Seismic Considerations

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"Recommended Practice for Seismic Design of Substations"

a more descriptive title would be: "Seismic Qualification of High Voltage Power Equipment"

Electrical Equipment: Annex C-P

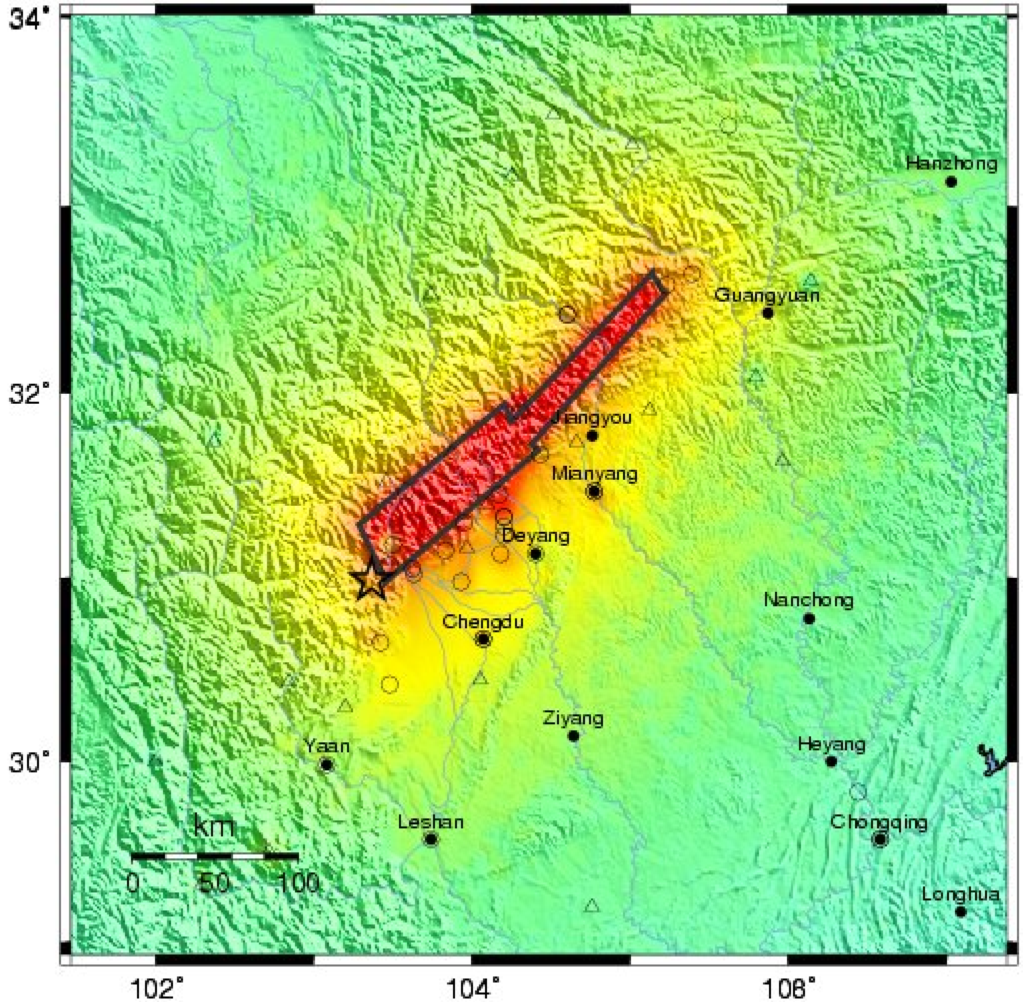
- Circuit Breakers
- Transformer, Liquid Reactor, Bushings
- Disconnect Switch
- Instrument Transformer
- Air Core Reactor
- Circuit Switcher
- Suspended Equipment
- Batteries and Racks
- Surge Arresters
- Electronic Devices
- Metalclad Switchgear
- Potheads
- Capacitors
- GIS Switchgear

Earthquake Magnitudes

Richter	TNT	Example
4.0	1,000 tons	Small Nuclear Weapon
4.5	5,100 tons	Average Tornado (total energy)
5.0	32,000 tons	
5.5	80,000 tons	Little Skull Mtn., NV Quake, 1992
6.0	1 million tons	Double Spring Flat, NV Quake, 1994
6.5	5 million tons	Northridge, CA Quake, 1994
7.0	32 million tons	Kobe, Japan Quake, 1995; Largest Thermonuclear Weapon
7.5	160 million tons	Landers, CA Quake, 1992
8.0	1 billion tons	San Francisco, CA Quake, 1906
8.5	5 billion tons	Anchorage, AK Quake, 1964
9.0	32 billion tons	Chilean Quake, 1960

USGS ShakeMap : EASTERN SICHUAN, CHINA

Mon May 12, 2008 06:28:01 GMT M 7.9 N30.99 E103.36 Depth: 19.0km ID:2008ryan



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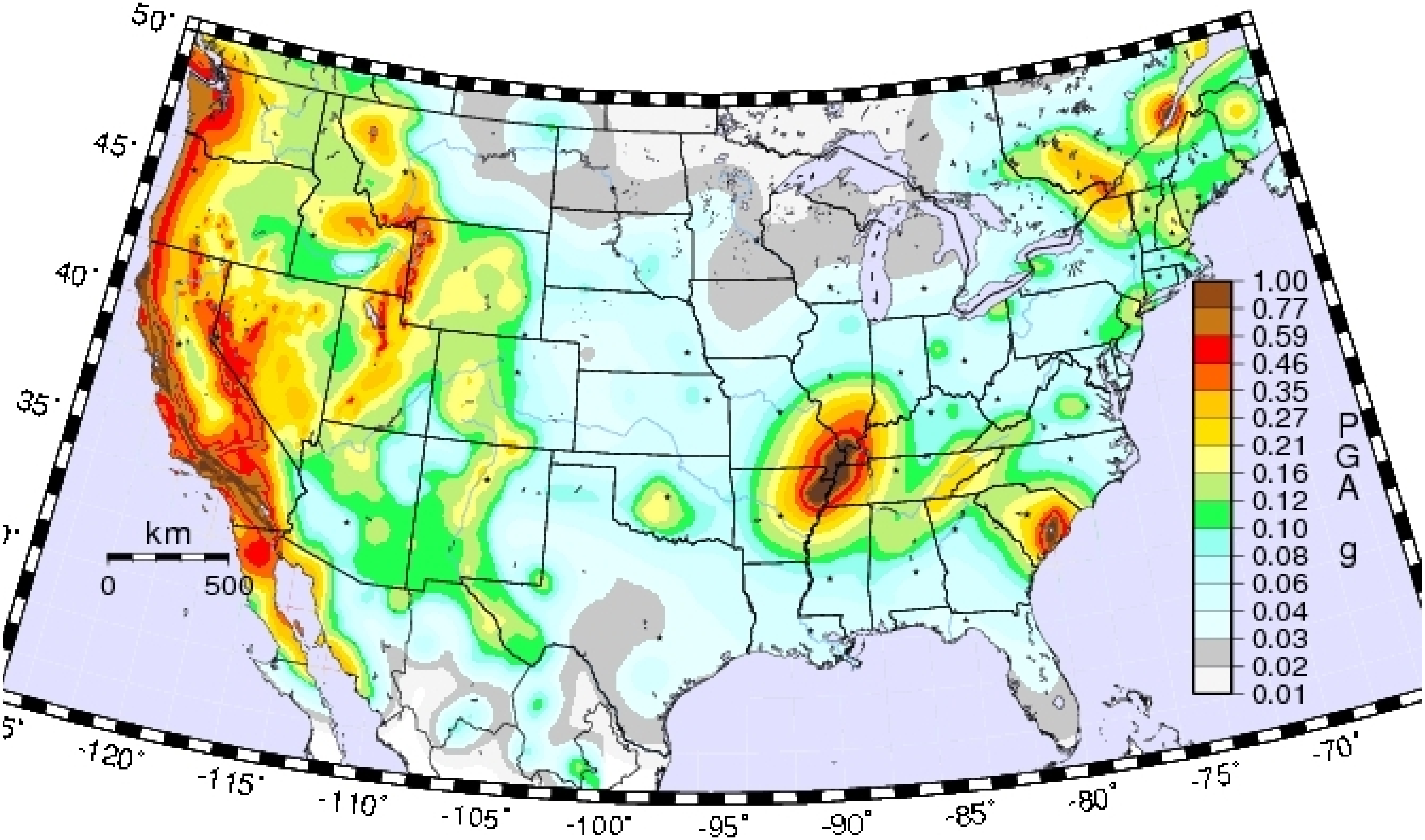
PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

2008 USGS Seismic Hazard Map

2% probability of exceeding in 50 years

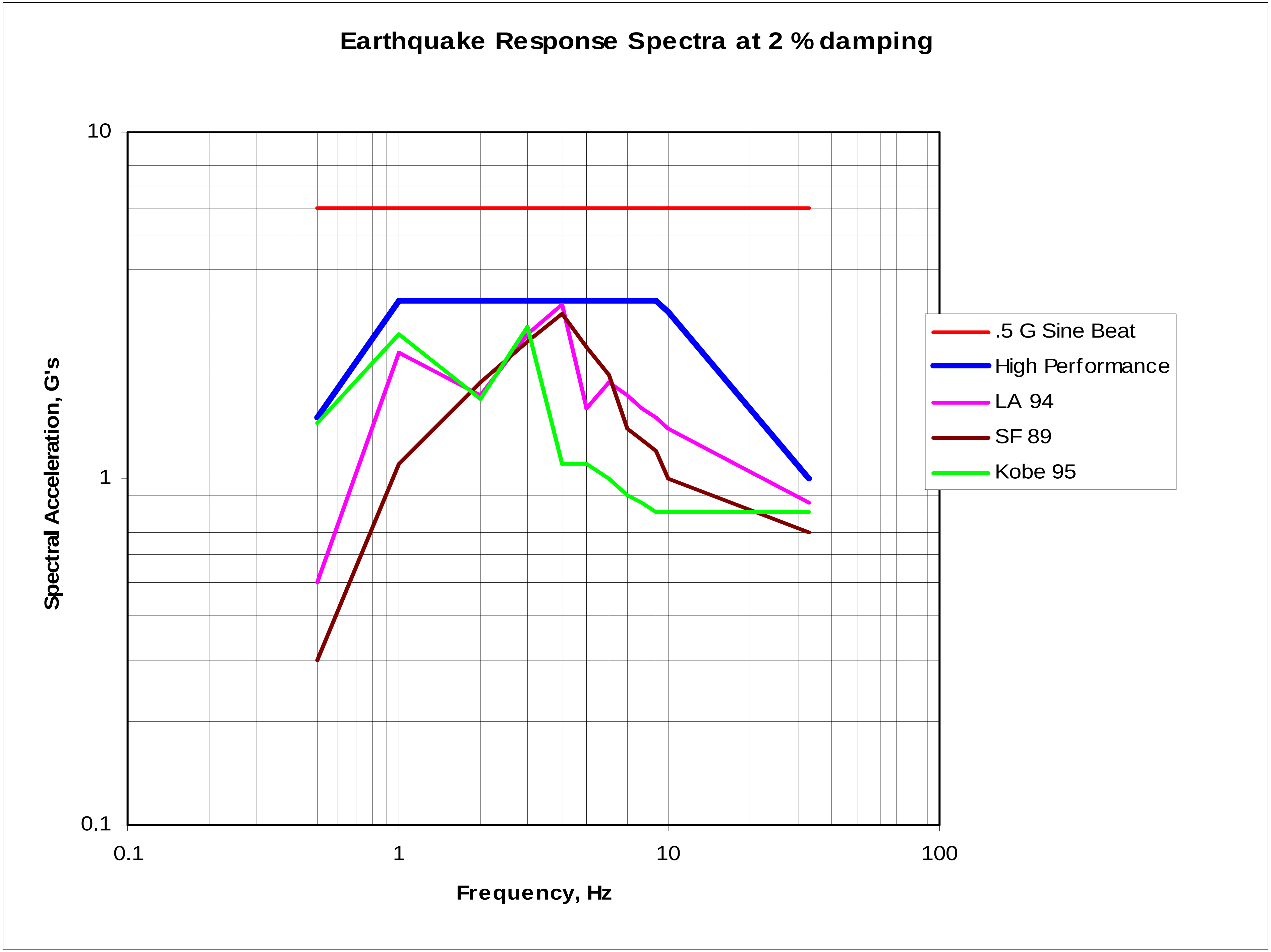


Seismic Qualification Levels

IEEE 693 Qualification Level	Ground Acceleration gs	Response Acceleration gs
Low	0.1	0.2
Moderate	0.25	0.8
High	0.5	1.6
Performance	1.0	3.2

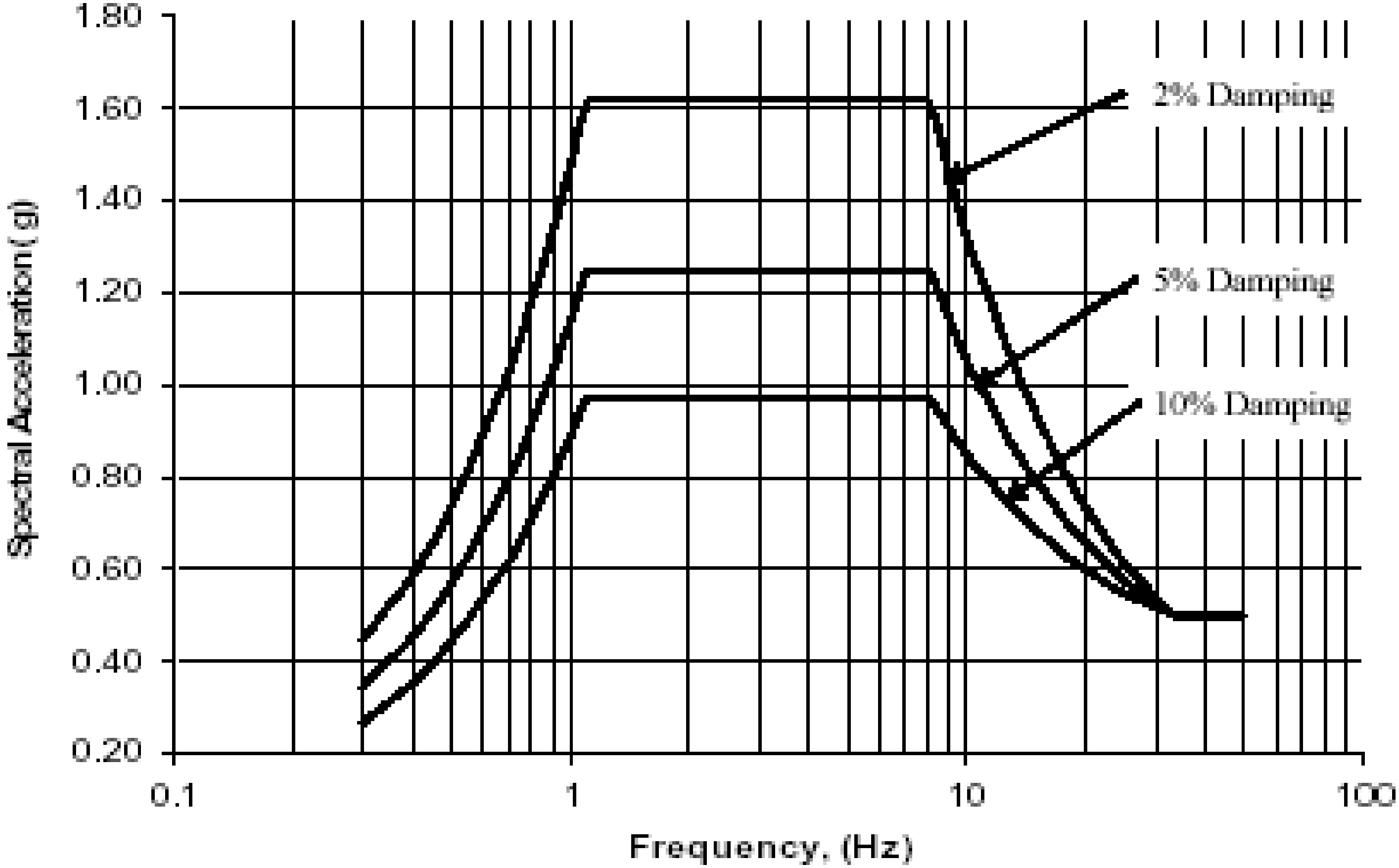
Response Spectrum (analytical tool)

- Plot of response acceleration to an earthquake ground acceleration (input)
- Theoretical response of SDOF oscillators to input
- Applied to dynamic (modal) analysis
- Calculated theoretical response (not actual response)
  - to shake table input acceleration
  - to determine if test input is sufficient



Earthquake Response Spectra at 2 % damping
10
1
0.1
Spectral Acceleration, G's
0.1
1
10
100
Frequency, Hz
.5 G Sine Beat
High Performance
LA 94
SF 89
Kobe 95

Required Response Spectrum
(High RRS, moderate is 50%)



Low Qualification Level for Breakers

- No required response spectrum or report
- Anchorage design
  - 0.2 x weight in horz. direction
  - 0.16 x weight in vert. direction
  - plus dead weight and operating loads
- Defined load path
- Adequate slack in terminal connections

Static Coefficient Analysis for Breakers 38 kV to 123 kV

- Include control cabinets, CTs, stored energy sources
- 1.5 x RRS peak x weight of each component in two principal horizontal direction
- 80% in the vertical direction
- Combine 3 principal directions by SRSS
- Add dead weight and operating loads

Dynamic Analysis for Breakers 123-145 kV

- Finite element model
- Modal spectrum analysis up to 33 Hz
- Account for at least 90 % of mass
- Sum (<10%) or SRSS plus operating loads
- Verify the low frequencies and damping

Test for Breakers 170 kV and above

- Cantilever test of insulators
- Resonant frequency search
- 0.5 g time history test in closed position
- 0.5 g time history test with O-CO operation
- 0.5 g Sine beat test or 1 g time history (new)
- Repeat resonant frequency search
- Repeat cantilever test of composite insulators

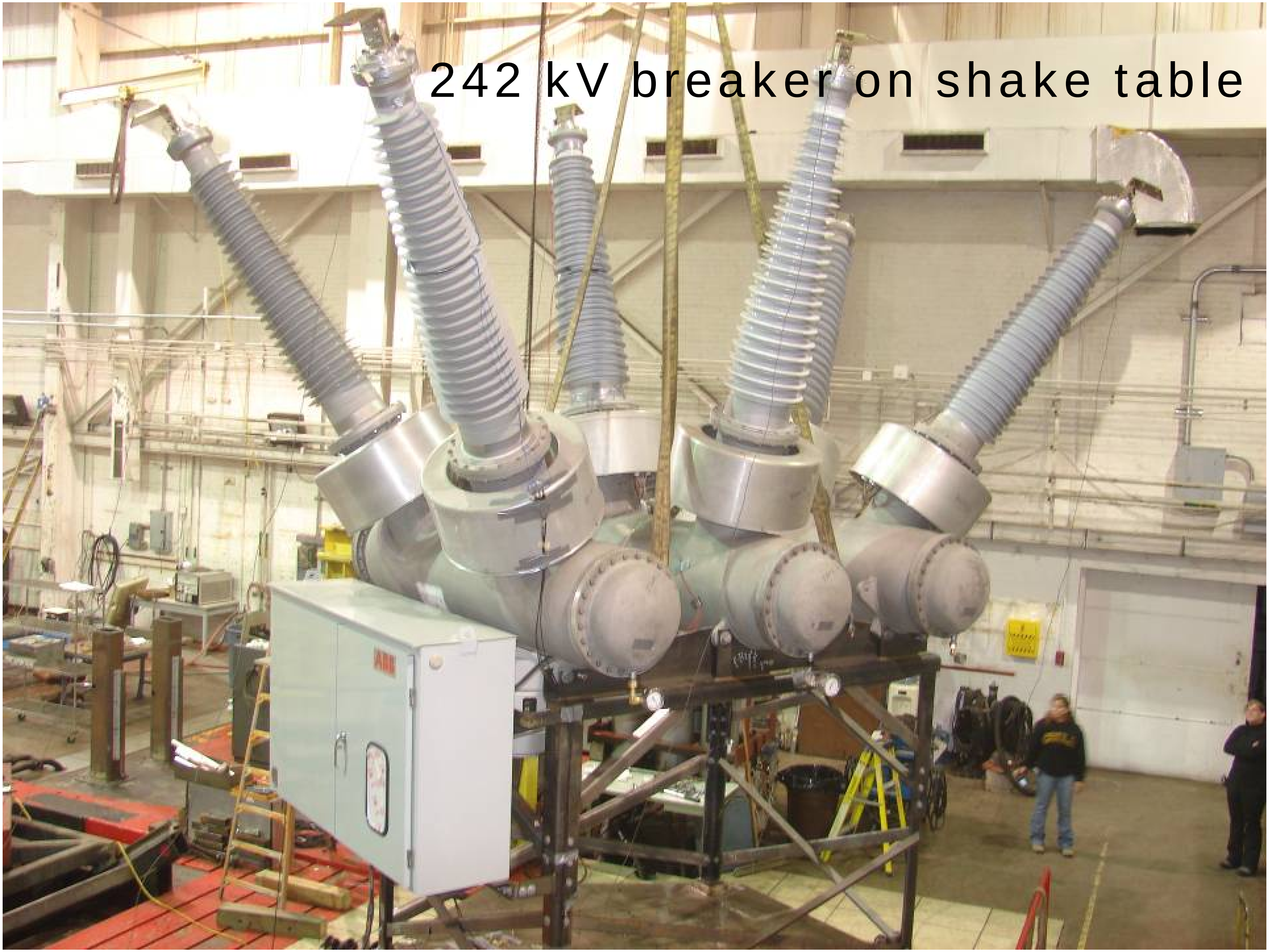
Seismic Qualification of Transformers

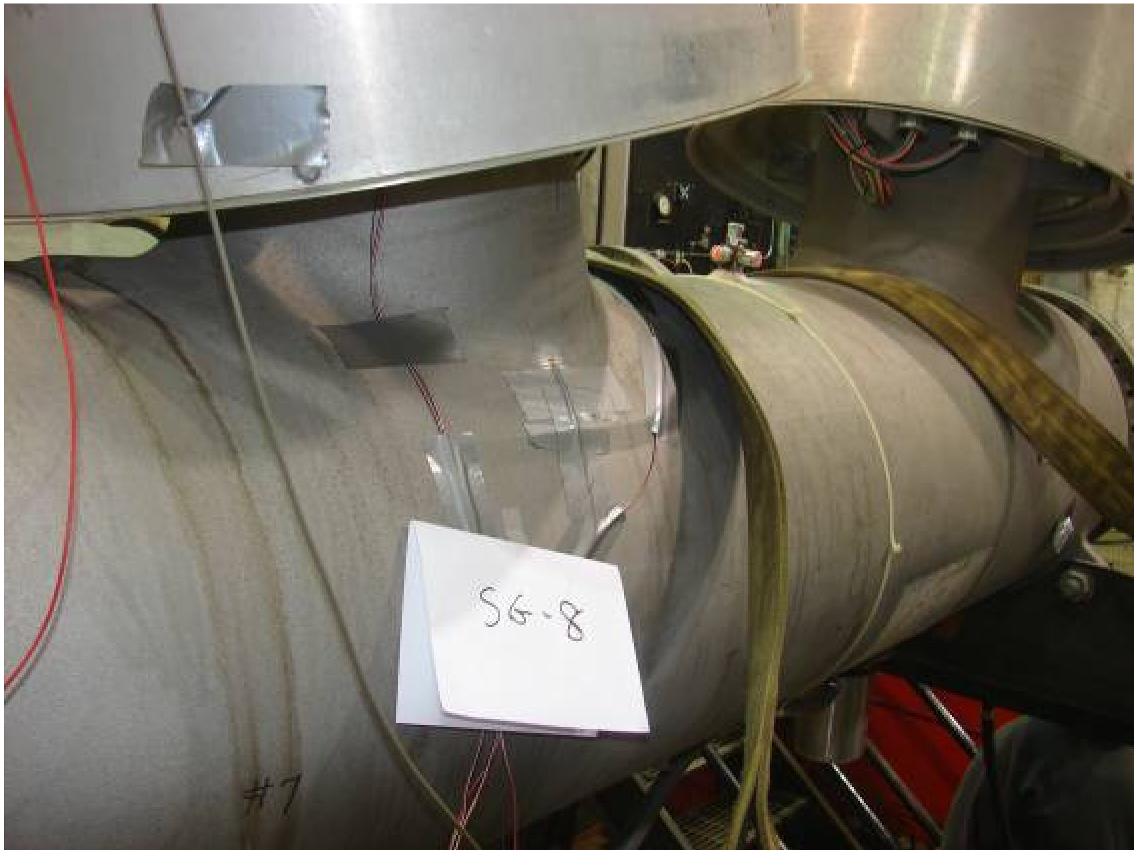
- Tank, core, coils for 69 kV and above
  - by static analysis (0.5 g in two horiz. dir.+ 0.4 g vert)
- Appendages:
  - radiators, conservators, 3 x 0.5 g static anal.
  - control cabinets, 1.5 x 0.5 g static analysis.
- Apparatus Bushings
  - Greater than 138 kV by time history test to four times the RRS (maybe reduced in next few years by special test program)
  - 35 to 138 kV by static pull test to 2 x weight

Test Setup

- Biaxial or triaxial shake table
- Complete breaker or independent pole unit with controls
- Pressurized and controls energized, fully operational
- Monitor relay and main contacts bounce
- Accelerometers on major components
- Strain gauges at critical location along load path
- Load bolts to anchor breaker
- Determine: max. stresses, displacements, foundation loads, damping and resonances

242 kV breaker on shake table

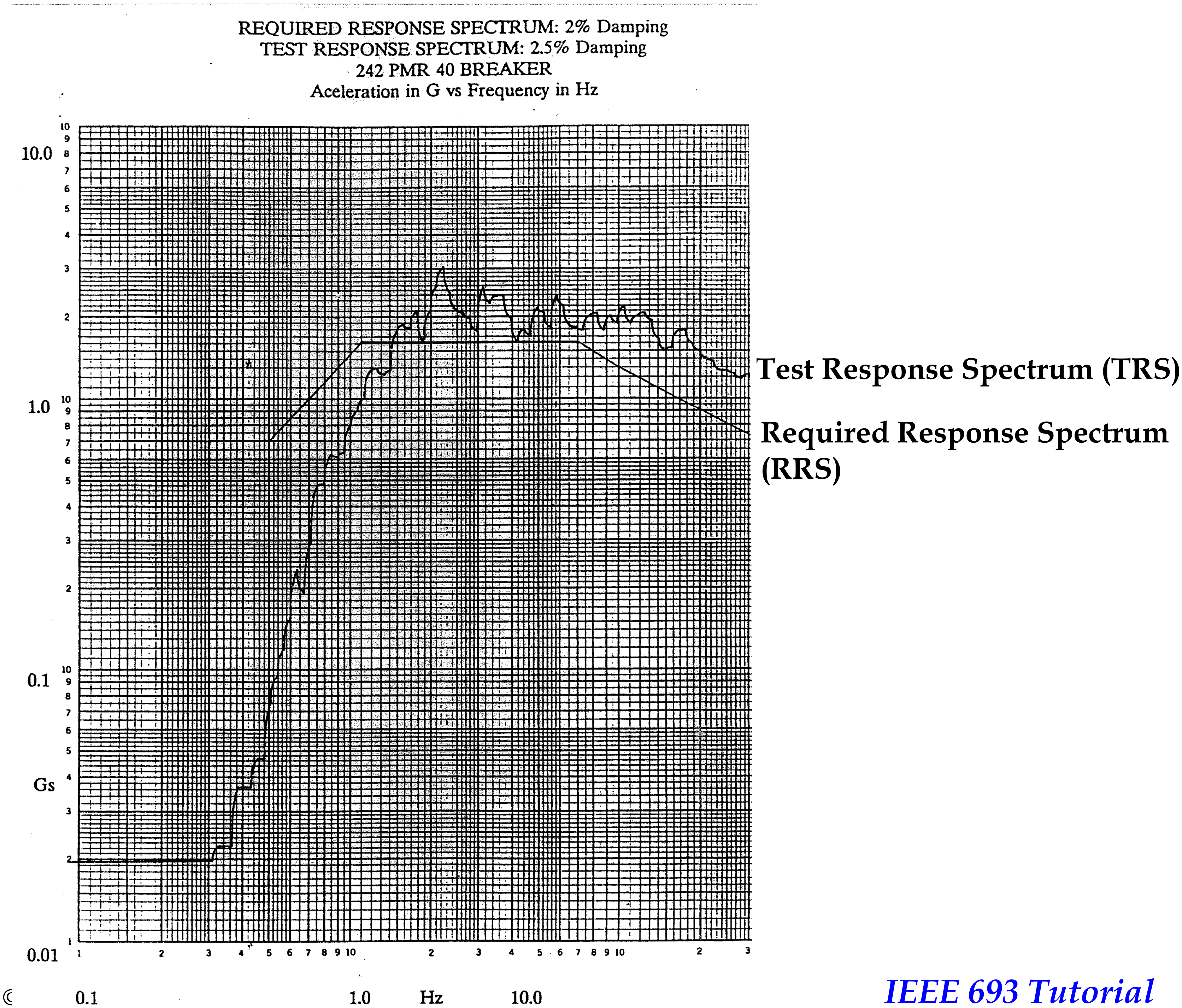




Strain gauges at critical locations on bushings, tank and frame

Comparison of Highest Strain Readings

Strain Reading	0.5 G Sine Beat	1.0 G Time History	Ratio
Frame Leg	212	358	1.69
Frame Leg	89	207	2.33
Bushing Cantilever	28	86	3.07
Tank Nozzle/Shell	265	796	3.00


REQUIRED RESPONSE SPECTRUM: 2% Damping
TEST RESPONSE SPECTRUM: 2.5% Damping
242 PMR 40 BREAKER
Aceleration in G vs Frequency in Hz
10.0
1.0
0.1
Gs
0.01
0.1
1.0
Hz
10.0
Test Response Spectrum (TRS)
Required Response Spectrum (RRS)

Functional Tests

- Pressure reading and leak check before and after each run
- Check for damage and operational state after each run
- Main contact resistance at beginning and end
- Production timing test at beginning and end
- Repeat production high voltage withstand test at factory

Acceptance Criteria

- No visible damage to equipment or supports
- Porcelain insulator stress < 50% ultimate
- Composite insulator stress < 50% SML
- Structural design per AISC or Alum. Assoc. manuals
- Materials not covered by other codes:
  - Brittle Materials < 50% of ultimate strength
  - Ductile Materials < 50% of yield strength
- Function must be maintained
- Sine beat stresses 1.8 x RRS allowable
- Performance level (1 g test) - slight bending but no failure

Documentation

- Test Plan
- Certified Report
- Seismic Outline Drawing
- Nameplate stating seismic qualification level

Good Seismic Design Features:

- Avoid stress concentrations in the load path.
- Reduce weights and moments of equipment.
- Use composite bushing insulators instead of porcelain.
- Use high strength insulation supports in the interrupter.
- Avoid bending loads in connections to critical components such as the tanks or housings.
- Keep higher stresses in ductile components along the load path and reduce stress in brittle elements to increase damping and improve seismic toughness.

Good Seismic Design Features

- Light weight alum. Tank
  - low CG
  - low foundation mom.
- Pinned connection
  - reduced tank stress
  - stronger load path
- Bolted steel structure
  - improved damping
  - Improved toughness

Good Seismic Design resists shipping stresses