Training Course on Civil/Structural Codes and Inspection

BMA Engineering, Inc.

Overall Outline

4000. Loads, Load Factors, and Load Combinations

- Objective and Scope
  - Introduce loads, load factors, and load combinations for nuclear-related civil & structural design and construction
  - Present and discuss
    - Types of loads and their computational principles
    - Load factors
    - Load combinations
    - Focus on seismic loads
    - Computer aided analysis and design (brief)

Scope: Primary Documents Covered

- Minimum Design Loads for Buildings and Other Structures [ASCE Standard 7-05]
- Seismic Analysis of Safety-Related Nuclear Structures and Commentary [ASCE Standard 4-98]
- Design Loads on Structures During Construction [ASCE Standard 37-02]

Load Types (ASCE 7-05)

- D = dead load
- D_i = weight of ice
- E = earthquake load
- F = load due to fluids with well-defined pressures and maximum heights
- F_a = flood load
- H = load due to lateral earth pressure, ground water pressure, or pressure of bulk materials
- L = live load

Load Types (ASCE 7-05)

- L_r = roof live load
- R = rain load
- S = snow load
- T = self-straining force
- W = wind load
- W_i = wind-on-ice loads

Dead Loads, Soil Loads, and Hydrostatic Pressure

- Dead loads consist of the weight of all materials of construction incorporated into the building, e.g.,
  - Walls, floors, roofs, ceilings, stairways, built-in partitions, finishes, cladding, and other fixed service equipment including weight of cranes
- Unit weight of materials and dimensions of components
- Soil loads, lateral pressure, hydrostatic loads, and uplift

Dead Loads

EXAMPLE 1-1

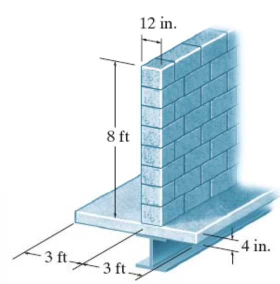


Fig. 1–8

The floor beam in Fig. 1–8 is used to support the 6-ft width of a lightweight plain concrete slab having a thickness of 4 in. The slab serves as a portion of the ceiling for the floor below, and therefore its bottom is coated with plaster. Furthermore, an 8-ft-high, 12-in.-thick lightweight solid concrete block wall is directly over the top flange of the beam. Determine the loading on the beam measured per foot of length of the beam.

Solution

Using the data in Tables 1–2 and 1–3, we have

Concrete slab:	$[8\ \text{lb}/(\text{ft}^2\cdot\text{in.})](4\ \text{in.})(6\ \text{ft}) =$	192 lb/ft
Plaster ceiling:	$(5\ \text{lb}/\text{ft}^2)(6\ \text{ft}) =$	30 lb/ft
Block wall:	$(105\ \text{lb}/\text{ft}^3)(8\ \text{ft})(1\ \text{ft}) =$	840 lb/ft
Total load		1062 lb/ft = 1.06 k/ft *Ans.*

Here the unit k stands for "kip," which symbolizes kilopounds. Hence, 1 k = 1000 lb.

Live Loads

- A load produced by the use and occupancy of the building or other structure that does not include construction or environmental loads, such as wind load, snow load, rain load, earthquake load, flood load, or dead load
- Tabulated unit loads by occupancy and use of a structure

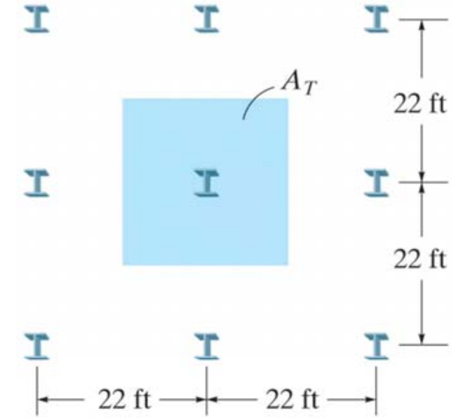
TABLE 4-1 MINIMUM UNIFORMLY DISTRIBUTED LIVE LOADS, L_o, AND MINIMUM CONCENTRATED LIVE LOADS

Occupancy or Use	Uniform psf (kN/m^2)	Conc. lb (kN)
Apartments (see *Residential*)		
Access floor systems		
Office use	50 (2.4)	2,000 (8.9)
Computer use	100 (4.79)	2,000 (8.9)
Armories and drill rooms	150 (7.18)	
Assembly areas and theaters		
Fixed seats (fastened to floor)	60 (2.87)	
Lobbies	100 (4.79)	
Movable seats	100 (4.79)	
Platforms (assembly)	100 (4.79)	
Stage floors	150 (7.18)	

Dead or Live Loads

- Tributary area and live load reduction

Figure: FG01_07UN Shown is a typical example of an interior building column. The live load office floor loading it supports can be reduced for purposes of design and analysis.



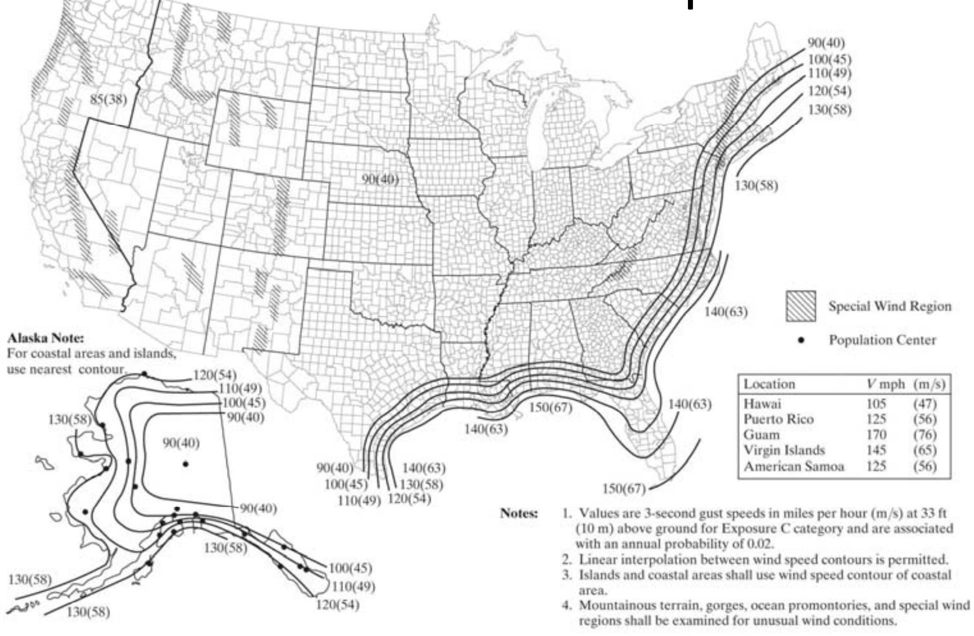
Flood Loads

- They apply to structures located in areas prone to flooding, and include
  - Hydrostatic loads
  - Hydrodynamic loads (moving)
  - Wave loads (repeated impact)
- Structures shall be designed, constructed, connected, and anchored to resist flotation, collapse, and permanent lateral displacement due to action of flood loads associated with the design flood and other loads in accordance with load combinations
- The effects of erosion and scour shall be included in the calculation of loads

Wind Loads

- Structures shall be designed and constructed to resist wind loads computed based in specified wind speed and various wind & pressure coefficients:
  - Simplified procedure for commonly used building geometries, closures, and stiffness without torsion
  - Analytical procedure for regular-shaped without special wind-related effects including torsion
  - Wind tunnel procedure is permitted in lieu of the above two methods for any building or structure

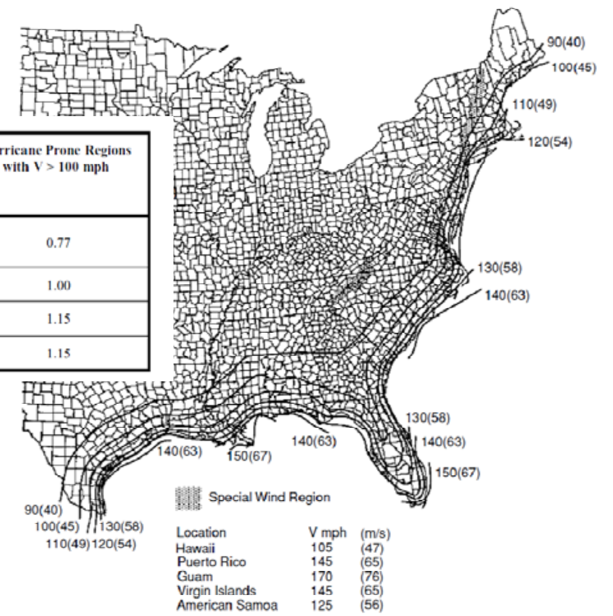
Wind Loads: Wind Speed



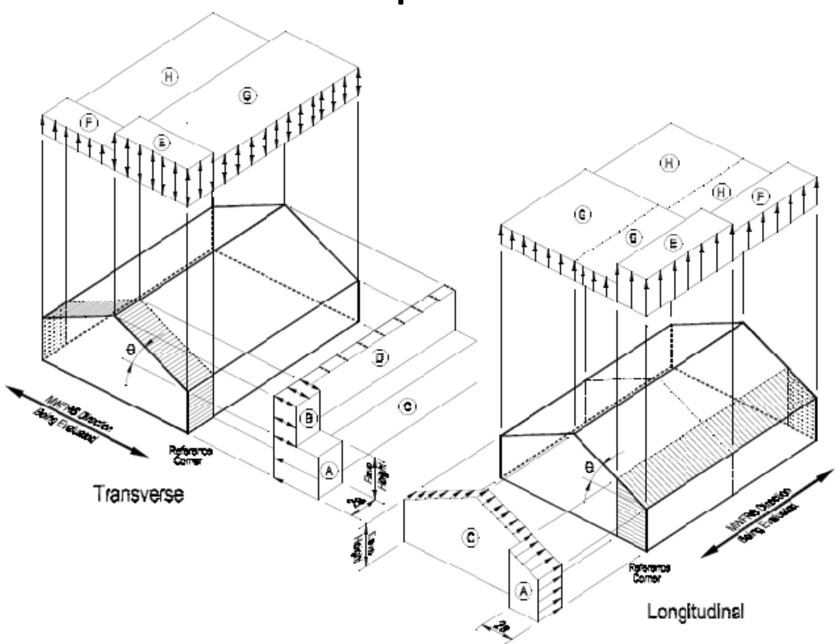
Wind Loads: Wind Speed

Importance Factors: Degree of hazard to human life and damage to property

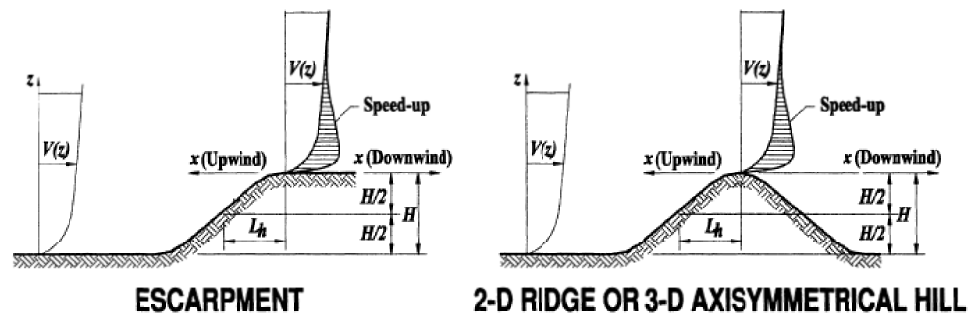
Category	Non-Hurricane Prone Regions and Hurricane Prone Regions with V = 85-100 mph and Alaska	Hurricane Prone Regions with V > 100 mph
I	0.87	0.77
II	1.00	1.00
III	1.15	1.15
IV	1.15	1.15



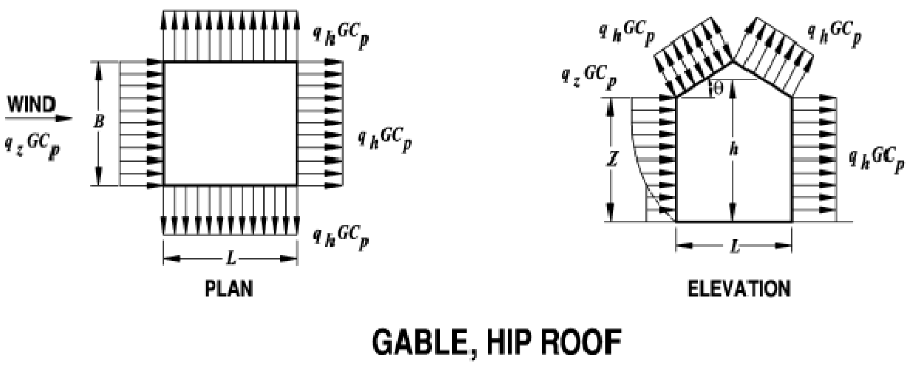
Method 1: Simplified Procedure



Method 2: Analytical Procedure



Method 2: Analytical Procedure



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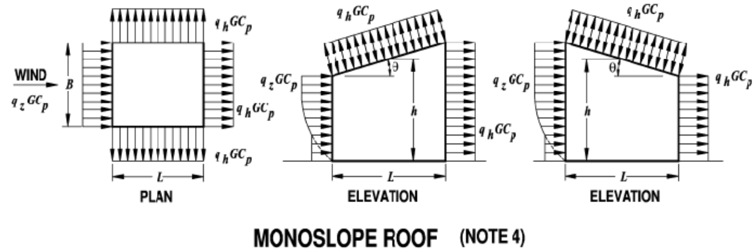
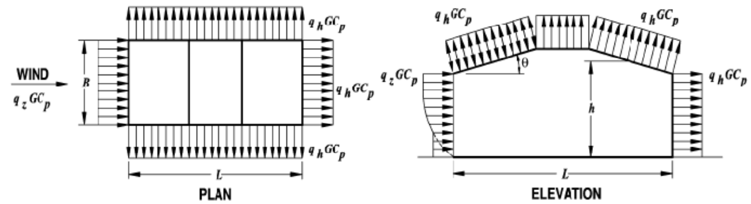
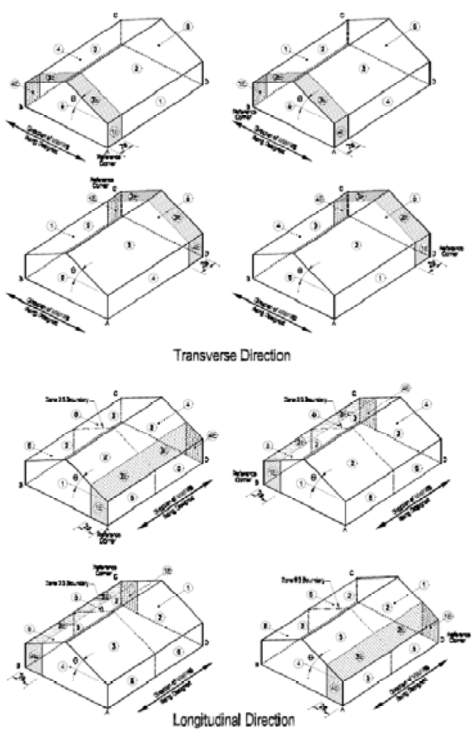


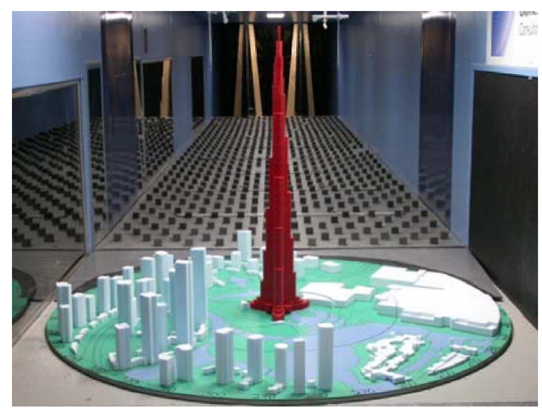


Method 2: Analytical Procedure

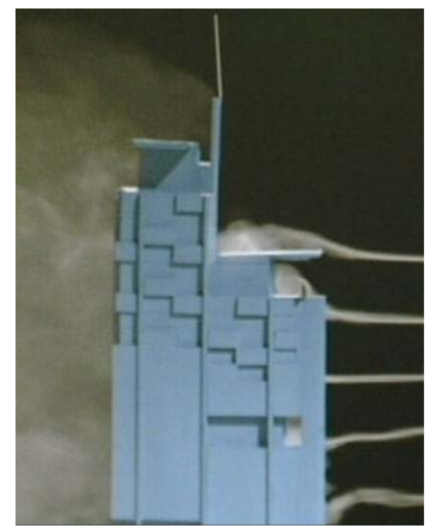
Main wind force resisting system



Method 3: Wind Tunnel

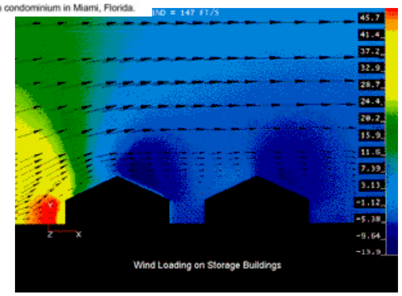


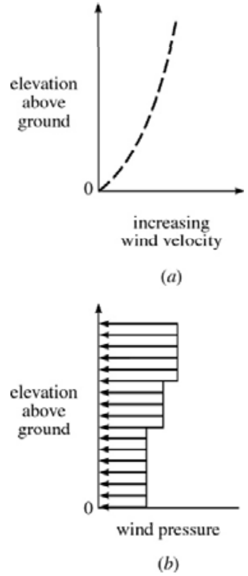
Burj Dubai



Wind Load Effects

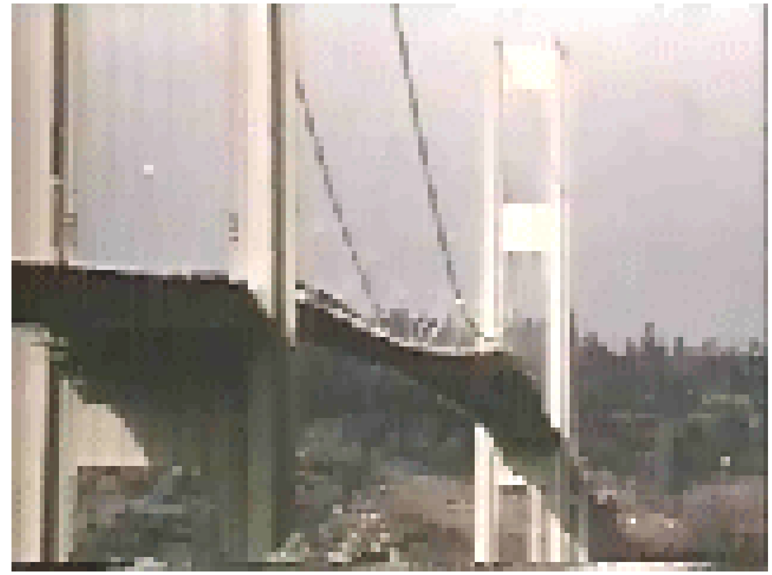
Figure: FG01_09UN Hurricane winds caused this damage to a condominium in Miami, Florida.





Wind Load Effects

Tacoma Narrow Bridge – **See also video file: Tacoma Bridge**



Snow Loads

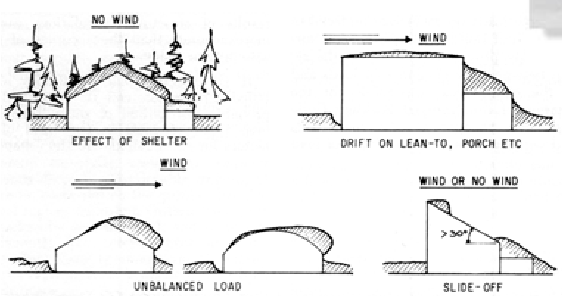
Snow load for flat roof (*f*) (<5%)

$$p_f = 0.7 C_e C_t I p_g$$

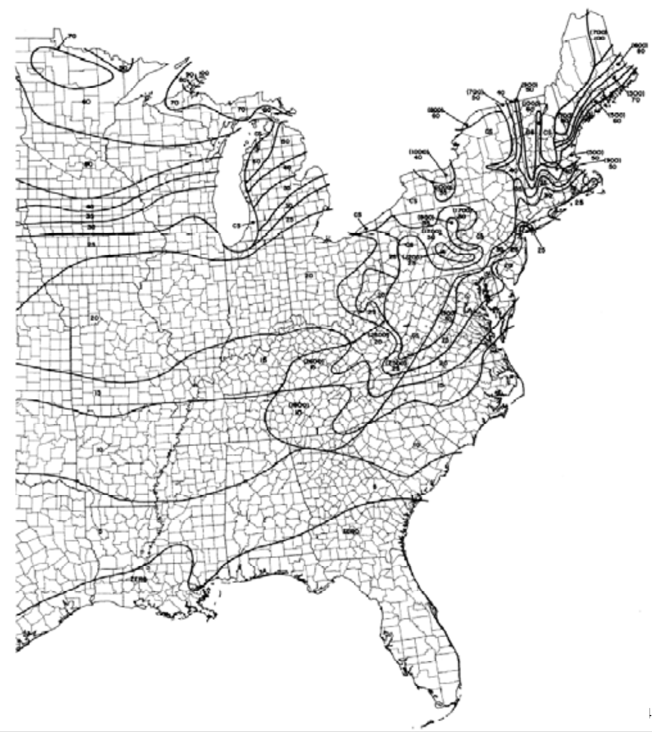
p_g = ground snow load (tabulated)

Exposure and thermal factors

Figure: FG01_10UN Excessive snow and ice loadings act on this roof.



Ground Snow Loads

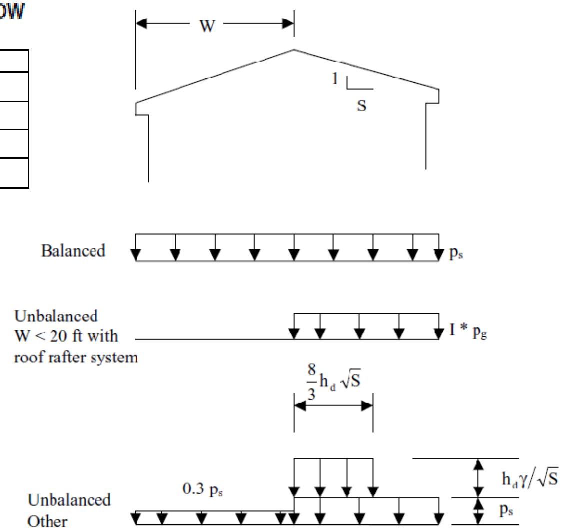


Snow Loads

TABLE 7-4 IMPORTANCE FACTOR, *I* (SNOW LOADS)

Category[a]	*I*
I	0.8
II	1.0
III	1.1
IV	1.2

[a] See Section 1.5 and Table 1-1.



Note: Unbalanced loads need not be considered for θ > 70° or for θ < larger of 2.38° and 70/W + 0.5.

Rain Loads

- Rain load on the undeflected roof, i.e., rain loads computed without any deflection from loads (including dead loads)
- Loads based on roof drainage systems
- Ponding instability, where "Ponding" refers to the retention of water due solely to the deflection of relatively flat roofs

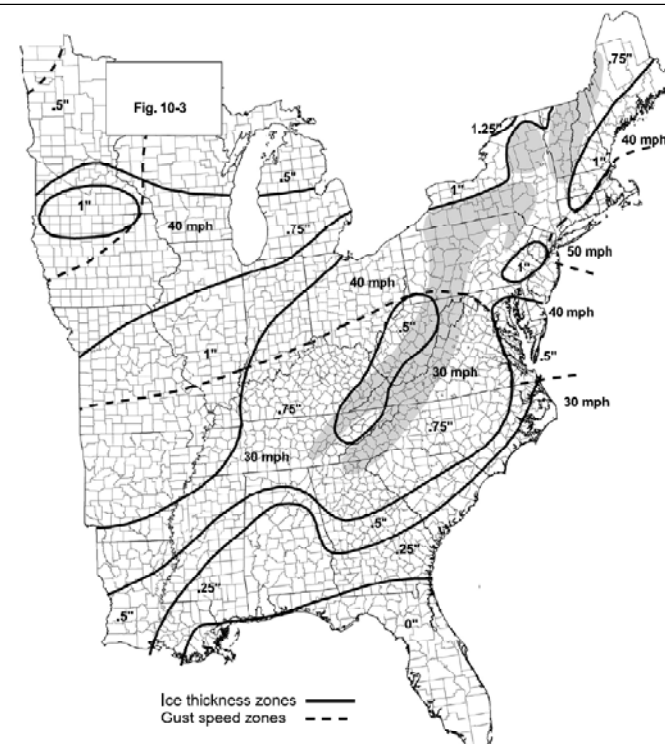
Ice Loads

- Atmospheric ice loads due to freezing rain, snow, and in-cloud icing shall be considered in the design of ice-sensitive structures
- 50-year mean recurrence interval uniform ice thickness due to freezing rain (next slide)

TABLE 10-1 IMPORTANCE FACTOR I_I AND I_W

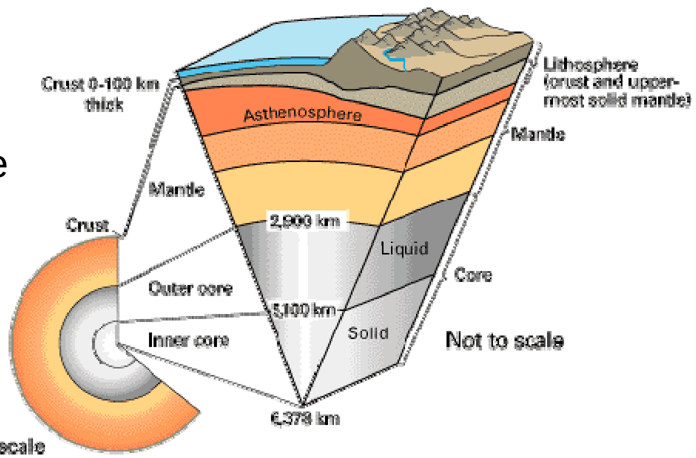
Structure Category	I_I (Multiplier on Ice Thickness)	I_W (Multiplier on Concurrent Wind Pressure)
I	0.80	1.0
II	1.00	1.0
III	1.25	1.0
IV	1.25	1.0

Ice Loads



Seismic Analysis (ASCE 4-98)

Earthquakes, Faults, Plate Tectonics, Earth Structure



See video: 10.5- Earthquake in San Francisco!

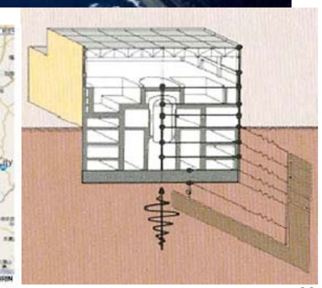
See video 10.5- Earthquake Destruction

See video 10.5- M7.0 Earthquake Simulation for Hayward Fault, California

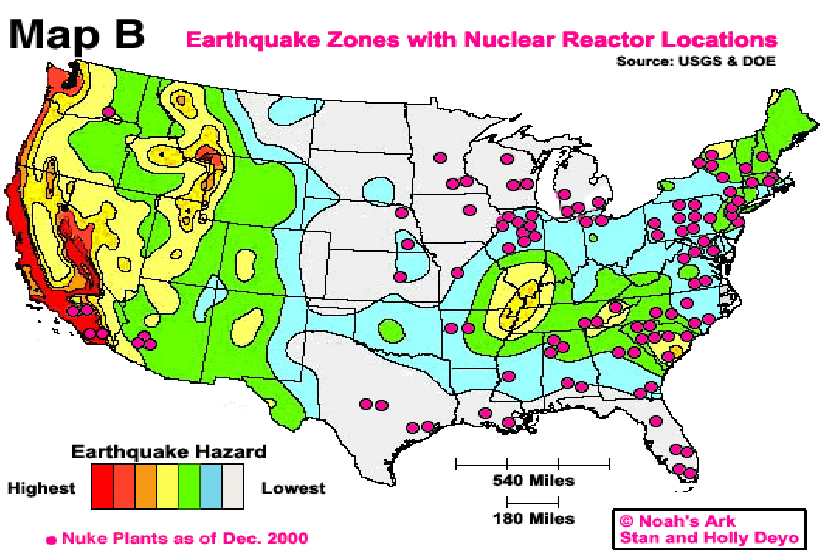
Seismic Analysis (ASCE 4-98)

TOKYO ELECTRIC POWER COMPANY

- The Niigata-ken Chuetsu-oki Earthquake (NCOE) occurred in 2007
- The Kashiwazaki Kariwa Nuclear Power Station located in the same area
- The station was hit by a big tremor more than its intensity assumed to be valid at the station design stage
- Preventive functions for the station safety worked as expected as it designed
- Critical facilities designed as high seismic class were not damaged, though considerable damages were seen in outside-facilities designed as low seismic class

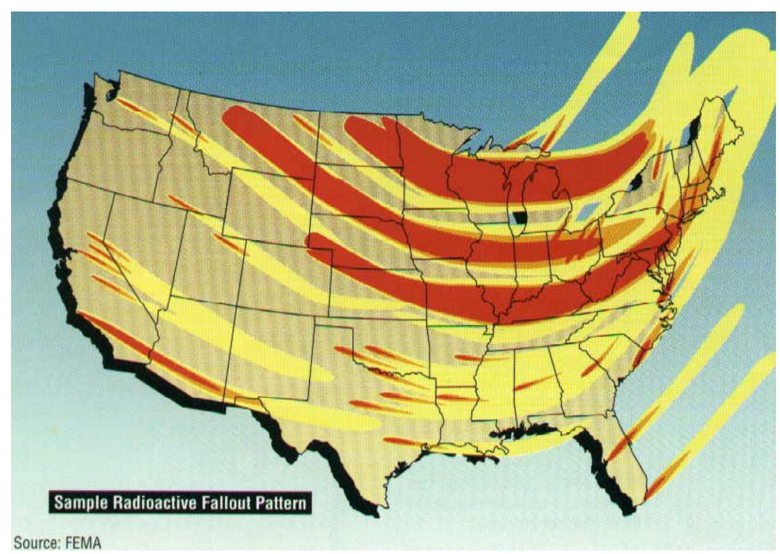


Seismic Analysis (ASCE 4-98)



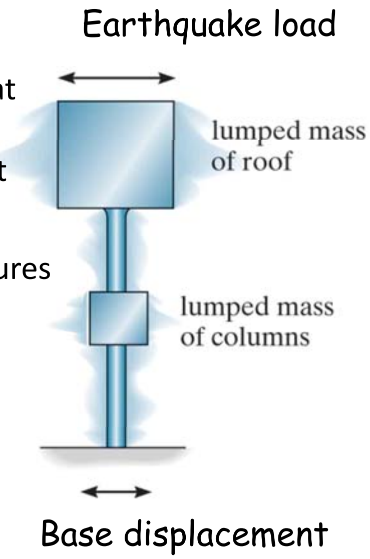
Seismic Analysis (ASCE 4-98)

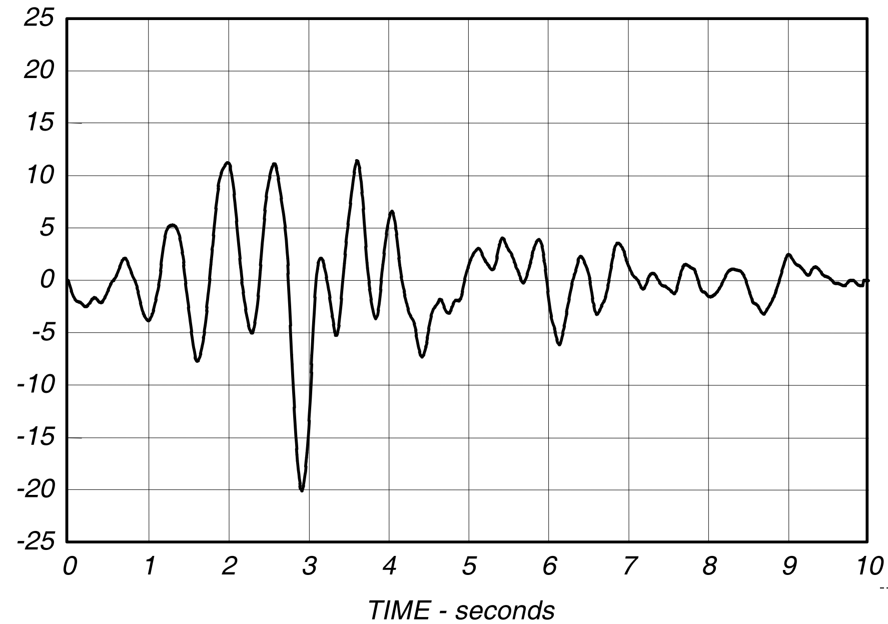
In case of a release, prevailing wind predicted fallout pattern



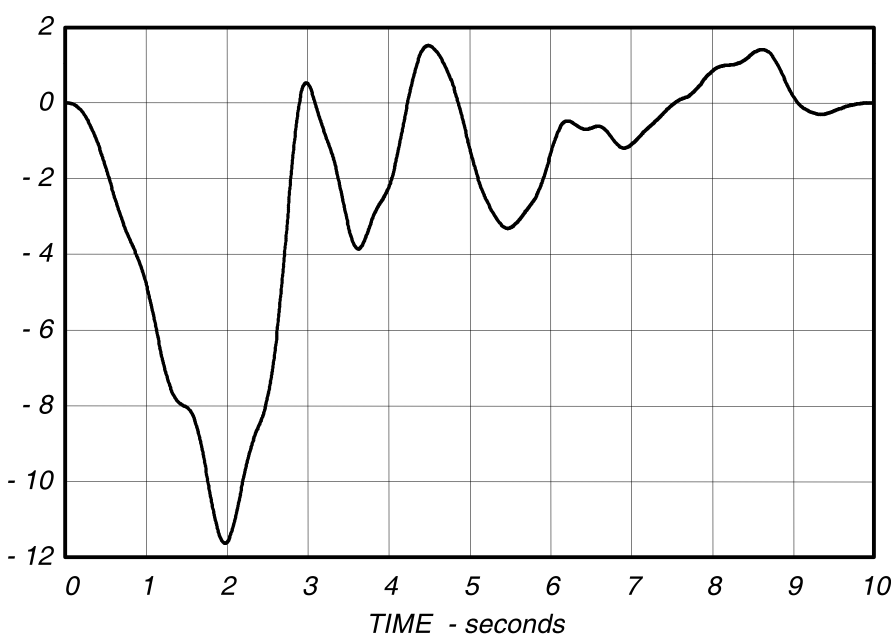
Seismic Analysis (ASCE 4-98)

- Requirements for performing analyses on structures under earthquake motion
- Provide rules and analysis parameters that produce seismic responses with same probability of non-exeedance as the input
- Specifications of input motions
- Analysis standards for modeling of structures
- Soil structure interaction modeling and analysis
- Input for subsystem seismic analysis
- Special structures
- Seismic probabilistic risk assessment and seismic margin assessments

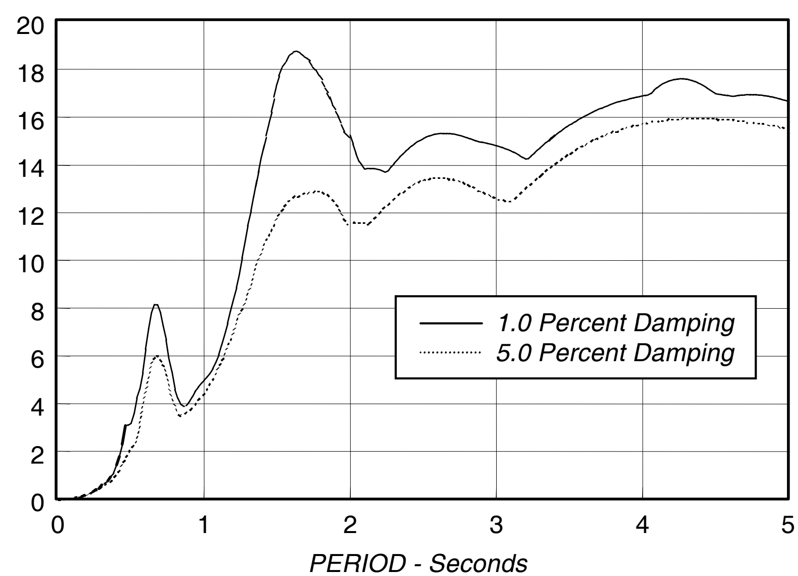




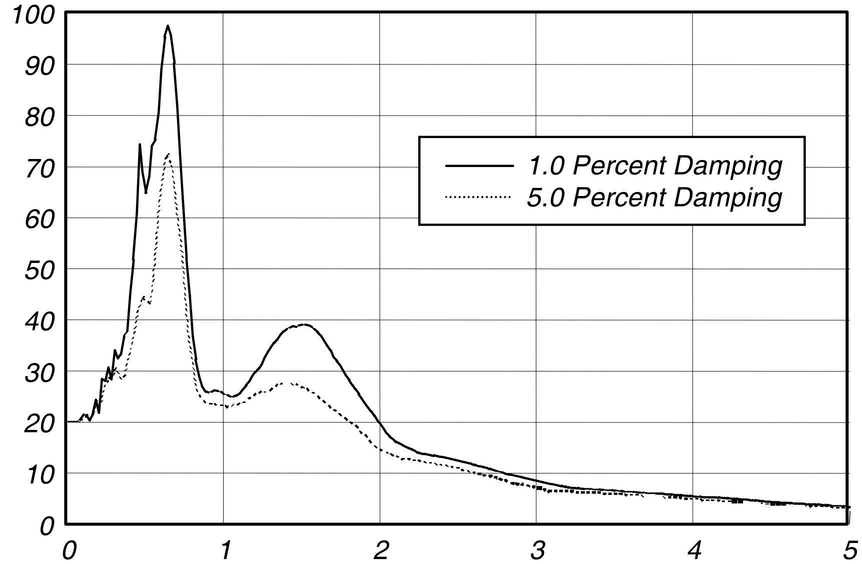
Typical Earthquake Ground Acceleration - Percent of Gravity



Absolute Earthquake Ground Displacements - Inches



Relative Displacement Spectrum $y\,(T)_{MAX}$ Inches



$$S_a = \omega^2 y(\omega)_{MAX}$$

PERIOD - Seconds

Pseudo-Acceleration Spectrum Percent of Gravity

Seismic Analysis (ASCE 4-98)

- Steps in design and construction process that lead to the reliability of nuclear safety-related structures under earthquake motion
  – Definition of seismic environment
  – Analysis to obtain seismic response information
  – Design or evaluation of the structural elements
  – Construction

Seismic Analysis (ASCE 4-98)

- Provides requirements for designing new facilities and evaluation of existing facilities
- Intent of analysis methodology
  – Output parameters maintain same non-exceedance probability as input
  – Example: produce seismic responses that have about a 90% chance of not being exceeded for an input response spectrum specified at the 84th percentile

Seismic Analysis (ASCE 4-98)

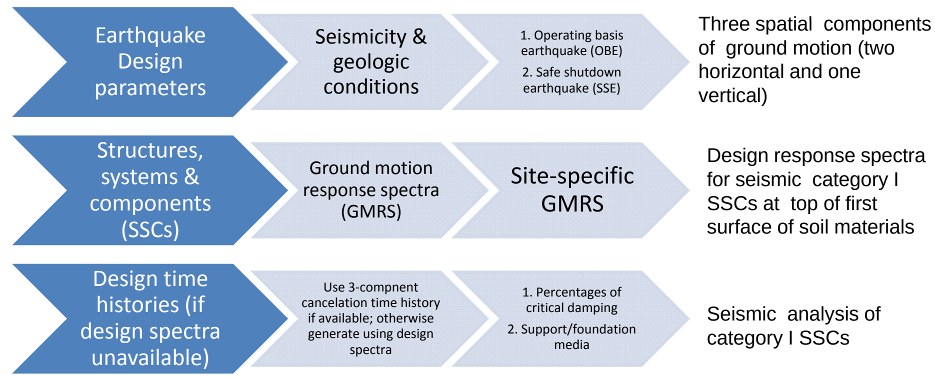
- Analysis provides small levels of conservatism to account for uncertainty
  – Soil-structure interaction
  – In-structure response spectra
  – Structural damping
- Analysis output has slightly greater probability of non-exceedance than that for inputs

NUREG 0800

- Applicable to Structures, Systems and Components (SSCs)
- Two earthquake intensities
  - Safe-shutdown earthquake ground motion (SSE)
  - Safe-operation earthquake ground motion (SOE)
- Category I SSCs are SSCs designed to remain functional if the SSE occurs

NUREG 0800 Section 3.0: Design of Structures, Components, Equipment, and Systems

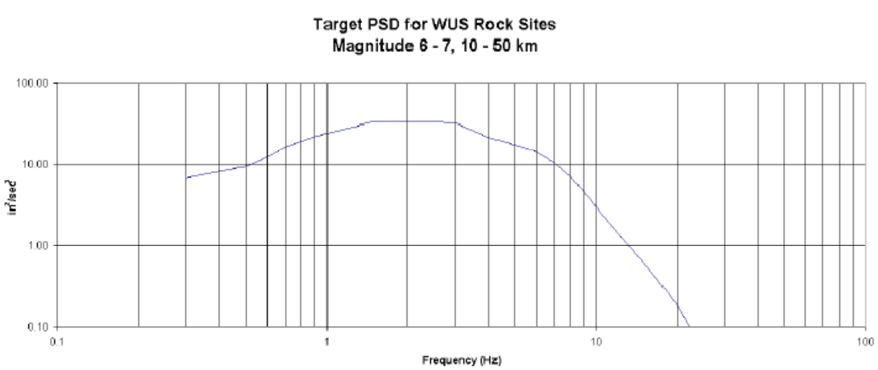
- Seismic (3.7.1 to 3.7.4)



NUREG 0800 Section 3.0: Design of Structures, Components, Equipment, and Systems

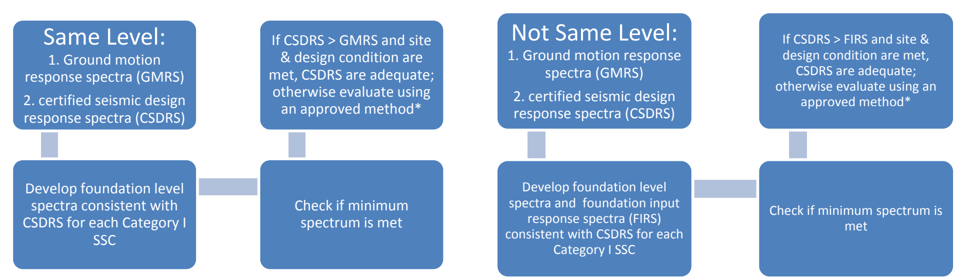
- Seismic (3.7.1 to 3.7.4)

Power Spectral Density (PSD) in in^2/sec^3 for Western US (WUS)



NUREG 0800 Section 3.0: Design of Structures, Components, Equipment, and Systems

- Seismic (3.7.1 to 3.7.4)



* Approved method accounts for soil-structure interaction (SSI), torsion, rocking, in-structure response, redesign, re-analysis as needed until limits are met. Cases without a certified design require developing GMRS, smoothed response spectra, foundation-level response spectra, analysis, redesign & reanalysis until meeting limits.

NUREG 0800 Section 3.0: Design of Structures, Components, Equipment, and Systems

- Seismic (3.7.1 to 3.7.4)
  - Analysis methods:
    - Response spectrum method
    - Time history analysis method
    - Equivalent static load analysis method
  - Natural frequencies and response
  - Material, damping, stiffness and mass properties
  - Hydrodynamic effects

NUREG 0800 Section 3.0: Design of Structures, Components, Equipment, and Systems

- Seismic (3.7.1 to 3.7.4)
  - Soil-structure interaction (SSI):
    - The random nature of the soil and rock configuration and material characteristics
    - Uncertainty in soil constitutive modeling (soil stiffness, damping, etc.)
    - Nonlinear soil behavior
    - Coupling between the structures and soil
    - Lack of uniformity in the soil profile, which is usually assumed to be uniformly layered in all horizontal directions

NUREG 0800 Section 3.0: Design of Structures, Components, Equipment, and Systems

- Seismic (3.7.1 to 3.7.4)
  - Soil-structure interaction (SSI) (cont.):
    - Effects of the flexibility of soil/rock
    - Effects of the flexibility of basemat
    - The effect of pore water on structural responses, including the effects of variability of ground-water level with time
    - Effects of partial separation or loss of contact between the structure (embedded portion of the structure and foundation mat) and the soil during the earthquake
    - Strain-dependent soil properties

NUREG 0800 Section 3.0: Design of Structures, Components, Equipment, and Systems

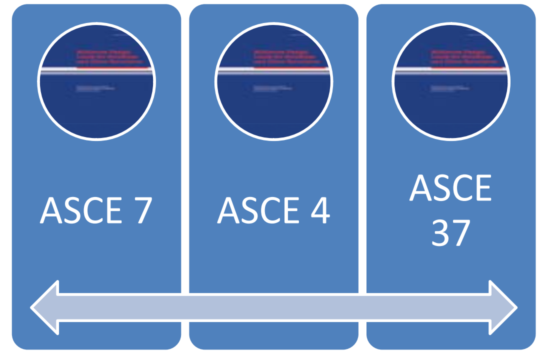
- Seismic (3.7.1 to 3.7.4)
  - Interaction of non-category I structures with Category I SSCs (decoupling criteria based on mass ratios and fundamental frequency ratios)
  - Effects of parameter variation on floor responses
  - Use of equivalent vertical static factors
  - Methods used to account for torsional effects
  - Procedures for damping
  - Overturning moments and sliding forces

NUREG 0800 Section 3.0: Design of Structures, Components, Equipment, and Systems

- Seismic (3.7.1 to 3.7.4)
  - Seismic analysis to cover Category 1 subsystems using similar approaches deployed for SSCs:
    - Platforms
    - Support frame structures
    - Yard structures
    - Buried piping, tunnels and conduits
    - Concrete dams
    - Atmospheric tanks

NUREG 0800 Section 3.0: Design of Structures, Components, Equipment, and Systems

- Seismic (3.7.1 to 3.7.4)
  - Seismic analysis to cover instrumentation (per RG 1.12 and RG 1.66)



Seismic Analysis (ASCE 4-98)

- Type of Structures
  - All safety related structures of nuclear facilities
- Assumes foundation material stability
- Determined seismic responses to be combined with responses due to dead loads and other loads

Seismic Analysis (ASCE 4-98)

Seismic Input
- Seismic ground motions
- Response spectra
- Time histories
- Power spectral density functions
- Additional requirements for structures sensitive to long period motions

Analysis
- Modeling of structures
- Analysis of structures
- Soil-structure interaction modeling and analysis
- Input for subsystem seismic analysis
- Special structures

Seismic Analysis (ASCE 4-98)

Seismic Input

- Seismic ground motions
- Response spectra
- Time histories
- Power spectral density functions
- Additional requirements for structures sensitive to long period motions

Seismic Input

- Seismic Ground Motions
  - Two orthogonal horizontal and one vertical components
  - Appropriate for geological and seismological environment and subsurface conditions
  - Free field ground surface motion at top of component foundation material
  - Specified in terms of peak ground acceleration (PGA), peak ground velocity (PGV), and response spectra

Seismic Input

- Seismic Ground Motions (cont.)
  - peak ground displacement if required (PGD) and Effective duration of seismic motion to be included if required
    - Nonlinear effects in foundation soils, special structures, structural response
  - Appropriate for the magnitude and distance of the largest contributor design earthquakes to the seismic hazard for the site

Seismic Input

- Respond Spectra
  - General requirements
  - Site-specific horizontal response spectra
  - Site-independent horizontal response spectra
  - Vertical response spectra

Seismic Input

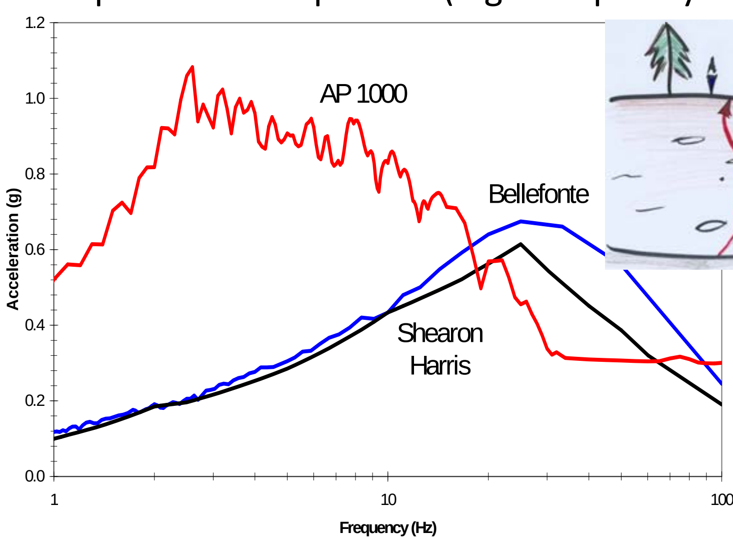
- Respond Spectra - General Requirements
  - Either site specific or standard
  - Response spectrum for an intermediate damping factor
  - Consider two potential ground motions separately

Seismic Input

- Respond Spectra - Site-Specific Horizontal Response Spectra
  - Necessary for sites with soft soils, i.e., soils having a low strain shear wave velocity of no greater than 750 ft/s averages for the top 100 ft of soil
  - Sites of hgh frequency motions $\geq$ 33 Hz
  - Facilities within 15 km of active fault

Seismic Input

- Respond Spectra - Site-Specific Horizontal Response Spectra: a comparison (high-frequency content)



Comparisons are between certified design spectra and 10^{-4} site specific spectra

Seismic Input

- Respond Spectra - Site-Independent Horizontal Response Spectra using:
  - Spectral acceleration (S_a)
  - Spectral velocity (S_v)
  - Spectral displacement (S_d)
- Computed using the dynamic amplification factors
- Instead of median, other exceedance probability can be used

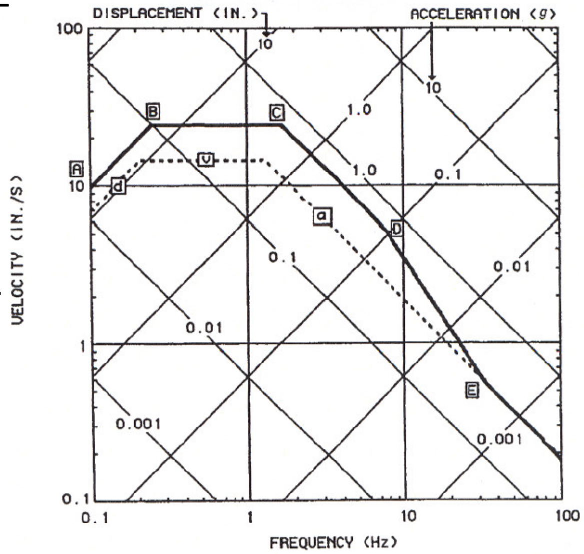
TABLE 2.2-1. Median Amplification Factors for Design Spectra

Spectral Parameter	Amplification Factor
S_a/a	$3.21 - 0.68 \ln(\lambda)$
S_v/v	$2.31 - 0.41 \ln(\lambda)$
S_d/d	$1.82 - 0.27 \ln(\lambda)$

Note: λ = damping in percent of critical; a = peak ground acceleration; $v = 48\ a/g$ for soil, $36\ a/g$ for rock (in./s); $d = 36\ a/g$ for soil, $20\ a/g$ for rock (in.); and g = acceleration of gravity.

Seismic Input

- Respond Spectra - Site-Independent Horizontal Response Spectra
- Example: Median-shaped response spectrum for horizontal motion scaled to 0.3g peak ground acceleration, 5% damping, soil site



Seismic Input

- Respond Spectra - Vertical Response Spectra
  - Use a value of 2/3 of the corresponding horizontal component throughout the frequency range
  - For source to site distance $\leq$ 15 km, use the following factors
    - 1 for frequency > 5 Hz
    - 2/3 at frequency $\leq$ 3 Hz
    - Linear interpolation for cases in between 3 and 5, unless a site-specific evaluation is conducted

Seismic Input

- Time Histories
  - Use duration envelope function for each direction

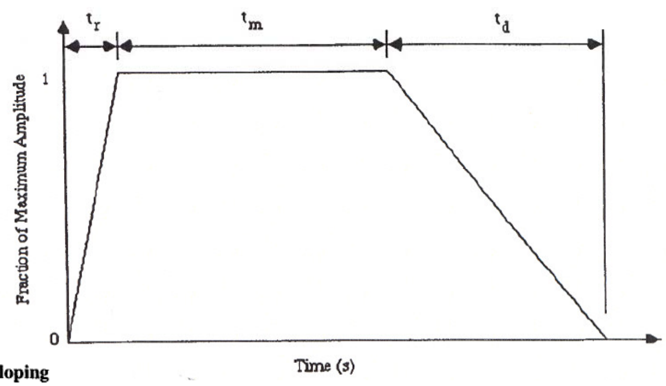


TABLE 2.3-1. Duration Enveloping Function Parameters

Magnitude	Rise Time (t_r)	Duration of Strong Motion (t_m)	Decay Time (t_d)
7.0–7.5	2	13	9
6.5–7.0	1.5	10	7
6.0–6.5	1	7	5
5.5–6.0	1	6	4
5.0–5.5	1	5	4

TABLE 2.3-2. Suggested Frequencies for Calculation of Response Spectra

Frequency Range (Hz)	Increment (Hz)
0.5–3.0	0.10
3.0–3.6	0.15
3.6–5.0	0.20
5.0–8.0	0.25
8.0–15.0	0.50
15.0–18.0	1.0
18.0–22.0	2.0
22.0–34.0	3.0

Seismic Input

- Time Histories
  - Compute spectral values at sufficient points
  - Use orthogonal components

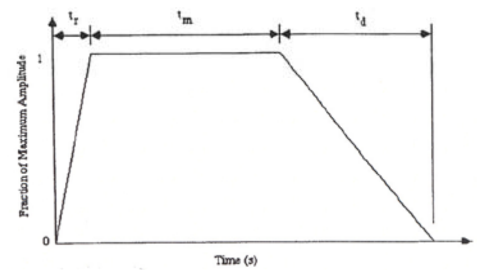


TABLE 2.3-2. Suggested Frequencies for Calculation of Response Spectra

Frequency Range (Hz)	Increment (Hz)
0.5–3.0	0.10
3.0–3.6	0.15
3.6–5.0	0.20
5.0–8.0	0.25
8.0–15.0	0.50
15.0–18.0	1.0
18.0–22.0	2.0
22.0–34.0	3.0

Seismic Input

TABLE C2.3-1. Verification of Compatibility of Response Spectra of Three Time History Motions with a Design or Evaluation Ground Response Spectrum

Number	Frequency[a] (Hz)	Spectral Value from Three Time Histories (g) a_1	a_2	a_3	Mean, a_m of a_1, a_2, and a_3	Design Acceleration Spectral Value, a	Ratio of Spectral Amplitude, R^b
1	33.00	0.3010	0.3128	0.2712	0.2950	0.2500	1.18
2	28.50	0.3836	0.4126	0.1050	0.3004	0.2808	1.07
3	25.00	0.3801	0.2900	0.1693	0.2798	0.3109	0.90
4	22.88	0.3515	0.3159	0.2815	0.3163	0.3295	0.96
5	20,00	0.3862	0.2968	0.5209	0.4013	0.3648	1.10
6	12.40	0.5939	0.4613	0.5423	0.5325	0.5170	1.03
7	9.00	0.6289	0.6778	0.4927	0.6001	0.6523	0.92
8	7.40	0.9638	0.8943	0.5778	0.8120	0.6711	1.21
9	5.00	0.8827	0.8579	0.6423	0.7943	0.7092	1.12
10	4.51	0.5710	0.8168	0.6297	0.6725	0.7310	0.92
11	4.50	0.5807	0.7946	0.6152	0.6635	0.7291	0.91
12	3.16	0.7720	0.8788	0.7264	0.7924	0.6831	1.16
13	2.50	0.7169	0.6213	0.6364	0.6582	0.5578	1.18
14	1.71	0.5227	0.4001	0.2547	0.3925	0.4046	0.97
15	1.46	0.5718	0.3968	0.2614	0.4100	0.3535	1.16
16	1.00	0.2873	0.2416	0.1866	0.2385	0.2564	0.93
17	0.74	0.2165	0.1864	0.1644	0.1891	0.1990	0.95
18	0.66	0.1934	0.2164	0.1623	0.1907	0.1799	1.06
19	0.50	0.1562	0.1611	0.1165	0.1446	0.1418	1.02
							Total = 19.75

Notes:
[a]The number of frequencies selected is for this illustration only. The actual number of frequencies shall be based on Section 2.3.1 of the standard.
[b]Ratio of spectral values at any frequency should not be less than 0.9 (i.e., not more than 10% below the design spectra).

Average of ratios in last column

$$\frac{\text{summation of ratio } (\Sigma R_i)}{\text{number of frequencies } (n)} \frac{19.75}{19} = 1.039 \text{ (should be 1.0)}$$

Seismic Input

- Power Spectral Density (PSD) Functions
  - PSD is computed from time histories using Fourier transformation
  - For zero-mean stochastic processes, spectral density is the variance as a function of frequency
  - It is related to energy as a function of frequency

Seismic Input

- Additional Requirements for Structures Sensitive to Long Period Motions
  - Structures for which isolation techniques, liquefaction and hydrodynamic effects are considered
  - Response spectral for 0.2 to 33 Hz, with smaller frequencies requiring site-specific analysis
  - Time histories can be used for special cases

Seismic Analysis (ASCE 4-98)

Analysis

- Modeling of structures
- Analysis of structures
- Soil-structure interaction modeling and analysis
- Input for subsystem seismic analysis
- Special structures

Seismic Analysis

- Modeling of Structures
  - General requirements
  - Structural material properties
  - Modeling of stiffness
  - Modeling of mass
  - Modeling of damping
  - Modeling of hydrodynamic effects
  - Dynamic coupling criteria
  - Requirements for modeling specific structures

Seismic Analysis

- Modeling of Structures - General Requirements
  - Models for horizontal and vertical motions can be separate if the motions are uncoupled; otherwise 3-D analysis is required
  - One-step method for seismic response analysis
  - Multistep method for seismic response analysis
    - In the first step, and overall response is obtained and used as an input to the second step, and so on
  - Discretization considerations (mesh size, finite element type, reduction of degrees of freedom, etc.)

Seismic Analysis

- Finite element analysis

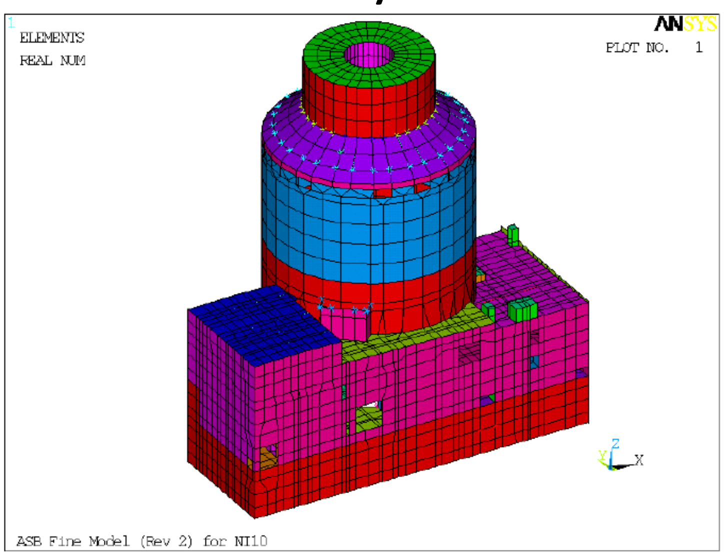


Figure 5: Nuclear Island Fine Model – ni10

Seismic Analysis

- Finite element analysis

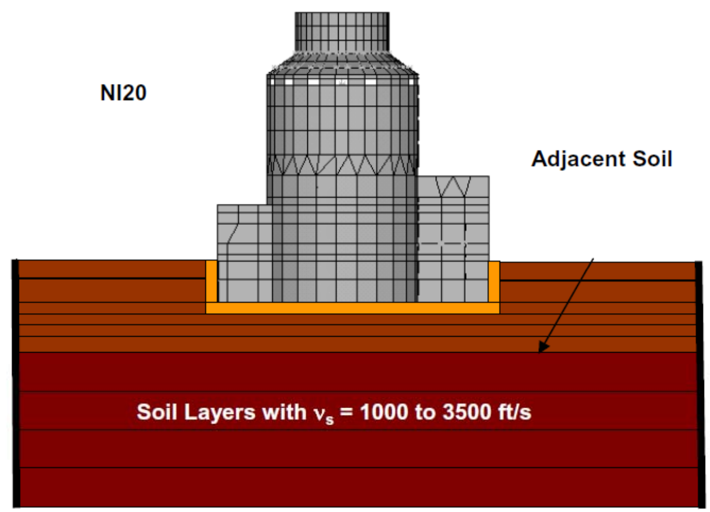


Figure 6: Soil Structure Interaction Model – ni20: Looking East

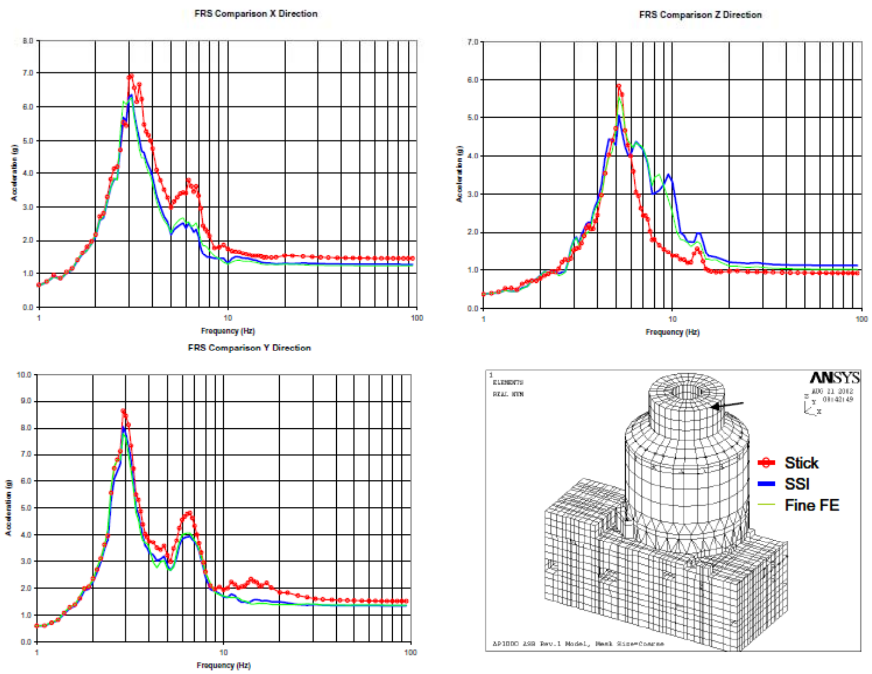


Figure 7: FRS results at Top of Shield Building

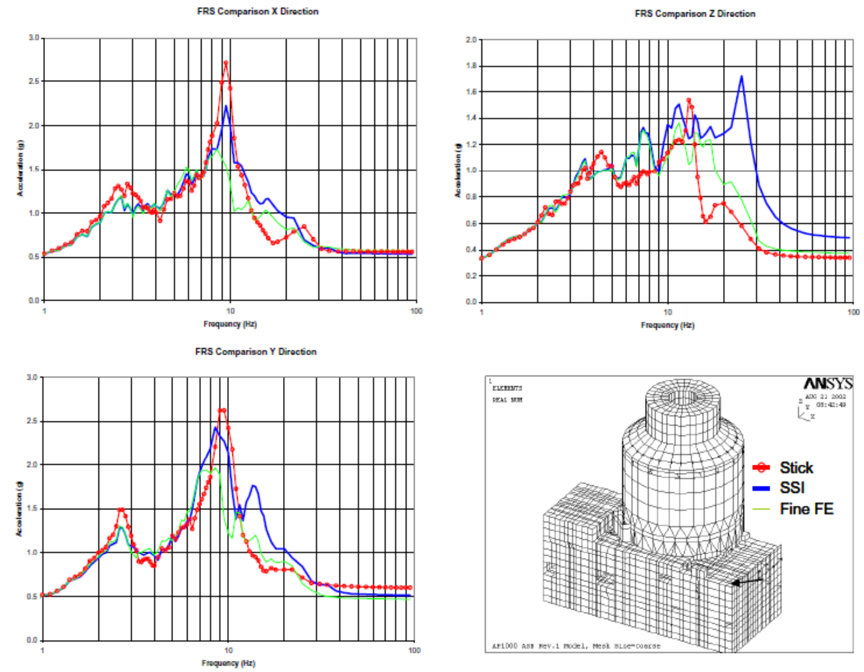


Figure 8: FRS results at Northeast corner of Auxiliary Building

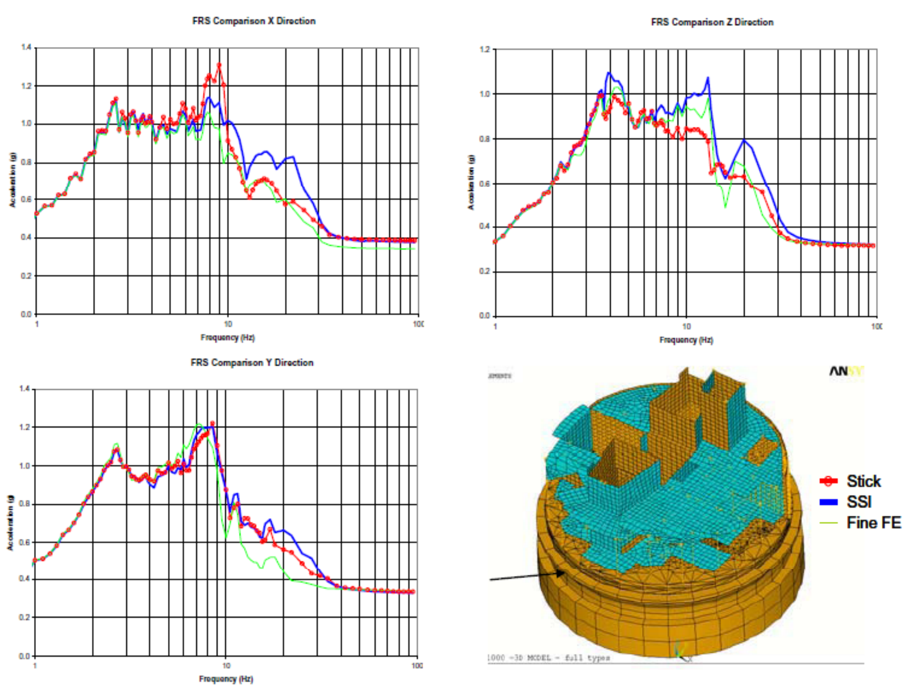


Figure 9: FRS results at CIS and Shield Building cylindrical wall interface

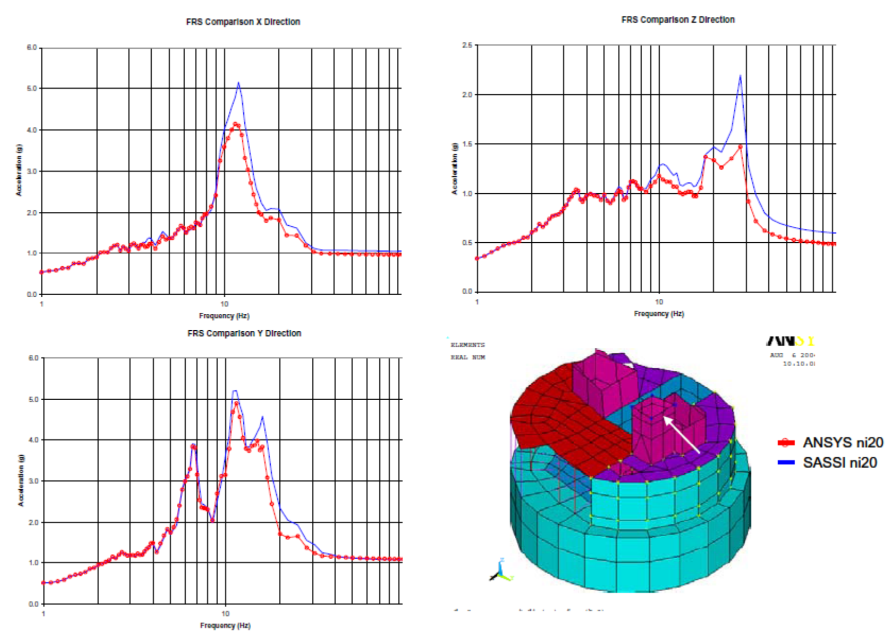


Figure 11: ANSYS vs SASSI FRS comparisons at Top of Pressurizer compartment

Seismic Analysis

- Modeling of Structures - Structural Material Properties
  - Modulus of elasticity for concrete (ACI code) , steel (29,000 ksi), aluminum (10,000 ksi)
  - Poisson's ratio for concrete (0.17) , steel (0.3), aluminum (0.3)
  - Damping

TABLE 3.1-1. Modal Damping Ratios[a]

Structure Type	Stress Level 1	Stress Level 2
Welded aluminum structures	0.02	0.04
Welded and friction-bolted steel structures	0.02	0.04
Bearing-bolted steel structures	0.04	0.07
Prestressed concrete structures	0.02	0.05
Reinforced concrete structures	0.04	0.07

[a]Fraction of critical damping.

Seismic Analysis

- Modeling of Structures
  - Stiffness
    - Steel and aluminum
    - Concrete (cracked or un-cracked)
  - Mass
    - Discretization
    - Modal mass to include all tributary mass such as fixed equipment, piping, etc.
  - Damping
    - Superposition of properties for a system of subsystems

Seismic Analysis

Modeling of hydrodynamic effects

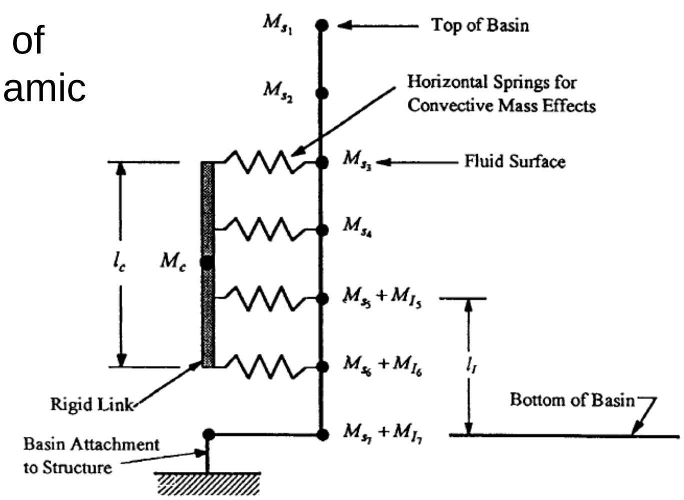


FIGURE 3.1-1. Distribution of Fluid Mass for Horizontal Seismic Response Analysis of Basins with Flexible Walls and/or Local Stress Problems

Seismic Analysis

Dynamic coupling criteria

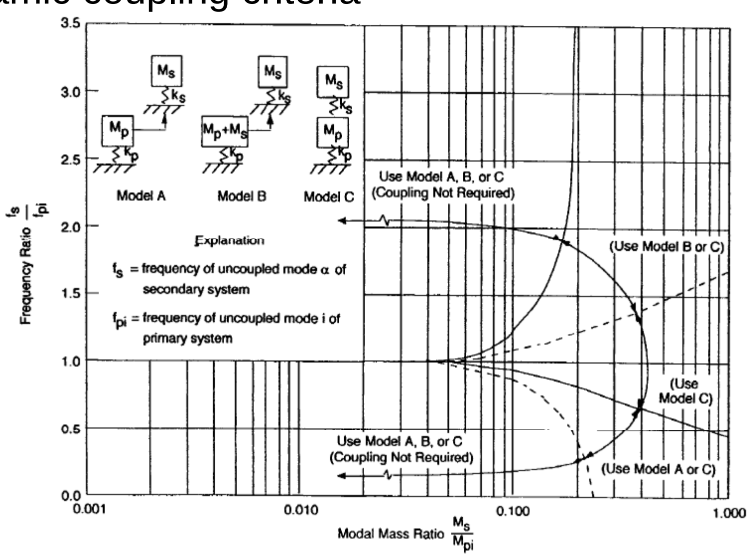


FIGURE 3.1-2. Decoupling Criteria for Secondary Systems with Single-Point Attachment to the Primary System

Seismic Analysis

- Requirements for Modeling Specific Structures
  - Structures with rigid floors
    - Degrees of freedom
    - Model type, e.g., lumped sum mass
  - Structures with flexible floors
  - Framed structures
  - Shear-wall structures
  - Plate and shell structures
  - Adjacent structures (spacing requirements)

Seismic Analysis

- Analysis of Structures
  - Time history method
  - Response spectrum method
  - Complex frequency response method
  - Equivalent static load method
- Three orthogonal components
  - Two horizontal
  - One vertical

Seismic Analysis

- Time history method: linear methods

$$[M]\{\ddot{X}\}+[C]\{\dot{X}\}+[K]\{X\}=-[M]\{U_h\}\ddot{u}_g$$

where M = mass, C = damping, K = stiffness, X = displacement, X dot = velocity, X two-dots = acceleration, U = influence vector, u = ground acceleration

- Discretization, min step size
- Solution methods
  - Modal superposition
  - Integration

TABLE 3.2-1. Maximum Time Step Size for Time History Analysis

Method	Fraction of Shortest Period of Interest
Houbolt	1/15
Newmark	1/10
Wilson θ	1/10
Nigam-Jennings	1/5

Seismic Analysis

- Approximations
  - The loads are applied directly to the structure
  - In the case of a real earthquake, displacements are applied at the foundation of the real structure

Seismic Analysis

- Time history method
- Sources of nonlinearities
  - Materials
  - Geometries

Seismic Analysis

- Response spectrum method
  - Linear methods
  - Nonlinear methods
- Complex frequency response method
  - Response time history
  - Transfer functions (ratios of Fourier transform of response to Fourier transform of input)
- Equivalent static load method
  - Cantilever model with uniform mass distribution

Soil-Structure Interaction (SSI)

- Soil-structure interaction modeling and analysis
  - Required for structures not supported by rock or rock-like soil foundation material
  - Two methods
    - Direct method
    - Impedance function approach
  - Fixed-base analysis

Soil-Structure Interaction (SSI)

- Fixed-base analysis (nonlinearity, uncertainties)

TABLE 3.3-1. Lumped Representation of Structure-Foundation Interaction at Surface for Circular Base

Motion	Equivalent Spring Constant	Equivalent Damping Coefficient
Horizontal	$k_x = \frac{32(1-\nu)GR}{7-8\nu}$	$c_x = 0.576 k_x R\sqrt{\rho/G}$
Rocking	$k_\Psi = \frac{8GR^3}{3(1-\nu)}$	$c_\Psi = \frac{0.30}{1+B_\Psi} k_\Psi R\sqrt{\rho/G}$
Vertical	$k_z = \frac{4GR}{1-\nu}$	$c_z = 0.85 k_z R\sqrt{\rho/G}$
Torsion	$k_t = 16GR^3/3$	$c_t = \frac{\sqrt{k_t I_t}}{1+2I_t/\rho R^5}$

Notes: ν = Poisson's ratio of foundation medium; G = shear modulus of foundation medium; R = radius of circular basemat; ρ = mass density of foundation medium; $B_\Psi = 3(1-\nu)I_o/8\rho R^5$; I_o = total mass moment of inertia of structure and basemat about the rocking axis at the base; and I_t = polar mass moment of inertia of structure and basemat.

Soil-Structure Interaction (SSI)

- Fixed-base analysis (nonlinearity, uncertainties)

TABLE 3.3-3. Lumped Representation of Structure-Foundation Interaction at Surface for Rectangular Base

Motion	Equivalent Spring Constant	Equivalent Damping Coefficient
Horizontal	$k_x = 2(1+\nu)G\beta_x\sqrt{BL}$	Use the results for circular base with the following equivalent radius R:
Rocking	$k_\psi = \frac{G}{1-\nu}\beta_\psi BL^2$	
Vertical	$k_z = \frac{G}{1-\nu}\beta_z\sqrt{BL}$	(1) $R = \sqrt{BL/\pi}$ for translation
Torsion	Use Table 3.3-1 with $R = \sqrt[4]{BL(B^2+L^2)/6\pi}$	(2) $R = \sqrt[4]{BL^3/3\pi}$ for rocking

Note: ν and G are as defined previously; B = width of the basemat perpendicular to the direction of horizontal excitation; L = length of basemat in the direction of horizontal excitation; β_x, β_ψ, β_z = constants that are functions of the dimensional ratio, L/B [see Fig. 3.3-3 (after Richart et al., 1970)].

Soil-Structure Interaction (SSI)

- Subsurface material properties
  - Shear modulus
  - Horizontal damping ratio
  - Poisson's ratio

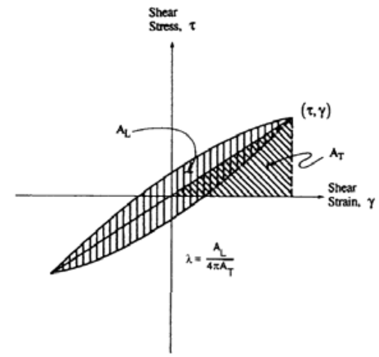


FIGURE 3.3-2. Definition Diagram for Hysteretic Damping Ratio

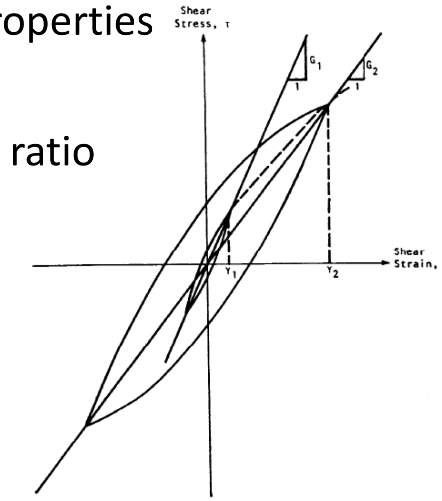


FIGURE 3.3-1. Definition Diagram for Shear Modulus, G

Shear Modulus

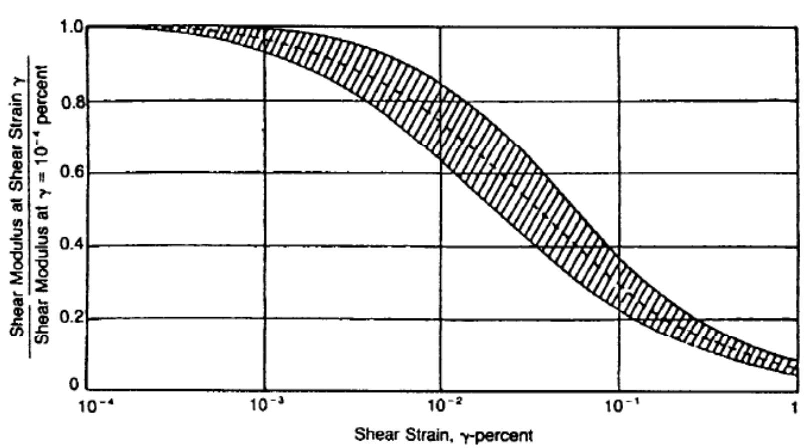


FIGURE C3.3-1. Variation of Shear Modulus with Shear Strain for Sands (From Ref. [C3.3-7])

Damping Ratio

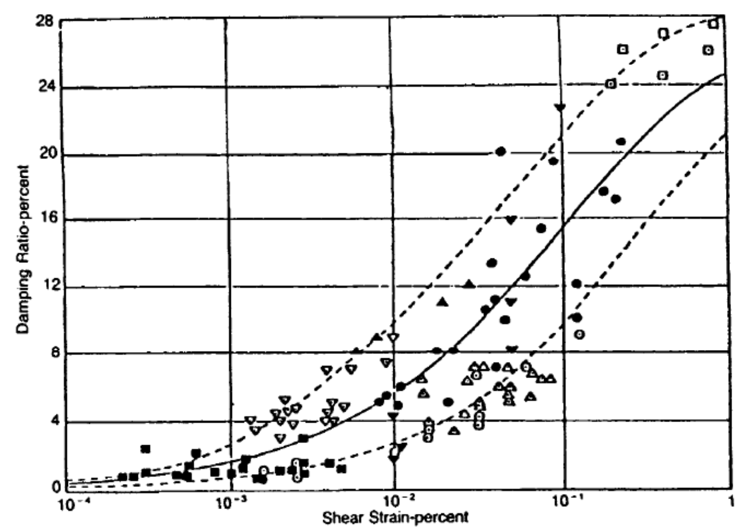


FIGURE C3.3-2. Typical Damping Ratios for Sand (from Ref. [C3.3-7])

Damping Stiffness

TABLE C3.3-1. Ratio of Embedded to Surface Stiffnesses and Damping Coefficients for Circular Footings with Embedment Ratio, *H/R*

Motion	Damping Stiffness Ratios	Coefficient Ratios
Horizontal	$1 + 1.3H/R$	$1 + 3.36H/R$
Rocking	$1 + 3.2H/R$	$1 + 4.2H/R + 8.2(H/R)^3$
Vertical	$1 + 0.8H/R$	$1 + 0.99H/R$
Torsion	$1 + 2.8H/R$	$1 + 0.77H/R$

Note: in which H = embedment depth; R = radius of the circular basemat.

Soil-Structure Interaction (SSI)

- Direct method, steps:
  - Locate the bottom and lateral boundaries of the SSI model
  - Establish input motion at the boundaries
- Soil element size
- Time step and frequency increment

Soil-Structure Interaction (SSI)

- Impedance method, steps:
  - Determine the input motion to the mass-less rigid foundation
  - Determine the foundation impedance (defined as force-resistance to motion measured as velocity) function
  - Analyze the coupled soil-structure system
- Impedance function can be determined using
  - Equivalent dimensions for mat foundations
  - Equivalent impedance for layered soil sites
  - Approximations relating to embedded foundations
- Analysis of coupled soil-structural system

Soil-Structure Interaction (SSI)

- Input for sub-system seismic analysis
  - Generation of seismic input for all systems and components which are not specifically modeled in the main dynamic model
- In-structure response spectra
  - Time history method
  - Frequency intervals
  - Uncertainties and interpolation
- In-structure time history

In Structure Response

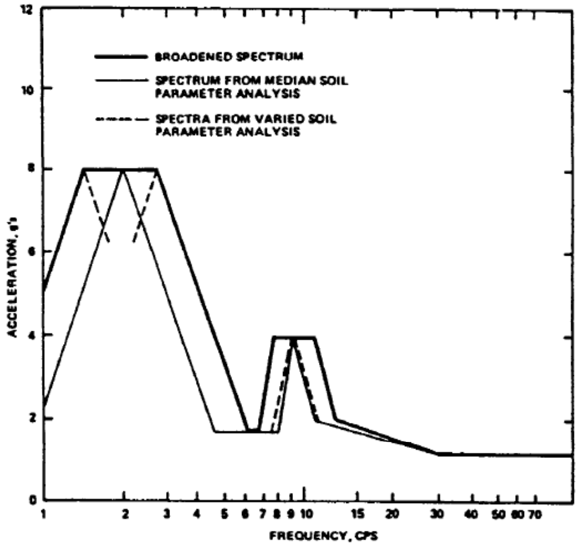


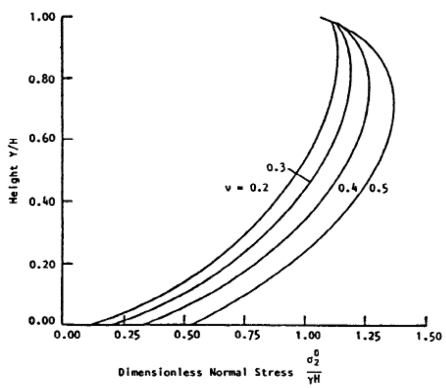
FIGURE C3.4-1. Broadened In-Structure Response Spectrum

Special Structures

- Buried pipes and conduits
- Earth-retaining walls
- Above ground vertical tanks
- Raceways including cable trays and conduit systems
- Base isolated structures

Special Structures

- Earth-retaining walls



Explanation

H = embedment height
Y = distance from base of retaining structure
γ = soil unit weight
υ = Poisson's ratio
σ_2^o = lateral dynamic soil pressure against the retaining structure for 1.0g horizontal earthquake acceleration

FIGURE 3.5-1. Variation of Normal Dynamic Soil Pressures for the Elastic Solution

Damping of Conduits

TABLE C3.5-1. Damping of Conduit Systems Based on Test

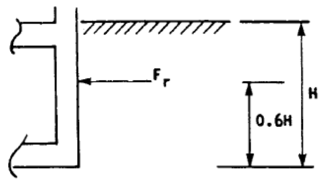
Input Motion	Support Type	Cable Fill	Damping
ZPA = 0.1 g	Rigid Clamp	100%	2.5%
ZPA = 0.1 g	Rigid Clamp	10%–40%	5%
ZPA = 0.5–1.5 g	Rigid Clamp	10%–40%	7%–8%
ZPA = 0.2–0.3 g	Strut Hanger	100%	9%–13%

Special Structures

- Earth-retaining walls

$$F_r = \alpha_h C_\upsilon \gamma H^2$$

$$M_r = \alpha_h D_\upsilon \gamma H^3$$



F_r	=	resultant force associated with dynamic soil pressure distribution shown in Fig. 3.5-1
M_r	=	resultant overturning moment about base of retaining structure for pressure distribution in Fig. 3.5-1
α_h	=	horizontal earthquake acceleration (g)
γ	=	soil unit weight
H	=	embedment height
υ	=	Poisson's ratio
C_υ, D_υ	=	coefficients as a function of Poisson's ratio

υ	C_υ	D_υ
0.5	1.13	0.67
0.4	1.04	0.63
0.3	0.94	0.56
0.2	0.87	0.52

FIGURE 3.5-2. Resultant Force and Overturning Moment for Elastic Solution Dynamic Soil Pressures

Special Structures

TABLE 3.5-2. Raceway Modal Damping Values[a]

Raceway Type	Stress Level 1	Stress Level 2
Steel or aluminum conduit systems	.05	.07
Welded steel or aluminum cable tray systems	.05	.10
Bolted steel or aluminum cable tray systems	.07	.15

[a]Fraction of critical damping.

Seismic Probabilistic Risk Assessment (SPRA)

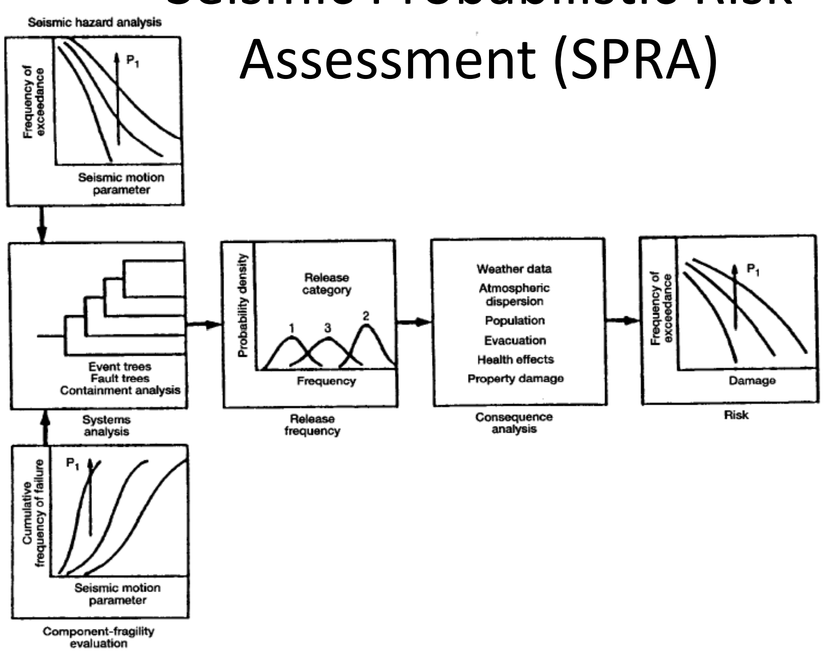


FIGURE A-1. Overview of Seismic Risk Analysis

Seismic Probabilistic Risk Assessment (SPRA)

TABLE A-1. Parameters Considered in Fragility Analysis

- Structures
  - Capacity
    - Strength (yield or ultimate)
    - Inelastic energy absorption
  - Response
    - Ground response spectra
    - Soil-structure interaction (including deconvolution and incoherence)
    - Damping
    - Frequency
    - Mode shape
    - Mode combination
    - Earthquake direction combination
- Equipment
  - Equipment capacity
  - Building structure response
  - Equipment response
    - Damping
    - Frequency
    - Mode shape
    - Modal combination
    - Earthquake direction combination

Seismic Probabilistic Risk Assessment (SPRA)

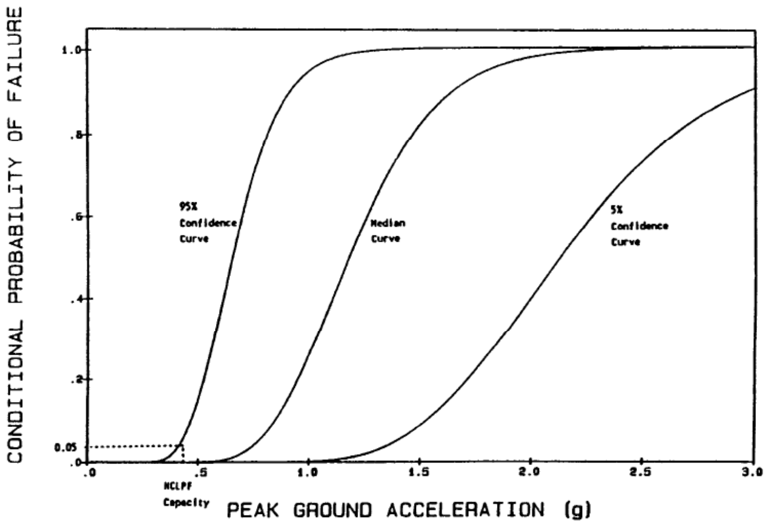


FIGURE A-2. Typical Fragility Curves for a Component

Seismic Probabilistic Risk Assessment (SPRA)

TABLE A-2. Summary of Conservative Deterministic Failure Margin Approach

Load combination	Normal + SME
Ground response spectrum	Conservative specified (84% Nonexceedance probability)
Damping	Conservative estimate of median damping
Structural model	Best estimate (median) + uncertainty variation in frequency
Soil-structure-interaction	Best estimate (median) + parameter variation
Material strength	Code specified minimum strength or 95% exceedance actual strength if test data are available.
Static capacity equations	Code ultimate strength (ACI), maximum strength (AISC), Service Level D (ASME), or functional limits. If test data are available to demonstrate excessive conservatism of code equations, then use a value exceeded by 84% of test data for capacity equation.
Inelastic energy absorption	For non-brittle failure modes and linear analysis, use 80% of computed seismic stress in capacity evaluation to account for ductility benefits, or perform nonlinear analysis and go to 95% exceedance ductility levels.
In-structure (floor) spectra generation	Use frequency shifting rather than peak broadening to account for uncertainty plus use median damping.

SMA = Seismic Margin Earthquake
(larger than the design basis)

Seismic Probabilistic Risk Assessment (SPRA)

TABLE A-6. Four Approaches for Specifying Seismic Margin Earthquake

Approach	Advantages	Disadvantages
Specify peak ground acceleration (PGA) and an 84% NEP response spectrum such as from NUREG/CR-0098, NRC Regulatory Guide 1.60, or as given in this Standard.	The HCLPF is conditional on only the PGA values not being exceeded.	The resultant response spectrum does not have a uniform annual frequency of exceedance over all dynamic frequencies (i.e., more conservatism at the lower frequencies, i.e., 2 to 10 Hz).
Specify the SME in terms of a uniform annual frequency of exceedance response spectrum (UHS) shape (i.e., mean or 84% NEP level).	The HCLPF is conditional on the specified earthquake conditions.	The SMA and the seismic hazard assessment are tied together. Also, the UHS reflect uncertainty in the underlying seismological parameter as well as the randomness in ground motion response.
Specify the input in terms of an 84% NEP response spectrum for specified earthquake magnitude and distance range.	The HCLPF is conditional on the specified earthquake conditions.	This alternative is less useful than the previous alternative for inferring plant seismic risk.
Specify a generic response spectrum shape anchored to a PGA.	The HCLPF is conditional on the generic standard shape anchored to the SME level PGA not being exceeded at more than 16% of the natural frequencies in the frequency range and direction of interest. No seismic hazard information is required at the time the SMA is performed.	Potentially, this is an inappropriate spectral shape for the site. The resultant HCLPF statement can be expressed only approximately in terms of PGA, annual frequency of exceedance, or margin scale factor over the ground motion from a specified earthquake magnitude and epicentral range.

HCLPF = High Confidence Low Probability of Failure

Seismic Probabilistic Risk Assessment (SPRA)

TABLE A-7. Modal Damping Values for Standard versus SMA[a]

Structure Type	Stress Level 1	Stress Level 2
Welded aluminum structures	0.02	0.04
Welded and friction-bolted steel structures	0.02 (0.03)[b]	0.04 (0.07)[b]
Bearing-bolted steel structures	0.04	0.07
Prestressed concrete structures	0.02 (0.03)[b]	0.05 (0.07–0.10)[b]
Reinforced concrete structures	0.04 (0.03–0.05)[b]	0.07 (0.10)[b]

Note: Use of higher damping values, if properly justified and determined, is permitted.
[a]Fraction of critical damping.
[b]SMA values from ref. [A14] are shown in parentheses.

SMA = Seismic Margin Assessment

Load Factors and Load Combinations

- Normal Loads: encountered during normal plant start-up, operation, and shutdown

ANSI/AISC N690-06

D = dead loads due to the weight of the structural elements, fixed-position equipment, and other permanent appurtenant items; weight of crane trolley and bridge

L = live load due to occupancy and moveable equipment, including impact

L_r = roof live load

R = rain load

R_o = pipe reactions during normal operating, start-up, or shutdown conditions, based on the most critical transient or steady-state condition

S = snow load as stipulated in *Minimum Design Loads for Buildings and Other Structures* (SEI/ASCE 7) for Category IV facilities

T_o = thermal effects and loads during normal operating, start-up, or shutdown conditions, based on the most critical transient or steady-state condition

C = rated capacity of crane (shall include the maximum wheel loads of the crane and the vertical, lateral, and longitudinal forces induced by the moving crane)

Load Factors and Load Combinations

- Severe Environmental Loads: encountered infrequently during the service life

ANSI/AISC N690-06

E_o = where required as part of the design basis, loads generated by the *operating basis earthquake* (OBE) as defined in the Nuclear Regulatory Commission document, "Earthquake Engineering Criteria for Nuclear Power Plants, Appendix S, 10 CFR, Part 50," or as specified by the *authority having jurisdiction* (AHJ)

W = wind load as stipulated in SEI/ASCE 7 for Category IV facilities, or as specified by the AHJ

Load Factors and Load Combinations

ANSI/AISC N690-06

- Extreme Environmental Loads: highly improbable but are used as a design basis

E_s = loads generated by the *safe shutdown*, or *design basis earthquake,* as defined in the Nuclear Regulatory Commission document, "Earthquake Engineering Criteria for Nuclear Power Plants, Appendix S, 10 CFR, Part 50, or as specified by the AHJ"

W_t = loads generated by the *specified design tornado*, including wind pressures, pressure differentials, and *tornado-borne missiles,* as defined in US Nuclear Regulatory Commission Standard Review Plan 3.3.2 (NUREG-0800) or as specified by the AHJ

Load Factors and Load Combinations

ANSI/AISC N690-06

- Abnormal Loads: generated by a postulated high-energy pipe break accident used as a design basis

P_a = maximum differential pressure load generated by the postulated accident

T_a = thermal loads generated by the postulated accident, including T_o

R_a = pipe and equipment reactions generated by the postulated accident, including R_o

Y_r = loads on the structure generated by the reaction of the broken high-energy pipe during the postulated accident

Y_j = *jet impingement load* generated by the postulated accident

Y_m = *missile impact* load, such as pipe whipping generated by or during the postulated accident

Load Factors and Load Combinations

ANSI/AISC N690-06

- Load and Resistance Factor Design (LRFD)
  - The design strength (ϕR_n) *of each structural component shall be equal to or* greater than the required strength (R_u)*, determined from the appropriate critical* combinations of the loads
  - The most critical structural effect may occur when one or more loads are not acting

Load Factors and Load Combinations

ANSI/AISC N690-06

- LRFD Normal Load Combinations

$$1.4(D + R_o) + T_o + C$$

$$1.2(D + R_o) + 1.6L + 1.4C + 0.5(L_r \text{ or } S \text{ or } R) + 1.2T_o$$

$$1.2(D + R_o) + 1.6(L_r \text{ or } S \text{ or } R) + 0.8L + 1.4C + 1.2T_o$$

Load Factors and Load Combinations

ANSI/AISC N690-06

- LRFD Severe Load Combinations

$$1.2(D + R_o) + 1.6W + 0.8L + C + 0.5(L_r \text{ or } S \text{ or } R) + T_o$$

$$1.2(D + R_o) + 1.6E_o + 0.8L + C + 0.2(L_r \text{ or } S \text{ or } R) + T_o$$

- LRFD Extreme and Abnormal Load Combinations

$$D + 0.8L + C + T_o + R_o + E_s$$

$$D + 0.8L + T_o + R_o + W_t$$

$$D + 0.8L + C + 1.2P_a + R_a + T_a$$

$$D + 0.8L + (P_a + R_a + T_a) + (Y_r + Y_j + Y_m) + 0.7E_s$$

Load Factors and Load Combinations

ANSI/AISC N690-06

- Allowable Stress Design (ASD)
  - The allowable strength *(R/Ω) of each structural component shall be equal to* or greater than the required strength (R_a)*, determined from the appropriate* critical combinations of the loads
  - The most critical structural effects may occur when one or more loads are not acting

Load Factors and Load Combinations

ANSI/AISC N690-06

- ASD Normal Load Combinations

$$D + L + R_o + T_o + C$$

$$D + (L_r \text{ or } S \text{ or } R) + R_o + T_o + C$$

$$D + 0.75L + 0.75(L_r \text{ or } S \text{ or } R) + T_o + C$$

Load Factors and Load Combinations

ANSI/AISC N690-06

- ASD Severe Load Combinations

$$D + R_o + W + 0.75L + C + 0.75(L_r \text{ or } S \text{ or } R) + T_o$$

$$D + R_o + E_o + 0.75L + C + 0.75(L_r \text{ or } S \text{ or } R) + T_o$$

- LRFD Extreme and Abnormal Load Combinations

$$D + L + C + R_o + T_o + E_s$$

$$D + L + R_o + T_o + W_t$$

$$D + L + C + P_a + R_a + T_a$$

$$D + L + P_a + R_a + T_a + Y_r + Y_j + Y_m + 0.7E_s$$

4000. Loads, Load Factors, and Load Combinations

- Minimum Design Loads for Buildings and Other Structures [ASCE Standard 7-05]
- Seismic Analysis of Safety-Related Nuclear Structures and Commentary [ASCE Standard 4-98]
- Design Loads on Structures During Construction [ASCE Standard 37-02]

Design Loads on Structures During Construction [ASCE Standard 37-02]

- General
  - Purpose: Minimum design load requirements during construction
  - Scope: Partially completed structures and temporary structures
  - Basic Requirements:
    - Safety
    - Structural integrity
    - Serviceability
    - Load types
    - Construction methods

Design Loads on Structures During Construction [ASCE Standard 37-02]

- Loads and Load Combinations
  - Loads Specified
    - Dead and live loads
    - Construction loads (temporary structures, etc.)
    - Material loads
    - Construction procedure loads
    - Lateral earth pressure
    - Environmental loads (thermal, snow, earthquake, rain, ice)

Design Loads on Structures During Construction [ASCE Standard 37-02]

- Loads and Load Combinations
  - Load Combinations and Load Factors for Strength Design

    Combined design load = dead load and/or material load + loads at their max value + loads at their APT reduced values

  APT = arbitrary point in time

Design Loads on Structures During Construction [ASCE Standard 37-02]

- Construction Loads
  - General Requirement
  - Material Loads
  - Personnel and Equipment Load
  - Horizontal Construction Loads
  - Erection and Fitting Forces
  - Equipment Reactions
  - Form Pressure
  - Application of Loads

Design Loads on Structures During Construction [ASCE Standard 37-02]

- Basic Combinations (example)

  $1.4\ D + 1.4\ C_D + 1.2\ C_{FML} + 1.4\ C_{VML}$

  D = dead load

  C_D = construction dead load

  C_{FML} = fixed material load

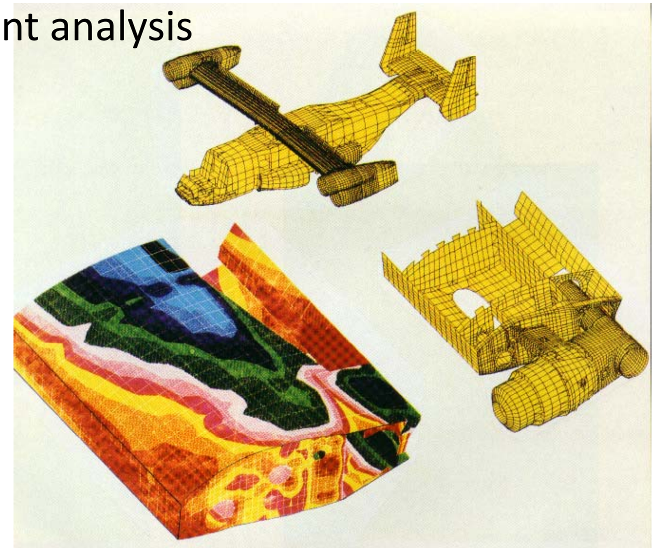
  C_{VML} = variable material load

Design Loads on Structures During Construction [ASCE Standard 37-02]

- Loads and Load Combinations
  - Overturning and sliding
  - Allowable Stress Design
  - Bridges (use AASHTO Code)

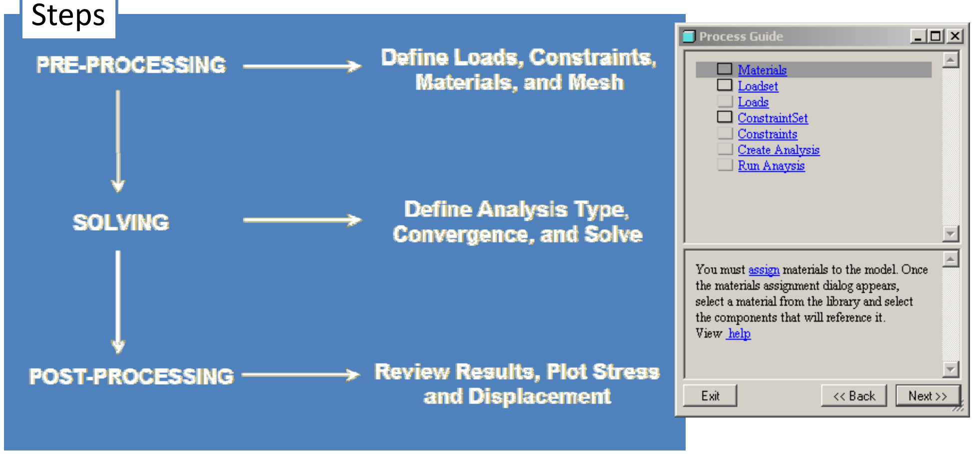
Computer Aided Analysis and Design

- Finite element analysis
- Software



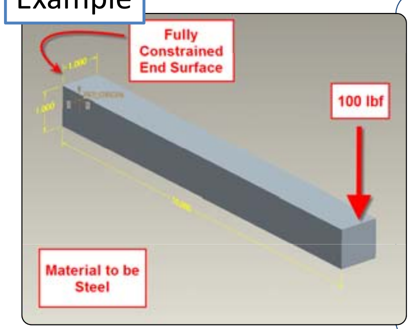
Computer Aided Analysis and Design

Steps

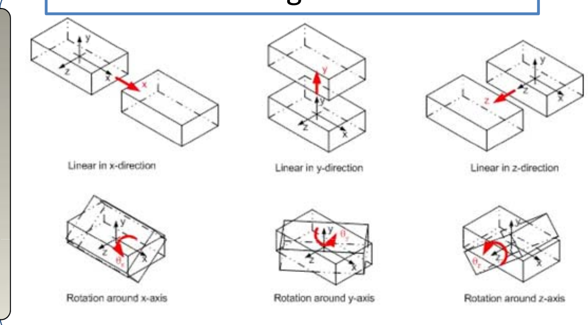


Computer Aided Analysis and Design

Example

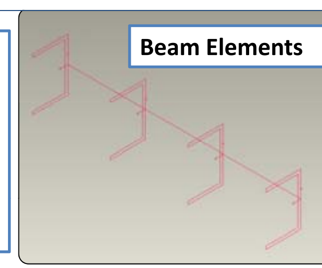


Elements and degrees of freedom



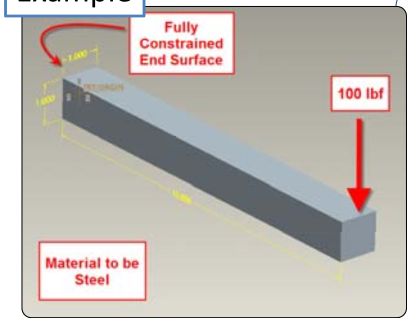
- 2D or 3D point-to-point or thru curve
- 6 translational DOFs at nodes
- Shown in light blue with cross-section (Shown here in red for clarity)
- Well suited to represent beams with a 10:1 slenderness ratio

Beam Elements

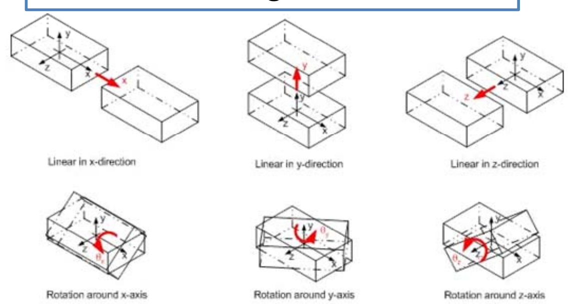


Computer Aided Analysis and Design

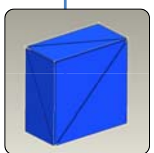
Example



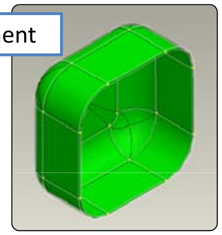
Elements and degrees of freedom



- Tetrahedral shape
- 3 translational DOFs at nodes
- Rotational constraints not required
- Shown in blue
- Ideal for solid bodies with large cross-sectional areas
- Not well suited for thin bodies

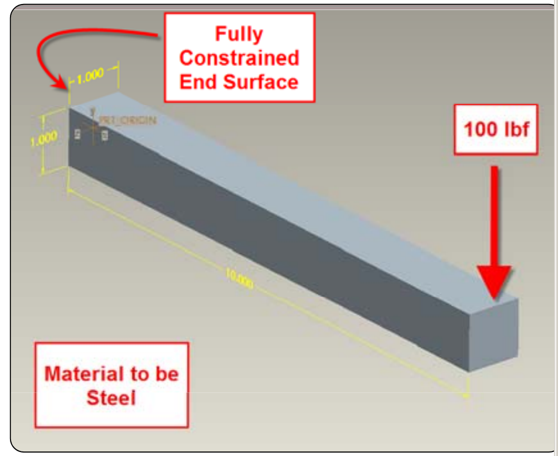


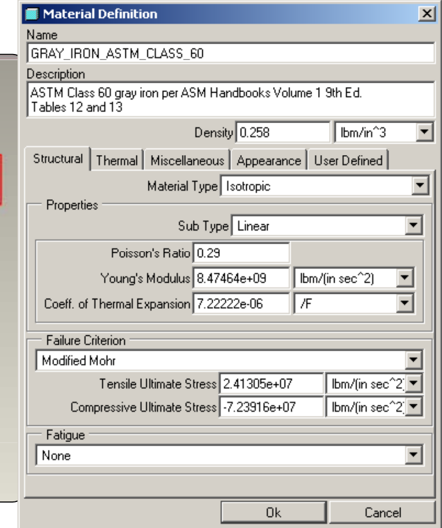
Shell element



Computer Aided Analysis and Design

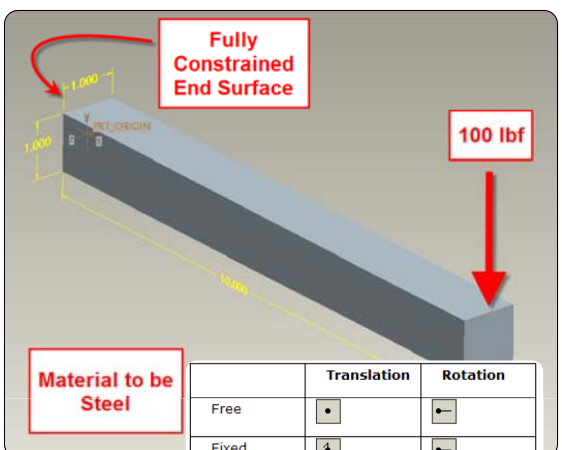
Materials



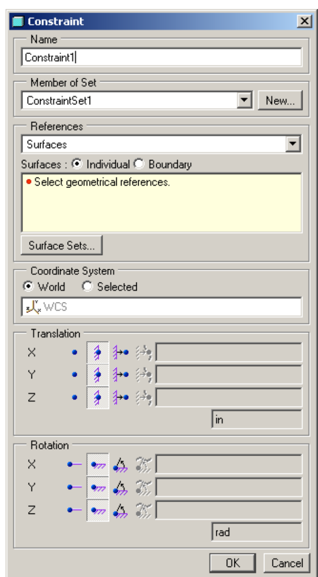


Computer Aided Analysis and Design

Constraints

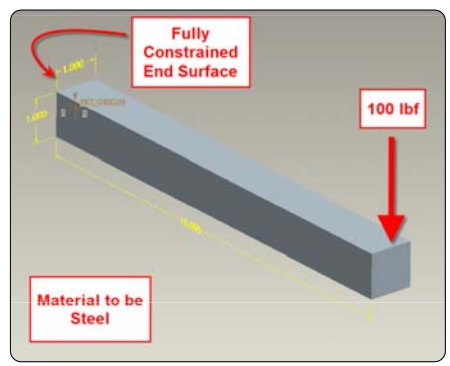


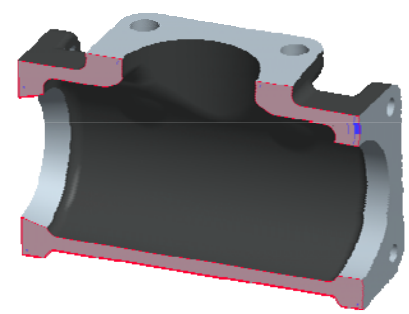
	Translation	Rotation
Free		
Fixed		
Prescribed		



Computer Aided Analysis and Design

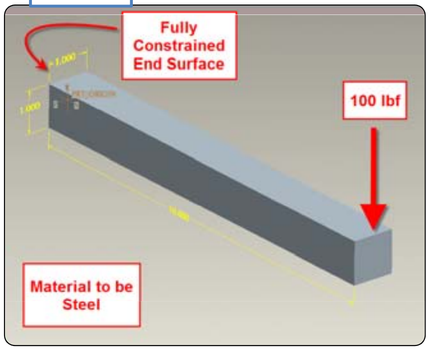
Symmetry constraints

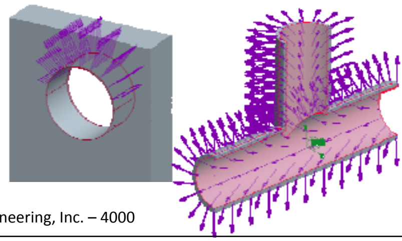


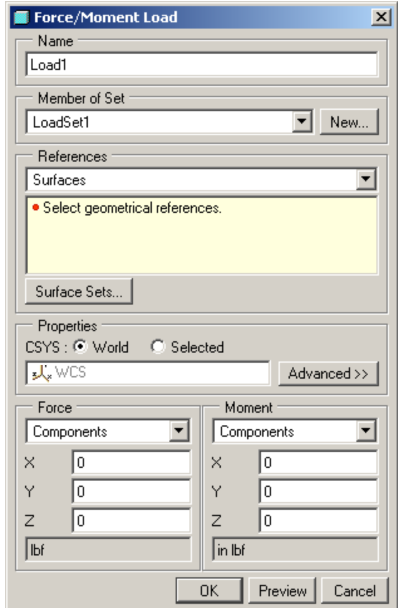


Computer Aided Analysis and Design

Loads

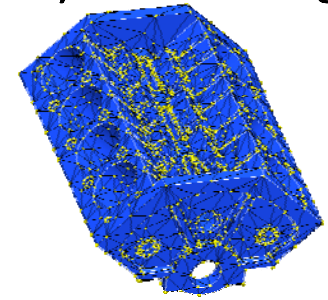


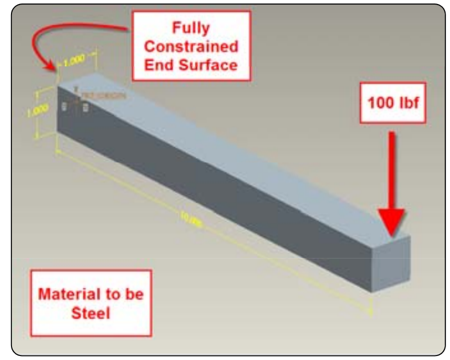


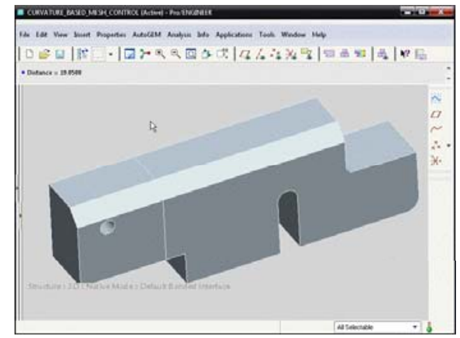


Computer Aided Analysis and Design

Mesh and control

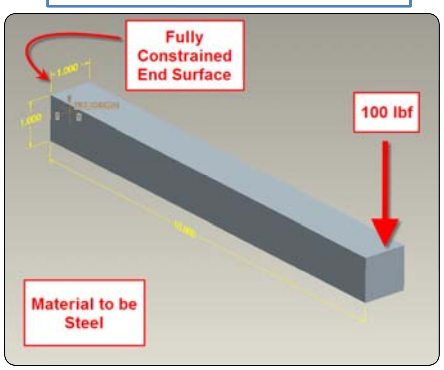


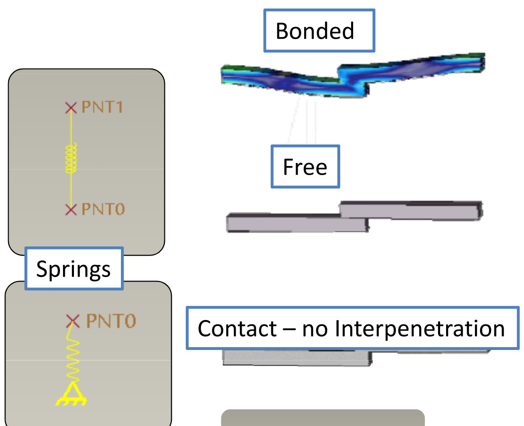




Computer Aided Analysis and Design

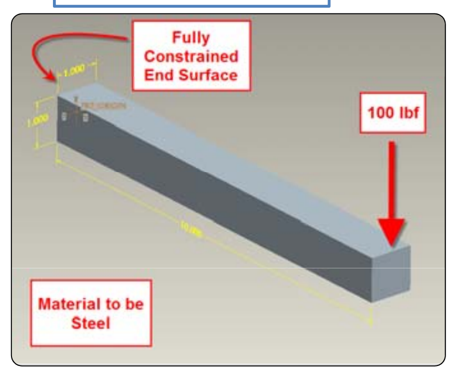
Connections and Springs

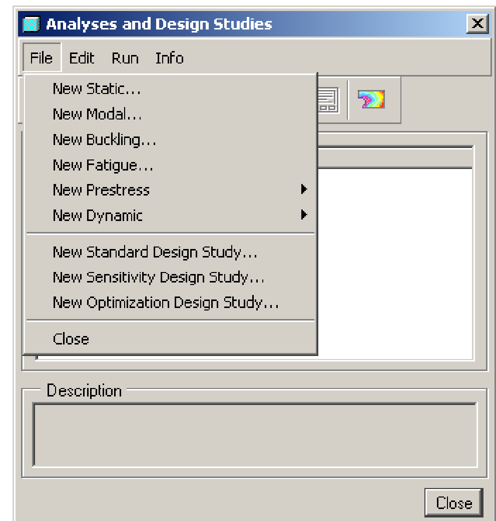




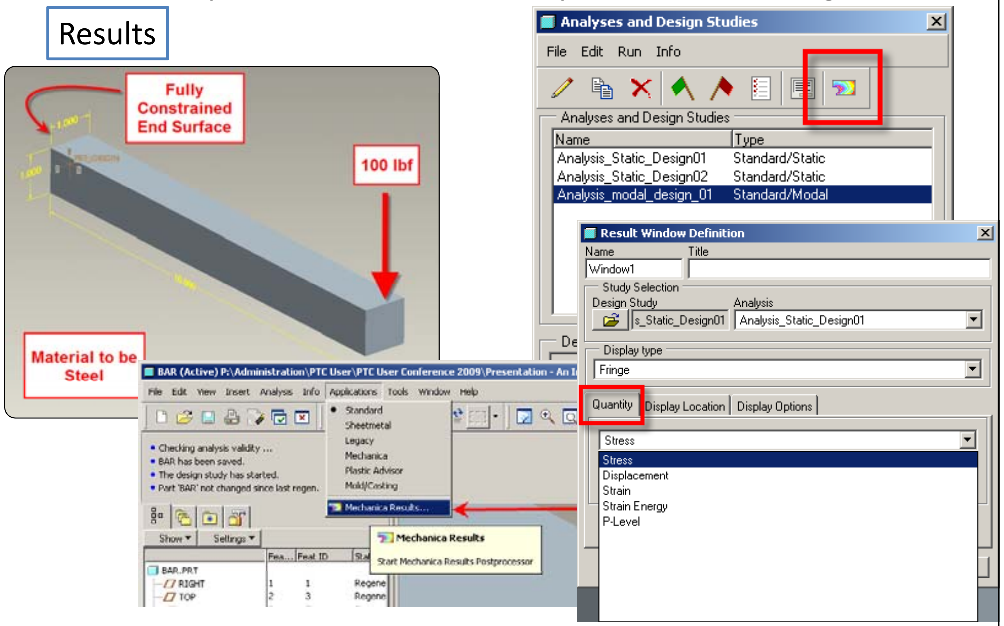
Computer Aided Analysis and Design

Analysis definition

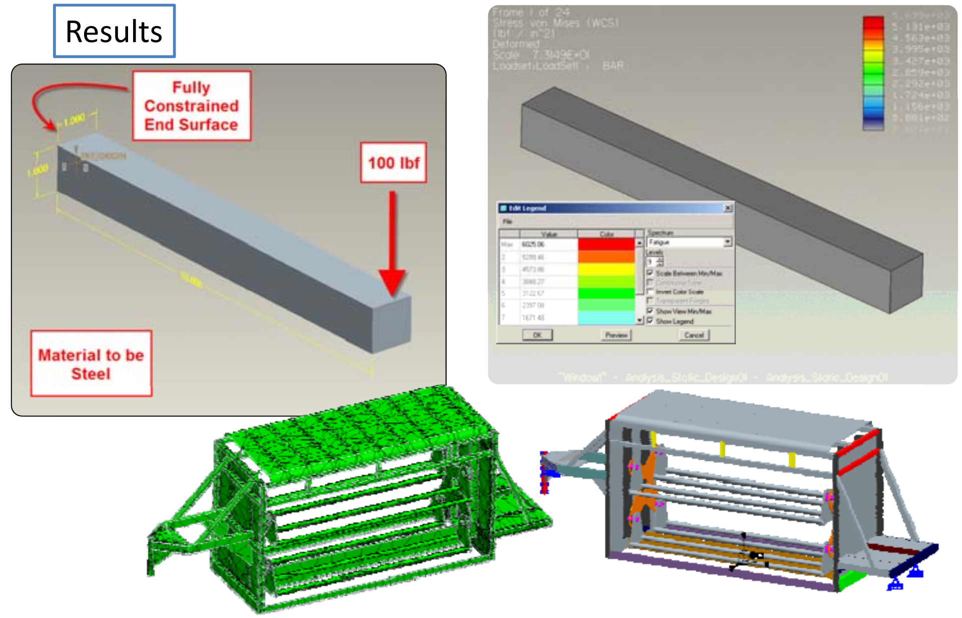




Computer Aided Analysis and Design



Computer Aided Analysis and Design



Open source software (source Wikipedia)

Computer Aided Analysis and Design

- CalculiX is an Open Source FEA project. The solver uses a partially compatible ABAQUS file format. The pre/post-processor generates input data for many FEA and CFD applications
- Code Aster: French software written in Python and Fortran, GPL license
- DUNE, Distributed and Unified Numerics Environment GPL Version 2 with Run-Time Exception, written in C++
- FEBio, Finite Elements for Biomechanics

Open source software (source Wikipedia)

Computer Aided Analysis and Design

- Elmer FEM solver: Open source multiphysical simulation software developed by Finnish Ministry of Education's CSC, written in C, C++ and Fortran
- FEniCS Project: a LGPL-licensed software package developed by American and European researchers
- Hermes Project: Modular C/C++ library for rapid prototyping of space- and space-time adaptive hp-FEM solvers

Open source software (source Wikipedia)

Computer Aided Analysis and Design

- Impact: Dynamic Finite Element Program Suite, for dynamic events like crashes, written in Java, GNU license
- OOFEM: Object Oriented Finite EleMent solver, written in C++, GPL v2 license
- OpenSees is an Open System for Earthquake Engineering Simulation
- Z88: FEM-software available for Windows and Linux/UNIX, written in C, GPL license

Commercial software (source Wikipedia)

Computer Aided Analysis and Design

- Abaqus: Franco-American software from SIMULIA, owned by Dassault Systemes
- ADINA
- ALGOR Incorporated
- ANSA: An advanced CAE pre-processing software for complete model build up.
- ANSYS: American software
- COMSOL Multiphysics COMSOL Multiphysics Finite Element Analysis Software formerly Femlab

Commercial software (source Wikipedia)

Computer Aided Analysis and Design

- Femap, Siemens PLM Software: A pre and post processor for Windows
- FlexPDE
- Flux : American electromagnetic and thermal FEA
- JMAG: Japanese software Actran: Belgian Software (Acoustic)
- LS-DYNA, LSTC - Livermore Software Technology Corporation
- LUSAS: UK Software

Commercial software (source Wikipedia)

Computer Aided Analysis and Design

- MADYMO: TASS - TNO Automotive Safety Solutions
- Nastran: American software
- nastran/EM: Nastran Suit for highly advanced Durabilty & NVH Analyses of Engines; born from the AK32 Benchmark of Audi, BMW, Daimler, Porsche & VW; Source Code available
- NEi Fusion, NEi Software: 3D CAD modeler + Nastran FEA

Commercial software (source Wikipedia)

Computer Aided Analysis and Design

- NEi Nastran, NEi Software: General purpose Finite Element Analysis
- NEi Works, NEi Software: Embedded Nastran for SolidWorks users
- NISA: Indian software
- PZFlex: American software for wave propagation and piezoelectric devices
- Quickfield : Physics simulating software
- Radioss: A linear and nonlinear solver owned by Altair Engineering

Commercial software (source Wikipedia)

Computer Aided Analysis and Design

- Range Software: Multiphysics simulation software
- RFEM
- SAMCEF: CAE package developed by the Belgian company
- SAP2000: American software
- STRAND7: Developed in Sydney Australia by Strand7 Pty. Ltd. Marketed as Straus7 in Europe

Commercial software (source Wikipedia)

Computer Aided Analysis and Design

- StressCheck developed by ESRD, Inc USA
- Vflo™: Physics-based distributed hydrologic modeling software, developed by Vieux & Associates, Inc.
- Zébulon: French software

4000. Loads, Load Factors, and Load Combinations

- Objective and Scope Met
  - Introduce loads, load factors, and load combinations for nuclear-related civil & structural design and construction
  - Present and discuss
    - Types of loads and their computational principles
    - Load factors
    - Load combinations
    - Focus on seismic loads
    - Computer aided analysis and design (brief)

Scope: Primary Documents Covered

- Minimum Design Loads for Buildings and Other Structures [ASCE Standard 7-05]
- Seismic Analysis of Safety-Related Nuclear Structures and Commentary [ASCE Standard 4-98]
- Design Loads on Structures During Construction [ASCE Standard 37-02]

Completed Items of Overall Outline

1000. Introduction
2000. Federal Regulations, Guides, and Reports
3000. Site Investigation
4000. Loads, Load Factors, and Load Combinations
5000. Concrete Structures and Construction
6000. Steel Structures and Construction
7000. General Construction Methods
8000. Exams and Course Evaluation
9000. References and Sources