
**ASME STANDARDS USED TO DEVELOP
ACCEPTANCE REQUIREMENTS AND TYPICAL
ANALYSES PROCEDURES USED IN SEISMIC
DESIGN OF SAFETY RELATED PRESSURE
RETAINING MECHANICAL DISTRIBUTION
SYSTEMS AND COMPONENTS IN NUCLEAR
POWER PLANTS**

Dr. John D. Stevenson

ASME CODES USED FOR SAFETY RELATED NUCLEAR MECHANICAL PRESSURE RETAINING SYSTEMS AND COMPONENTS

- ASME B&PVC SECTION III – APPLICABLE TO NUCLEAR FACILITY DISTRIBUTION SYSTEMS (PIPING) AND COMPONENTS (VESSELS, HEAT EXCHANGES, PUMPS AND TANKS) ASSOCIATED WITH NUCLEAR REACTOR CORE RADIOLOGICAL RELEASE SAFETY BOTH IN THE REACTOR AND AS SPENT FUEL WHICH IS STILL CAPABLE OF MELTING WITHOUT FORCED COOLING

IN GENERAL THE LIMITING SEISMIC DESIGN LOAD FOR THESE DISTRIBUTION SAFETY RELATED SYSTEMS AND COMPONENTS IS TERMED THE SAFE SHUTDOWN EARTHQUAKE IN THE U.S. WITH A 10^{-4} /YR. TO 10^{-5} /YR PROBABILITY OF EXCEEDENCE DEPENDING ON WHETHER A MEAN OR MEDIAN SEISMIC HAZARD CURVE IS USED.

ASME CODES USED FOR SAFETY RELATED NUCLEAR MECHANICAL PRESSURE RETAINING SYSTEMS AND COMPONENTS

- ASME B&PVC SECTION VIII – APPLICABLE TO PRESSURE VESSELS COMPONENTS AND ASME B31.1 PIPING ASSOCIATED WITH RADIOLOGICAL RELEASE FROM PROCESS AND STORAGE OF RADIOACTIVE MATERIAL AND WASTE AT NUCLEAR POWER PLANTS

IN GENERAL THE LIMITING SEISMIC DESIGN LOAD FOR THESE DISTRIBUTION SYSTEMS AND COMPONENTS IS EQUAL TO 0.5 TIMES THE SSE.

BY FAR, THE GREATEST SEISMIC DESIGN EFFORT HAS BEEN EXPENDED TOWARD THE POSTULATED MUCH HIGHER HAZARD REACTOR CORE RADIOLOGICAL RELEASES. THIS IS BECAUSE THE POTENTIAL RADIOLOGICAL RELEASE FROM THE PROCESS AND STORAGE OF RADIOACTIVE MATERIAL AND WASTE OTHER THAN THAT ASSOCIATED WITH THE REACTOR CORE AT A NPP WOULD TYPICALLY BE MEASURED IN MILLI REM AT THE SITE BOUNDARY AND AS SUCH WOULD HAVE NO EFFECT ON PUBLIC SAFETY.

ORGANIZATION OF THE ASME B&PVC SECTION III FOR NUCLEAR PRESSURE RETAINING COMPONENTS

- DIVISION 1 – METAL COMPONENTS AND DISTRIBUTION SYSTEMS
 - SUBSECTION NCA GENERAL REQUIREMENTS TO INCLUDE DESIGN SPECIFICATIONS AND DESIGN REPORT DOCUMENTATION REQUIREMENTS
 - SUBSECTION NB CLASS 1 – PARTS OF REACTOR COOLANT SYSTEM
 - SUBSECTION NC CLASS 2 – HEAT TRANSPORT AND ENGINEERED SAFETY SYSTEMS
 - SUBSECTION ND CLASS 3 – AUXILIARY COMPONENTS FOR CLASS 1 AND CLASS 2 COMPONENTS
 - SUBSECTION NE METAL REACTOR SYSTEM CONTAINMENT
 - SUBSECTION NF COMPONENT AND DISTRIBUTION SYSTEM SUPPORTS
 - SUBSECTION NG REACTOR CORE SUPPORTS
 - SUBSECTION NH ELEVATED TEMPERATURE SERVICE

ORGANIZATION OF THE ASME B&PVC SECTION III FOR NUCLEAR PRESSURE RETAINING COMPONENTS

- DIVISION 2 – CONCRETE COMPONENTS
 - SUBSECTION NCA
 - SUBSECTION CB CONCRETE REACTOR VESSELS (NOT BEING MAINTAINED)
 - SUBSECTION CC CONCRETE CONTAINMENTS

- DIVISION 3 – SHIPPING & STORAGE CONTAINMENTS
 - WA GENERAL REQUIREMENTS
 - WB SHIPPING CONTAINMENTS
 - WC STORAGE CONTAINMENTS
 - WD CONTAINMENT INTERNALS (IN PREPARATION)

ORGANIZATION OF THE ASME B&PVC SECTION III FOR NUCLEAR PRESSURE RETAINING COMPONENTS

- **SUBSECTIONS NB TO NH, CC, WB & WC
ORGANIZATION OF ARTICLES**
 - NX 1000 INTRODUCTION & SCOPE
 - NX 2000 MATERIALS
 - NX 3000 DESIGN
 - NX 4000 FABRICATION
 - NX 5000 EXAMINATION
 - NX 6000 TESTING
 - NX 7000 OVERPRESSURE PROTECTION
 - NX 8000 STAMPING & REPORTS

ORGANIZATION OF THE ASME B&PVC SECTION III FOR NUCLEAR PRESSURE RETAINING COMPONENTS

ASME B&PVC III MANDATORY APPENDICES OF INTEREST TO DESIGNERS

- I DESIGN FATIGUE CURVES
- III BASES FOR ESTABLISHING ALLOWABLE STRESS INTENSITY & STRESS VALUES
- XII DESIGN CONSIDERATIONS FOR BOLTED FLANGE CONNECTIONS
- XIII DESIGN BASED ON STRESS ANALYSIS FOR CLASS 2 AND WC VESSELS
- XIV DESIGN BASED ON FATIGUE ANALYSIS OF CLASS 2 AND WC VESSELS

ORGANIZATION OF THE ASME B&PVC SECTION III FOR NUCLEAR PRESSURE RETAINING COMPONENTS

ASME B&PVC SECTION III NON-MANDATORY APPENDICES OF INTEREST

- B DESIGN SPECIFICATION FORMAT AND CONTENT
- C DESIGN REPORT FORMAT AND CONTENT
- F RULES FOR SERVICE LEVEL D
- G PROTECTION AGAINST NON-DUCTILE FAILURE-FRACTURE MECHANICS
- N DYNAMIC ANALYSIS METHODS INCLUDING SEISMIC
- O DESIGN OF SAFETY VALVES
- W ENVIRONMENTAL EFFECTS ON COMPONENTS
- Y DESIGN OF INTEGRAL ATTACHMENTS

ORGANIZATION F APPENDIX F RULES FOR EVALUATION OF SERVICE LOADINGS WITH LEVEL D SERVICE LIMITS

APPENDIX F IS IMPORTANT BECAUSE IT DEFINES THE CODE ACCEPTANCE CRITERIA APPLICABLE TO SSE LOADS APPLIED TO SECTION III SYSTEMS AND COMPONENTS

- F-1100 INTRODUCTION AND SCOPE
- F-1200 INTENT OF LEVEL D SERVICE LIMITS
- F-1300 LEVEL D SERVICE LIMITS AND DESIGN RULES
- F-1400 DESIGN RULES APPLICABLE TO SPECIFIC COMPONENTS AND SYSTEMS (VESSELS, PUMPS, VALVES, PIPING AND REACTOR CORE SUPPORT STRUCTURES)

ORGANIZATION OF APPENDIX N – DYNAMIC ANALYSIS METHODS APPLIED TO SEISMIC ANALYSIS

APPENDIX N IS IMPORTANT BECAUSE IT DESCRIBES THE ANALYTICAL METHODS GENERALLY APPLICABLE TO SEISMIC DESIGN OF SECTION III SYSTEMS AND COMPONENTS

- N 1100 – ORGANIZATION & SCOPE
- N 1200 – SEISMIC ANALYSIS
 - N 1210 – EARTHQUAKE DESCRIPTION
 - GROUND RESPONSE SPECTRA
 - TIME-HISTORY

ORGANIZATION OF APPENDIX N – DYNAMIC ANALYSIS METHODS APPLIED TO SEISMIC ANALYSIS

- N 1220 – METHODS OF DYNAMIC ANALYSIS
 - TIME-HISTORY
 - MODAL ANALYSIS
 - DIRECT INTEGRATION
 - RESPONSE SPECTRUM
 - MODAL ANALYSIS
 - FLOOR RESPONSE SPECTRA
 - DAMPING

ORGANIZATION OF THE ASME B&PVC SECTION VIII

- DIVISION 1 – BASIC RULES (PRESSURE)
- DIVISION 2 – ALTERNATE RULES TO INCLUDE DESIGN BY ANALYSIS REQUIRES
- DIVISION 3 – HIGH PRESSURE VESSELS

ORGANIZATION OF ASME B&PVC SECTION VIII – DIVISION 1

- SUBSECTION A – GENERAL REQUIREMENTS
- SUBSECTION B – REQUIREMENTS PERTAINING TO METHODS OF FABRICATION OF PRESSURE VESSELS
- SUBSECTION C – REQUIREMENTS PERTAINING TO CLASSES OF MATERIALS

ORGANIZATION OF ASME B&PVC SECTION VIII – DIVISION 2

- PART AG GENERAL REQUIREMENTS
- PART AM MATERIAL REQUIREMENTS
- PART AD DESIGN REQUIREMENTS
- PART AF FABRICATION REQUIREMENTS
- PART AR PRESSURE RELIEF DEVICES
- PART AI INSPECTION & RADIOGRAPHY
- PART AT TESTING
- PART AS MARKING, STAMPING, REPORTS & RECORDS
- MANDATORY APPENDICES
- NON-MANDATORY APPENDICES

ORGANIZATION OF ASME B31.1 POWER PIPING AND B31.3 PROCESS PIPING CODES

- CHAPTER I – SCOPE & DEFINITIONS
- CHAPTER II – DESIGN
- CHAPTER III – MATERIALS
- CHAPTER IV – DIMENSIONAL REQUIREMENTS
- CHAPTER V – FABRICATION ASSEMBLY & ERECTION
- CHAPTER VI – INSPECTION EXAMINATION & TESTING

THERE ARE TYPICALLY 5 LEVELS OF ANALYSIS USED IN SEISMIC DESIGN

- STATIC ANALYSIS – USE OF BUILDING CODE (ASCE-7) TYPICALLY APPLIED TO SECTION VIII AND B31.1 COMPONENTS AND DISTRIBUTION SYSTEMS
- EQUIVALENT STATIC ANALYSIS – TYPICALLY APPLIED TO SECTION III, SECTION VIII AND B31.1 COMPONENTS AND SYSTEMS
- RESPONSE SPECTRUM MODAL ANALYSIS – TYPICALLY APPLIED TO SECTION III COMPONENTS AND SYSTEMS
- TIME HISTORY MODAL ANALYSIS - TYPICALLY APPLIED TO SECTION III COMPONENTS AND SYSTEMS
- TIME HISTORY TIME STEP INTEGRATION ANALYSIS - TYPICALLY APPLIED TO SECTION III COMPONENTS AND SYSTEMS

STATIC ANALYSIS METHOD

THE STATIC ANALYSIS METHOD TYPICALLY USES THE ANALYTICAL PROCEDURE AND SEISMIC LOADING DEFINED IN ASCE-7 STANDARD FOR ORDINARY BUILDING STRUCTURES AND MECHANICAL COMPONENTS AND SYSTEMS. THE 0.5 SSE U.S. NRC REGULATORY SEISMIC LOADING REQUIREMENT RESULTS IN AN DESIGN BASIS EARTHQUAKE SOMEWHERE BETWEEN 10^{-3} AND 4×10^{-4} PROBABILITY OF EXCEEDENCE (1000 TO 2500 YEAR RETURN PERIOD) DEPENDING ON THE SLOPE OF THE SEISMIC HAZARD CURVE AT THE SITE.

EQUIVALENT STATIC ANALYSIS METHOD

THE EQUIVALENT STATIC ANALYSIS METHOD USES THE APPLICABLE SEISMIC RESPONSE SPECTRAL ACCELERATION VALUES APPLIED AS A STATIC LOAD TO THE MASSES REPRESENTED IN A LUMPED MASS OR FINITE ELEMENT MODEL OF THE COMPONENT OR SYSTEM BEING DESIGNED.

RESPONSE SPECTRUM MODAL ANALYSIS METHOD

THE RESPONSE SPECTRUM MODAL ANALYSIS METHOD MAKES USE OF THE DYNAMIC FREQUENCY AND MODE SHAPE AND ASSOCIATED MODAL PARTICIPATION FACTORS OF THE COMPONENT OR DISTRIBUTION SYSTEM IN DETERMINING THE RESULTANT SEISMIC STRESSES IN THE COMPONENT OR DISTRIBUTION SYSTEM

TIME HISTORY MODAL ANALYSIS METHOD

THE TIME HISTORY MODAL ANALYSIS METHOD IS SIMILAR TO THE RESPONSE SPECTRUM MODAL ANALYSIS METHOD EXCEPT THAT THE INPUT MOTION OF THE EARTHQUAKE IS DEFINED AS A TIME HISTORY RATHER THAN A RESPONSE SPECTRUM.

TIME HISTORY TIME STEP INTEGRATION METHOD

THE TIME HISTORY TIME STEP INTEGRATION METHOD USES A TIME HISTORY INPUT AND SOLVES THE EQUATION OF MOTION TO OBTAIN RESULTANT TIME DEPENDENT STRESS IN THE SYSTEM.

THE REASON FOR THE FIVE DIFFERENT METHODS OF SEISMIC ANALYSIS IS THE RELATIVE COST, DESIGN SCHEDULE IMPACT AND CONSERVATISM DEVELOPED BY THE METHOD USED.

THE STATIC METHOD IS USUALLY THE LEAST CONSERVATIVE THAN ANY OF THE OTHER METHODS AND THE LEAST EXPENSIVE AND COMPLEX DESIGN METHOD. IT IS LIMITED TO ASME B&PVC SECTION VIII AND B31.1 TYPE COMPONENTS AND DISTRIBUTION SYSTEMS

THE EQUIVALENT STATIC METHOD IS
CONSIDERED THE MOST CONSERVATIVE
METHOD OF SEISMIC ANALYSIS AND IS
THE SECOND LEAST SCHEDULE
INTENSIVE AND EXPENSIVE DESIGN
PROCEDURE.

THE RESPONSE SPECTRUM MODAL ANALYSIS METHOD IS CONSIDERED SIGNIFICANTLY LESS CONSERVATIVE AND MORE ACCURATE THAN THE EQUIVALENT STATIC ANALYSIS METHOD BUT ALSO REQUIRES A SIGNIFICANTLY GREATER DESIGN SCHEDULE EFFORT PRIMARILY ASSOCIATED WITH DYNAMIC MODELING OF THE SYSTEM OR COMPONENT.

BOTH THE TIME HISTORY RESPONSE SPECTRUM AND TIME STEP INTEGRATION METHODS ARE CONSIDERED THE MOST ACCURATE METHODS OF SEISMIC DESIGN BUT WITH DESIGN EFFORTS APPROXIMATELY EQUAL TO THE RESPONSE SPECTRUM MODAL ANALYSIS METHOD. IN ADDITION, THE TIME STEP INTEGRATION METHOD CAN BE EMPLOYED WHEN THE COMPONENT OR SYSTEM NON-LINEAR OR INELASTIC BEHAVIOR IS CONSIDERED (I.E. THE SYSTEM OR COMPONENT STIFFNESS CHARACTERISTICS ARE NO LONGER A CONSTANT).

SUMMARY OF EXPERIENCE IN THE U.S. WITH THE BEHAVIOR OF ASME B31.1 DESIGNED PIPING IN THE CONSTRUCTION OF POWER PLANT PIPING SUBJECT TO EARTHQUAKES WITH PEAK GROUND ACCELERATIONS BETWEEN 200 AND 500 GAL.

REFERENCE: NUREG/CR-6239, "SURVEY OF STRONG MOTION EARTHQUAKE EFFORTS ON THERMAL POWER PLANTS IN CALIFORNIA WITH EMPHASIS ON PIPING SYSTEMS," VOLS. 1 AND 2, NOVEMBER 1995.

SUMMARY OF EARTHQUAKE AND SEISMIC DATA APPLICABLE TO POWER PLANT SITES IN CALIFORNIA

Effected Plant/Date of Earthquake	Facility Earthquake Name & Identification of Recording Station Closest to Plant	Earthquake Record				Power Plant Site
		Magnitude Richter	Epicentral Distance & Direction to Recording Station (Miles)	PGA ⁽¹⁾ at Recording Station (g)	Epicentral Distance & Direction to Plant Site (meters)	Measured or Estimated PGA at Plant Site (g)
Valley 09/71	San Fernando 8244 Orian BLvd. Los Angeles	6.8	14.6 SSW	.27H ₁ .14H ₂ .17V	11.7 SSE	.30H ₁ .15H ₂ .18V
Burbank 09/71	San Fernando 633 E. Broadway Glendale	6.8	20.2 SSE	.28H ₁ .23H ₂ .14V	16.2 SSE	.35H ₁ .29H ₂ .18V
Glendale 09/71	San Fernando 633 E. Broadway Glendale	6.8	20.2 SSE	.28H ₁ .23H ₂ .14V	14.0 SSE	.30H ₁ .25H ₂ .15V
Pasadena 09/71	a) San Fernando CIT, Millikan Library Pasadeno	6.8	24.4 SE	.18H ₁ .22H ₂ .12V	23.3 SE	.20H ₁ .16H ₂ .11V
10/87	b) Whittier Narrows 2800 Monterey Rd. San Marino	5.9	6.1 NNW	.22H	7.1 NNW	.20H
Kem 07/52	Kem Valley (Taft) Lincoln School 810 N. 6 th St. Taft	7.7	26.7 WNW	.17H	26.9 N	.25H

SUMMARY OF EARTHQUAKE AND SEISMIC DATA APPLICABLE TO POWER PLANT SITES IN CALIFORNIA (CONT.)

	Facility	Earthquake Record		Power Plant Site		
Effected Plant/Date of Earthquake	Earthquake Name & Identification of Recording Station Closest to Plant	Magnitude Richter	Epicentral Distance & Direction to Recording Station (Miles)	PGA ⁽¹⁾ at Recording Station (g)	Epicentral Distance & Direction to Plant Site (meters)	Measured or Estimated PGA at Plant Site (g)
El Centro 10/79	a) El Centro Station 5165 Corner Main St. & Dogwood Rd. El Centro	6.6	17.5 NW	.51H ₁ ⁽²⁾ .37H ₂ .93V	17.7 NW	.51H ₁ .37H ₂ .93V
11/87	b) Superstition Hills CSMIP 335 Imperial County Center 9 th & Main St. El Centro	6.0	23.5 SE	.27H ₁ .13H ₂ .36V	23.9 SE	.27H ₁ .13H ₂ .36V
Humboldt Bay 06/75	a) Ferndale Plant Site Humboldt Bay	5.5	11.8 NNW	.35H ₁ .26H ₂ .13V	11.8 NNW	.35H ₁ .26H ₂ .13V
11/80	b) Eureka Plant Site Humboldt Bay	7.0	39.1 SSE	.40H ₁ .20H ₂ .16V	39.1 SSE	.40H ₁ .20H ₂ .16V
Moss Landing 10/89	Loma Pierta	7.1	12.0 SSE	.36H ₁ .26H ₂ .56V	17.0 S	.24H ₁ .16H ₂ .34V

Note: Foundations at all Recording and Plant Sites are Alluvium

(1) H₁ is the maximum peak horizontal acceleration; H₂ is the orthogonal peak horizontal acceleration

(2) Measured on a small isolated approximately 5 ft. by 5 ft. pad. On a larger foundation, characteristic of recording instruments in large buildings, instrument accelerations would probably be lower in the range of about 0.3g.

CONCLUSIONS OF THE EARTHQUAKE RESPONSE SURVEY

- IN THE APPROXIMATELY 600000 METERS OF PIPE IN THE 8 POWER PLANTS SURVEYED THERE WERE LESS THAN 20 SINGLE POINT PIPE FAILURES AND NO PIPING SYSTEM FAILURES.
- EXCEPT FOR THE VERY LIMITED USE OF SWAY BRACES IN THE KERN AND VALLEY POWER STATIONS THERE WERE ALMOST NO EVIDENCE OF EARTHQUAKE RESISTANT DESIGN IN THE FORM OF LATERAL RESTRAINTS BEING APPLIED TO PIPING SYSTEMS IN THE POWER PLANTS SURVEYED.
- DEADWEIGHT (VERTICAL) SUPPORT SPACING WERE GENERALLY IN LINE WITH ASME/ANSI B31.1 RECOMMENDATIONS EXCEPT FOR SMALL BORE PIPING ($D_o \leq 2 \frac{1}{2}$ inch). THERE ARE MANY INSTANCES WHERE SMALL BORE PIPE DEAD WEIGHT SUPPORT SPACING EXCEED BY FACTORS OF TWO OR THREE THE RECOMMENDED SPACING OF THE B31.1 CODE.

CONCLUSIONS OF THE EARTHQUAKE RESPONSE SURVEY (CONT.)

- THE FAILURES THAT DID OCCUR WERE ASSOCIATED WITH TYPES OF PIPE CONNECTIONS (THREADED JOINTS), RELATIVELY RIGID CONNECTION OF BRANCH PIPING TO MAIN PIPING RUNS OR COMPONENTS SUBJECT TO LARGE SEISMIC DISPLACEMENT AND MAINTENANCE CONDITION OF THE PIPE ASSOCIATED WITH EROSION AND CORROSION RATHER THAN ANY SYSTEMATIC DESIGN DEFICIENCY.
- SOCKET WELDED CONNECTIONS APPEAR TO PERFORM AS WELL AS BUTT JOINTED, GROOVED WELDED CONNECTIONS.
- THREADED CONNECTIONS HAVE FAILURE RATIOS APPROXIMATELY THREE TIMES THAT OF WELDED CONNECTIONS.