RRS with a TRS as a criterion for the qualification test. Since this criterion is the basis for most current test specifications, it is imperative to provide specific modifications of the guidelines which will eliminate this discrepancy. The matter of further investigating the effects of excessive ZPA should be pursued. This recommendation is the most important one offered in this section.

Because of the structural independence of one axis from another on the specimen utilized in this investigation, the matter of cross-axis coupling and its influence on the outcome of various tests has not been resolved. A similar series of tests should be applied to another specimen, such as a valve with attached motor drive, so that significant cross-axis coupling will be present. The applicability of the developed methods to this type of specimen can then be determined.

The choice of random source or earthquake signal source for running tests appears to be immaterial. If anything, the use of a Gaussian noise source is much more convenient, and incorporates the desirable random character to the motion.

The order of severity for the various tests indicated by the damage factor ratios is a most significant result. It is especially important to recognize that a numerical relative damage potential has been established by these results. Note in particular that the damage severity of both sine beat and sine dwell tests is greater than that of the random type, as long as excitation exactly on resonances is included (which usually is the case). The obvious implication is that more often than not, these tests have inflicted over conservatism into testing at an almost unconscious rate. It is further currently being emphasized in test specification of the so-called RIM (Required Input Motion) type, which employs a 4.5-g sine sweep through the complete frequency range for line mounted items. It would appear that a swept narrow band random test at the same RMS level would be more than adquate for such a test, would even be a more realistic simulation from a physical reasoning point of view, and in fact would be significantly less severe at the same time. A comparison of the results for these two tests using the damage factor criterion should be investigated immediately.

Development of a standard normalized power spectrum which is analogous to the Reg. Guide 1.60 response spectrum should be considered carefully. This would of course be done similar to the procedure utilized for developing the standard response spectrum. Furthermore, the use of power spectral density techniques as a design tool which is complementary to response spectrum techniques should be considered as well. This development would be essential if the damage severity factor is to be utilized seriously.

Throughout this study, emphasis has been placed on measurement of mechanical effects in the specimen. However, it should not be overlooked that influences on electrical behavior in subcomponents attached to the cabinet are also implied. For example, chattering of relays can be related to both frequency content as well as peak acceleration levels at the point of attachment. Furthermore, the damage severity factors which were developed can readily be expanded to incorporate a threshold type of failure severity.

The matter of mechanical fatigue can also be included in a special manner. The concept of damage severity under seismic excitation obviously only has been introduced, as a result of this study, and deserves much further research consideration.

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16. ABSTRACT *(200 words or less)*

A series of seismic qualification tests has been conducted on a typical nuclear power plant electrical cabinet. Acceleration and strain responses were measured for four ground level and six floor level specifications. The test types include resonance search, biaxial independent random, biaxial dependent random, uniaxial random, sine beat, and sine dwell excitations. Tests involving random motion were derived both from a random generator and earthquake signal source. Response data are initially presented in terms of transfer functions, time histories and response spectra. Then, analytical parameters are developed for correlation of the data in terms of peak responses, time-average RMS responses, and a new parameter defined as a damage severity factor. Typical sine dwell and sine beat tests are found to be far more severe than biaxial random simulations. The developed damage severity factors indicate this result vividly, and also provide a useful design tool for comparison of test severities before the tests are conducted, so that a choice can be made.

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