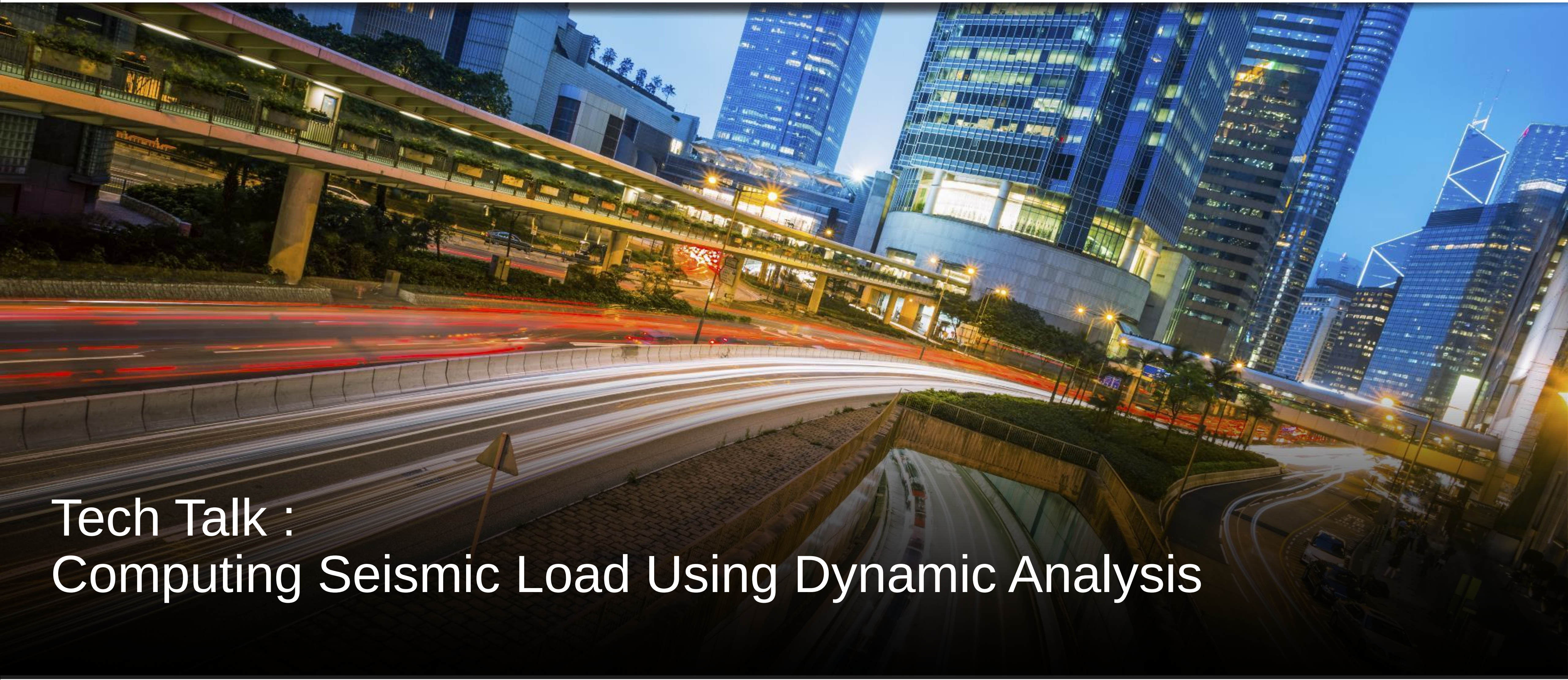

Tech Talk :
Computing Seismic Load Using Dynamic Analysis

Presenter : Sye Chakraborty, Senior Manager, Technical Support

Bentley® Advancing Infrastructure

Analysis Methods

Permitted analysis methods as per ASCE

- Equivalent Lateral Force Procedure (section 12.8)
- Modal Response Spectrum Analysis (section 12.9)
- Response History/Time History (Chapter 16)

Analysis Procedure Selection

Table 12.6-1 Permitted Analytical Procedures

Seismic Design Category	Structural Characteristics	Equivalent Lateral Force Analysis, Section 12.8[a]	Modal Response Spectrum Analysis, Section 12.9[a]	Seismic Response History Procedures, Chapter 16[a]
B, C	All structures	P	P	P
D, E, F	Risk Category I or II buildings not exceeding 2 stories above the base	P	P	P
	Structures of light frame construction	P	P	P
	Structures with no structural irregularities and not exceeding 160 ft in structural height	P	P	P
	Structures exceeding 160 ft in structural height with no structural irregularities and with $T < 3.5T_s$	P	P	P
	Structures not exceeding 160 ft in structural height and having only horizontal irregularities of Type 2, 3, 4, or 5 in Table 12.3-1 or vertical irregularities of Type 4, 5a, or 5b in Table 12.3-2	P	P	P
	All other structures	NP	P	P

[a]P: Permitted; NP: Not Permitted; $T_s = S_{D1}/S_{DS}$.

Risk Category

Table 1.5-1 Risk Category of Buildings and Other Structures for Flood, Wind, Snow, Earthquake, and Ice Loads

Use or Occupancy of Buildings and Structures	Risk Category
Buildings and other structures that represent a low risk to human life in the event of failure	I
All buildings and other structures except those listed in Risk Categories I, III, and IV	II
Buildings and other structures, the failure of which could pose a substantial risk to human life. Buildings and other structures, not included in Risk Category IV, with potential to cause a substantial economic impact and/or mass disruption of day-to-day civilian life in the event of failure. Buildings and other structures not included in Risk Category IV (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, hazardous waste, or explosives) containing toxic or explosive substances where their quantity exceeds a threshold quantity established by the authority having jurisdiction and is sufficient to pose a threat to the public if released.	III
Buildings and other structures designated as essential facilities. Buildings and other structures, the failure of which could pose a substantial hazard to the community. Buildings and other structures (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, or hazardous waste) containing sufficient quantities of highly toxic substances where the quantity exceeds a threshold quantity established by the authority having jurisdiction to be dangerous to the public if released and is sufficient to pose a threat to the public if released.[a] Buildings and other structures required to maintain the functionality of other Risk Category IV structures.	IV

Seismic Design Category

Table 11.6-1 Seismic Design Category Based on Short Period Response Acceleration Parameter

Value of S_{DS}	Risk Category I or II or III	Risk Category IV
$S_{DS} < 0.167$	A	A
$0.167 \le S_{DS} < 0.33$	B	C
$0.33 \le S_{DS} < 0.50$	C	D
$0.50 \le S_{DS}$	D	D

Table 11.6-2 Seismic Design Category Based on 1-S Period Response Acceleration Parameter

Value of S_{D1}	Risk Category I or II or III	Risk Category IV
$S_{D1} < 0.067$	A	A
$0.067 \le S_{D1} < 0.133$	B	C
$0.133 \le S_{D1} < 0.20$	C	D
$0.20 \le S_{D1}$	D	D

Selection of Analysis Procedure per ASCE7

Table 12.6-1 Permitted Analytical Procedures

Seismic Design Category	Structural Characteristics	Equivalent Lateral Force Analysis, Section 12.8[a]	Modal Response Spectrum Analysis, Section 12.9[a]	Seismic Response History Procedures, Chapter 16[a]
B, C	All structures	P	P	P
D, E, F	Risk Category I or II buildings not exceeding 2 stories above the base	P	P	P
	Structures of light frame construction	P	P	P
	Structures with no structural irregularities and not exceeding 160 ft in structural height	P	P	P
	Structures exceeding 160 ft in structural height with no structural irregularities and with $T < 3.5T_s$	P	P	P
	Structures not exceeding 160 ft in structural height and having only horizontal irregularities of Type 2, 3, 4, or 5 in Table 12.3-1 or vertical irregularities of Type 4, 5a, or 5b in Table 12.3-2	P	P	P
	All other structures	NP	P	P

[a]P: Permitted; NP: Not Permitted; $T_s = S_{D1}/S_{DS}$.

Structural Modeling 2D vs 3D model

Requirements in ASCE7-10 Section 12.7.3

3D model required for following situations (refer table 12.3-1)

- Horizontal structural irregularity type 1a 1b
- Type 4 Out of plane offset irregularity
- Type 5 Non-parallel system irregularity

Choice of Lateral Framing Systems

- Table 12.2-1 lists Design Coefficients & Factors

Table 12.2-1 Design Coefficients and Factors for Seismic Force-Resisting Systems

Seismic Force-Resisting System	ASCE 7 Section Where Detailing Requirements Are Specified	Response Modification Coefficient, R^a	Overstrength Factor, Ω_0^g	Deflection Amplification Factor, C_d^b	Structural System Limitations Including Structural Height, h_n (ft) Limits[c] — Seismic Design Category: B	C	D[d]	E[d]	F[e]
A. BEARING WALL SYSTEMS									
1. Special reinforced concrete shear walls[l, m]	14.2	5	2½	5	NL	NL	160	160	100
2. Ordinary reinforced concrete shear walls[l]	14.2	4	2½	4	NL	NL	NP	NP	NP

Dynamic Analysis

- Calculation of modes and frequencies from

$$\omega^2 [m] \{ q \} - [K] \{q\} = 0$$

ω= natural frequency

{q} = mode shape

[m] = mass matrix

[K] = Stiffness matrix

Mass Modeling

- All DL above base
- 25% min of LL
- Max (partition weight, 10 psf)
- Equipment
- Where Pf > 30psf, 20% of that
- Landscaping or materials at roof

12.7.2 Effective Seismic Weight

The effective seismic weight, *W*, of a structure shall include the dead load, as defined in Section 3.1, above the base and other loads above the base as listed below:

1. In areas used for storage, a minimum of 25 percent of the floor live load shall be included.

   EXCEPTIONS:

   a. Where the inclusion of storage loads adds no more than 5% to the effective seismic weight at that level, it need not be included in the effective seismic weight.
   b. Floor live load in public garages and open parking structures need not be included.

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Mass Modeling Contd …

- All masses that can vibrate should be modeled
- Should be applied in all possible directions
- Should be devoid of sign

```
LOAD 3 : DYNAMIC LOAD
SELFWEIGHT X 1
SELFWEIGHT Y 1
SELFWEIGHT Z 1
JOINT LOAD
60 FX 19 FY 19 FZ 19
MEMBER LOAD
232 UNI GX 1
232 UNI GY 1
232 UNI GZ 1
```


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Stiffness Modeling

- Cross sectional property, material, supports, releases
- Modeling of lateral force resisting systems
- Modeling of diaphragms

Number of modes

MASS PARTICIPATION FACTORS IN PERCENT

MODE	X	Y	Z	SUMM-X	SUMM-Y	SUMM-Z
1	0.00	0.00	91.14	0.000	0.000	91.140
2	0.00	0.00	7.70	0.000	0.000	98.837
3	0.00	0.00	0.00	0.000	0.000	98.837
4	86.53	0.00	0.00	86.529	0.000	98.837
5	0.00	0.00	1.16	86.529	0.000	99.999
6	0.00	0.00	0.00	86.529	0.000	99.999
7	0.00	0.00	0.00	86.529	0.000	99.999
8	0.00	0.00	0.00	86.529	0.000	99.999
9	10.80	0.00	0.00	97.333	0.000	99.999

```
CUT OFF MODE SHAPE 30
SUPPORTS
1 TO 16 FIXED
```

12.9.1 Number of Modes

An analysis shall be conducted to determine the natural modes of vibration for the structure. The analysis shall include a sufficient number of modes to obtain a combined modal mass participation of at least 90 percent of the actual mass in each of the orthogonal horizontal directions of response considered by the model.

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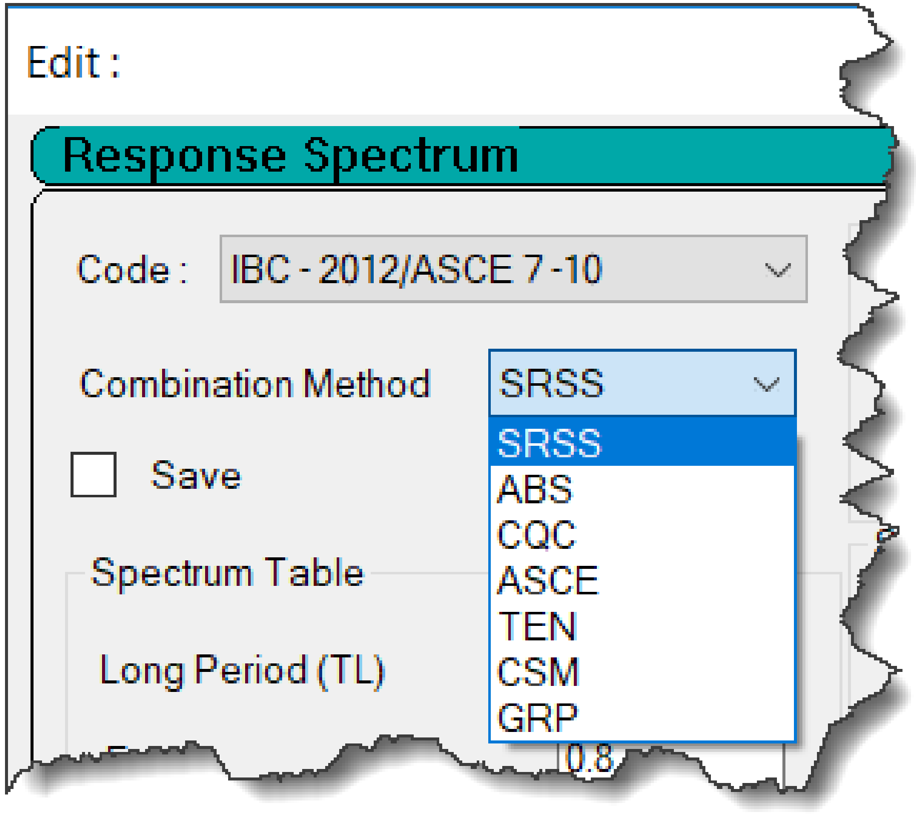
Combining Modal Responses



12.9.3 Combined Response Parameters

The value for each parameter of interest calculated for the various modes shall be combined using the square root of the sum of the squares (SRSS) method, the complete quadratic combination (CQC) method, the complete quadratic combination method as modified by ASCE 4 (CQC-4), or an approved equivalent approach. The CQC or the CQC-4 method shall be used for each of the modal values where closely spaced modes have significant cross-correlation of translational and torsional response.

```
LOAD 4 LOADTYPE None  TITLE RESPONSE SPECTRUM
SPECTRUM SRSS IBC 2012 X 1 ACC DAMP 0.05 LIN MIS 0
```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Design Response Spectrum

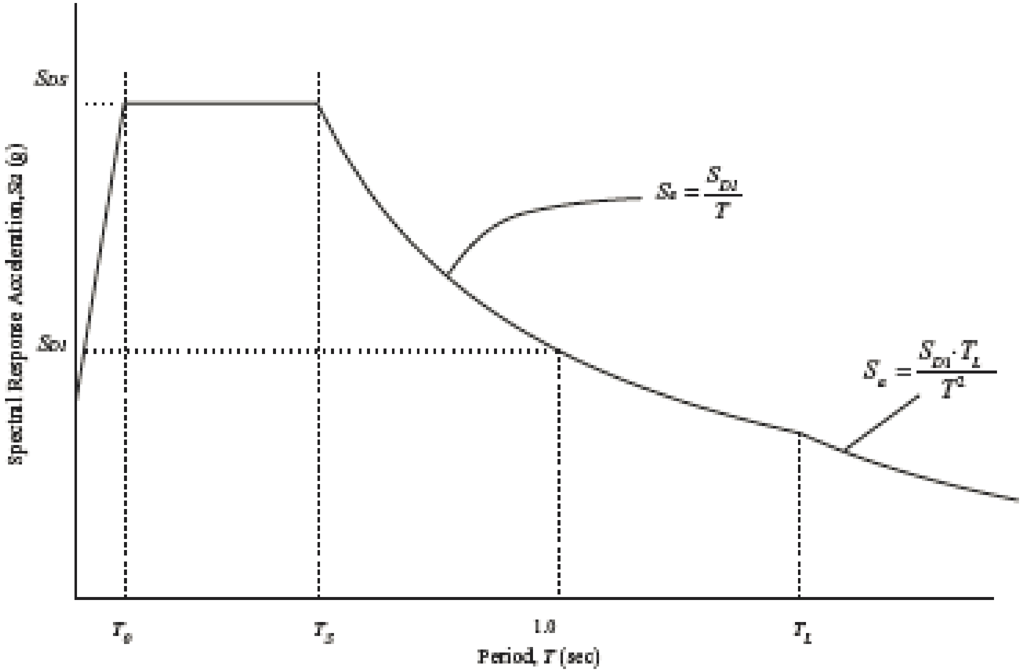


FIGURE 11.4-1 Design Response Spectrum.

1. For periods less than T_0, the design spectral response acceleration, S_a, shall be taken as given by Eq. 11.4-5:

$$S_a = S_{DS}\left(0.4 + 0.6\frac{T}{T_0}\right) \qquad (11.4\text{-}5)$$

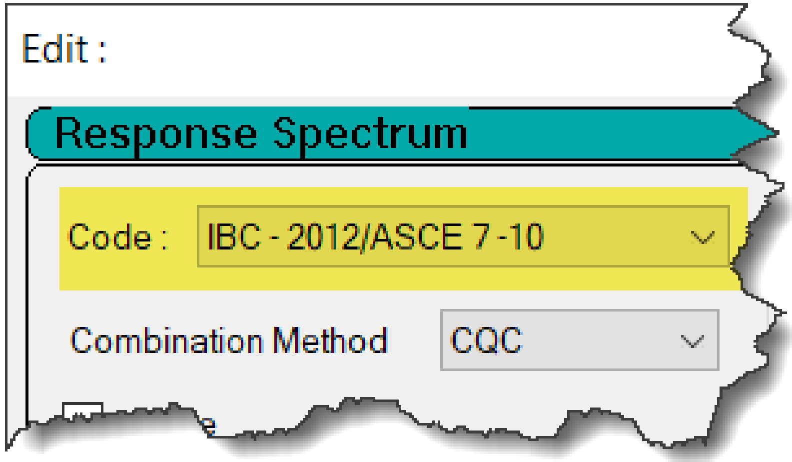
2. For periods greater than or equal to T_0 and less than or equal to T_S, the design spectral response acceleration, S_a, shall be taken equal to S_{DS}.
3. For periods greater than T_S, and less than or equal to T_L, the design spectral response acceleration, S_a, shall be taken as given by Eq. 11.4-6:

$$S_a = \frac{S_{D1}}{T} \qquad (11.4\text{-}6)$$

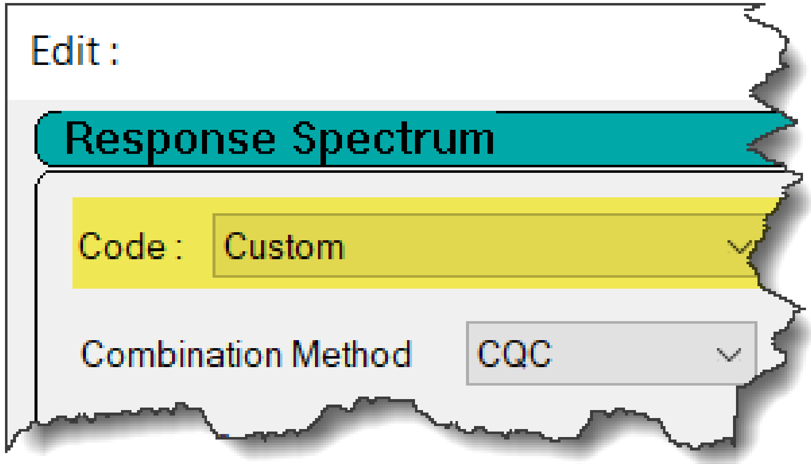
4. For periods greater than T_L, S_a shall be taken as given by Eq. 11.4-7:

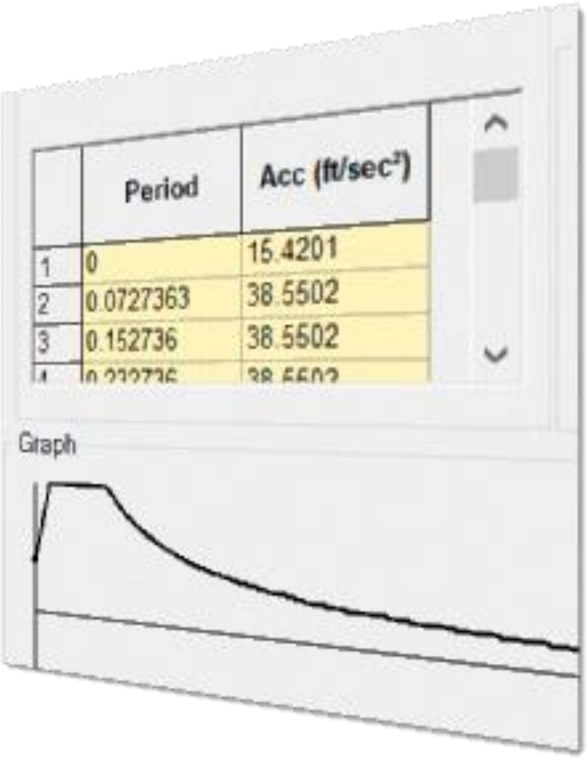
$$S_a = \frac{S_{D1}T_L}{T^2} \qquad (11.4\text{-}7)$$

Design Response Spectrum



Generic Response Spectrum as per ASCE





Site Specific Response Spectrum

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Scaling of the Response Spectrum Data

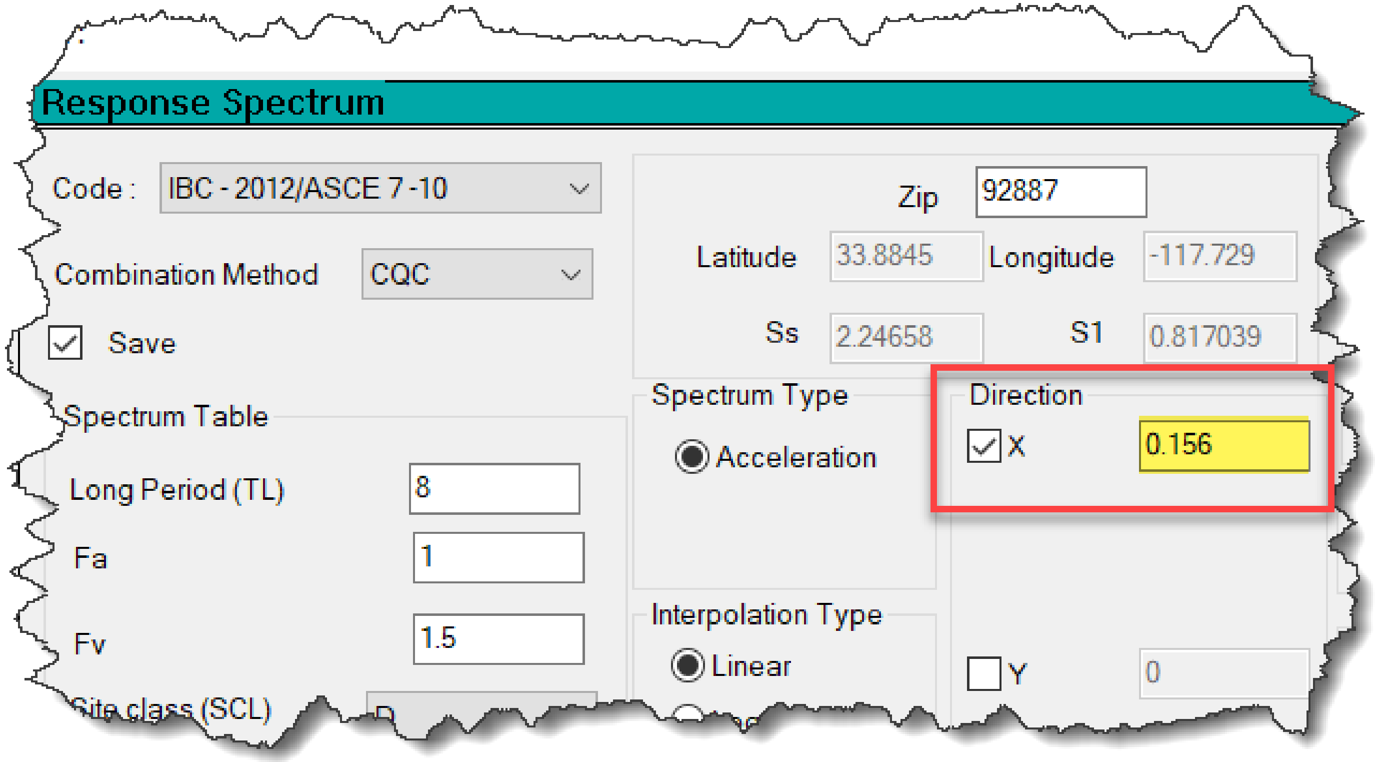
- Scaling of Spectrum data if normalized
- Additional Scaling as per ASCE

12.9.2 Modal Response Parameters

The value for each force-related design parameter of interest, including story drifts, support forces, and individual member forces for each mode of response shall be computed using the properties of each mode and the response spectra defined in either Section 11.4.5 or 21.2 divided by the quantity R/I_e. The value for displacement and drift quantities shall be multiplied by the quantity C_d/I_e.

Scaling of Spectrum Data Contd …

- Scale factor = Ie/R = 1.25/8 = 0.156
- Applied through the direction factor



Scaling of the results

12.9.4.1 Scaling of Forces

Where the calculated fundamental period exceeds C_uT_a in a given direction, C_uT_a shall be used in lieu of T in that direction. Where the combined response for the modal base shear (V_t) is less than 85 percent of the calculated base shear (V) using the equivalent lateral force procedure, the forces shall be multiplied by $0.85\frac{V}{V_t}$:

where

Scaling of Forces (base shears)

- ELFP Base shear Vx = 71.13 Kip, Vz = 71.13 Kip
- Response spectrum Base shear Vtx = 60.73 Kip , Vtz=53.85
- Vtx/Vx = 60.73/71.13 =0.853 > 0.85 .. no scaling required
- Vtz/Vz = 53.85/71.13 = 0.757 < 0.85 .. so scaling required

Scale factor in Z = 0.85/0.757 = 1.123

Scaling of the drifts

Section 12.8.6

The deflection at Level x (δ_x) (in. or mm) used to compute the design story drift, Δ, shall be determined in accordance with the following equation:

$$\delta_x = \frac{C_d \delta_{xe}}{I_e} \qquad (12.8\text{-}15)$$

where

C_d = the deflection amplification factor in Table 12.2-1
δ_{xe} = the deflection at the location required by this section determined by an elastic analysis
I_e = the importance factor determined in accordance with Section 11.5.1

12.9.4.2 Scaling of Drifts

Where the combined response for the modal base shear (V_t) is less than $0.85C_sW$, and where C_s is determined in accordance with Eq. 12.8-6, drifts shall be multiplied by $0.85\frac{C_sW}{V_t}$

Scaling of the drifts contd …

- As per 12.8.6, Cd/Ie = 5.5/1.25 = 4.4

As per 12.9.4.2

- S1 = 0.817 > 0.6

In addition, for structures located where S_1 is equal to or greater than 0.6*g*, C_s shall not be less than

$$C_s = 0.5S_1/(R/I_e) \qquad (12.8\text{-}6)$$

- Cs = 0.5x0.817/(8/1.25) = 0.064
- 0.85xCsxW = 0.85x0.064x303.96 = 16.535 Kip
- Lowest Response spectrum base shear (Vtz) = 60.41 > 16.535

Scaling of the drifts contd …

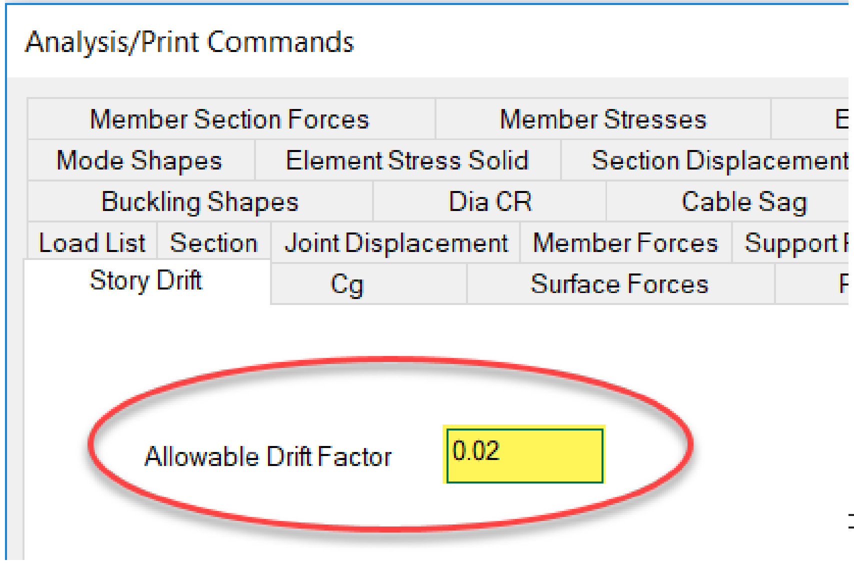


Table 12.12-1 Allowable Story Drift, $\Delta_a^{a,b}$

	Risk Category		
Structure	I or II	III	IV
Structures, other than masonry shear wall structures, 4 stories or less above the base as defined in Section 11.2, with interior walls, partitions, ceilings, and exterior wall systems that have been designed to accommodate the story drifts.	$0.025h_{sx}^{c}$	$0.020h_{sx}$	$0.015h_{sx}$
Masonry cantilever shear wall structures[d]	$0.010h_{sx}$	$0.010h_{sx}$	$0.010h_{sx}$
Other masonry shear wall structures	$0.007h_{sx}$	$0.007h_{sx}$	$0.007h_{sx}$
All other structures	$0.020h_{sx}$	$0.015h_{sx}$	$0.010h_{sx}$

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Distribution of Horizontal Shear (Response Spectrum)

12.9.5 Horizontal Shear Distribution

The distribution of horizontal shear shall be in accordance with Section 12.8.4 except that amplification of torsion in accordance with Section 12.8.4.3 is not required where accidental torsion effects are included in the dynamic analysis model.

Fig. 12.8-1 and determined from the following equation:

$$A_x = \left(\frac{\delta_{max}}{1.2\delta_{avg}}\right)^2 \qquad (12.8\text{-}14)$$

P-Delta Effects

12.9.6 P-Delta Effects

The P-delta effects shall be determined in accordance with Section 12.8.7. The base shear used to determine the story shears and the story drifts shall be determined in accordance with Section 12.8.6.

P-Delta Effects Contd …

12.8.7 P-Delta Effects

P-delta effects on story shears and moments, the resulting member forces and moments, and the story drifts induced by these effects are not required to be considered where the stability coefficient (θ) as determined by the following equation is equal to or less than 0.10:

$$\theta = \frac{P_x \Delta I_e}{V_x h_{sx} C_d} \qquad (12.8\text{-}16)$$

The stability coefficient (θ) shall not exceed θ_{max} determined as follows:

$$\theta_{max} = \frac{0.5}{\beta C_d} \leq 0.25 \qquad (12.8\text{-}17)$$

P-Delta Effects Contd …

Where the stability coefficient (θ) is greater than 0.10 but less than or equal to θ_{max}, the incremental factor related to P-delta effects on displacements and member forces shall be determined by rational analysis. Alternatively, it is permitted to multiply displacements and member forces by $1.0/(1 - \theta)$.

P-Delta Effects Contd …

Stability Coefficient (θ) calculation

- At lev 10 ft = 104.81x0.4839x1.25/(13.08x120x5.5) = 0.0073
- At Lev 20 ft = 104.22x0.5262x1.25/(26.01x120x5.5) = 0.004
- At lev 30 ft = 85.58x0.3213x1.25/(32.039x120x5.5) = 0.0016

- And θmax = 0.5/(1x5.5) = 0.091
- So $\theta < 0.1$ and $\theta < \theta$max

Calculating the Load Factor for the Dynamic Cases

- The largest value of θ is 0.0073
- $1/(1-\theta) = 1.007$

```
*LOAD COMBINATIONS INVOLVING SEISMIC LOADS FACTORED TO ACCOUNT FOR PDELTA
LOAD COMB 200 DL + LL + SL in X
5 1.007 50 1.007
LOAD COMB 201 DL + LL - SL in X
5 1.007 50 -1.007
LOAD COMB 202 DL + LL + SL in Z
5 1.007 52 1.007
LOAD COMB 203 DL + LL - SL in Z
5 1.007 52 -1.007
*
```

Load 5 = DL+LL ; Load 50 = SL in X ; Load 52 = SL in Z

Output from a response spectrum analysis

- Masses listed in modelname_MASS.TXT

JOINT #	DIRECTION	Pound-mass(inch) = LBf/386.08858
17	X	6.976073
17	Y	6.976073
17	Z	6.976073
18	X	10.011120
18	Y	10.011120
18	Z	10.011120

- Nodal accelerations listed in modelname.ACC

ACCELERATION - G'S & RAD/SEC**2 CASE NO 4

JOINT	X1	X2	X3	X4	X5	X6
17	5.83060E-01	2.73895E-02	1.33842E-01	3.87530E-02	5.97851E-01	1.46967E+00
18	5.83878E-01	2.20759E-03	1.67988E-01	1.89076E-02	2.70857E-01	9.52173E-01
19	5.83858E-01	1.81780E-03	2.07301E-01	1.91065E-02	2.68901E-01	9.52138E-01
20	5.83018E-01	2.77981E-02	2.43711E-01	4.36606E-02	5.96664E-01	1.46957E+00
21	6.36129E-01	2.90906E-02	1.33620E-01	2.12333E-02	3.98756E-01	1.44616E+00
22	6.36854E-01	2.09734E-03	1.68074E-01	6.31898E-03	2.37342E-01	9.32921E-01
23	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Output from a response spectrum analysis contd …

- Accelerations for each mode in the anl file

MODE	ACCELERATION-G	DAMPING
1	1.49772	0.05000
2	1.49772	0.05000
3	1.49772	0.05000
4	1.41649	0.05000
5	1.11992	0.05000

- Dynamic weight, modal weight and missing weights

```
DYNAMIC WEIGHT X Y Z   2.946117E+02  2.946117E+02  2.946117E+02 KIP
MISSING WEIGHT X Y Z  -8.543709E-05 -2.403820E+01 -2.524574E-04 KIP
  MODAL WEIGHT X Y Z   2.946116E+02  2.705735E+02  2.946115E+02 KIP
```


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Output from a response spectrum analysis contd …

- Base shear in the anl file

TOTAL SRSS SHEAR	60.72	0.00	0.00
TOTAL 10PCT SHEAR	60.72	0.00	0.00
TOTAL ABS SHEAR	68.06	0.00	0.00
TOTAL CQC SHEAR	60.73	0.00	0.00

- Peak Story Shears

STORY	LEVEL IN FEET	PEAK STORY SHEAR IN KIP	
		X	Z
3	30.00	26.22	0.00
2	20.00	49.04	0.00
1	10.00	60.73	0.00
BASE	0.00	60.73	0.00

Load Combinations involving dynamic cases

DL + LL + SL in X

DL + LL – SL in X

DL + LL + SL in Z

DL + LL – SL in Z

Linear Response History (Time History)

- Ground Motion applied as time varying load
- [m]{x''} + [c]{x'} + [k]{x} = {P(t)}

Using the transformation

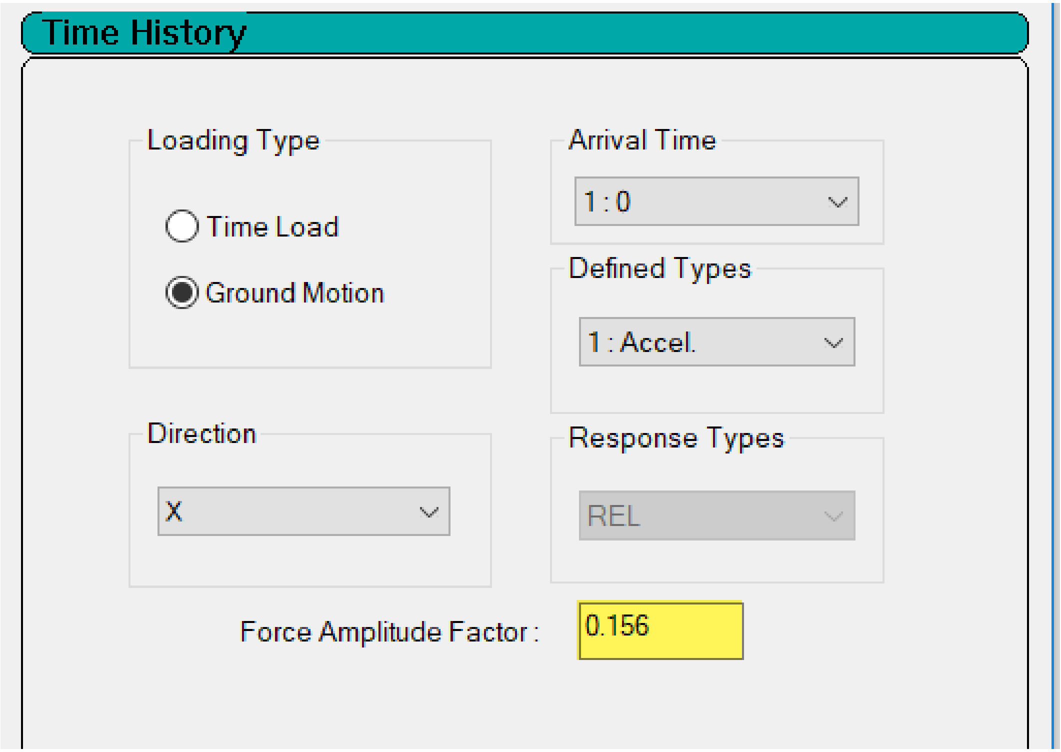
$$\{x\} = \sum_{i=1}^{p} \{\phi\}_i q_i$$

The equation for {P(t)} reduces to "p" separate uncoupled equations of the form

$$q''_i + 2\,\xi_i \omega_i q'_i + \omega_i^2 q_i = R_i(t)$$

Scaling of Forces and Drifts

Scale factor Ie/R = 1.25/8 =0.156



16.1.4 Response Parameters

For each ground motion analyzed, the individual response parameters shall be multiplied by the following scalar quantities:

a. Force response parameters shall be multiplied by I_e/R, where I_e is the importance factor determined in accordance with Section 11.5.1 and R is the Response Modification Coefficient selected in accordance with Section 12.2.1.

b. Drift quantities shall be multiplied by C_d/R, where C_d is the deflection amplification factor specified in Table 12.2-1.

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Scaling of Results (Section 16.1.4)

Base shear

Where the maximum scaled base shear predicted by the analysis, V_i, is less than 85 percent of the value of V determined using the minimum value of C_s set forth in Eq. 12.8-5 or when located where S_1 is equal to or greater than 0.6g, the minimum value of C_s set forth in Eq. 12.8-6, the scaled member forces, Q_{Ei}, shall be additionally multiplied by $\frac{V}{Vi}$

Drifts

Where the maximum scaled base shear predicted by the analysis, V_i, is less than $0.85C_sW$, where C_s is from Eq. 12.8-6, drifts shall be multiplied by $0.85\frac{C_sW}{V_i}$.

Scaling of Results Contd …

```
BASE SHEAR UNITS ARE -- KIP   FEET

MAXIMUM BASE SHEAR   X=    3.186149E+01  Y=  -4.958436E-03  Z=  -2.746851E-01
    AT TIMES                 2.548611          2.427778          5.423611
```

Eqn 12.8-5, Cs =0.044xSdsxIe = 0.044x1.5x1.25=0.0825 > 0.1
0.85xCsxW = 0.85x0.0825x303.96 = 21.32 Kip < 31.86 Kip (=Vi)

Eqn 12.8-6 S1=0.817 > 0.6, Cs=0.5xS1/(R/Ie)= 0.5x0.817x1.25/8=0.064
0.85xCsxW = 0.85x0.064x303.96 = 16.535 Kip < 31.86 Kip (=Vi)

So no further scaling required for forces AND drifts

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Distribution of Horizontal Shear (Response History)

16.1.5 Horizontal Shear Distribution

The distribution of horizontal shear shall be in accordance with Section 12.8.4 except that amplification of torsion in accordance with Section 12.8.4.3 is not required where accidental torsion effects are included in the dynamic analysis model.

Fig. 12.8-1 and determined from the following equation:

$$A_x = \left(\frac{\delta_{max}}{1.2\delta_{avg}} \right)^2 \qquad (12.8\text{-}14)$$

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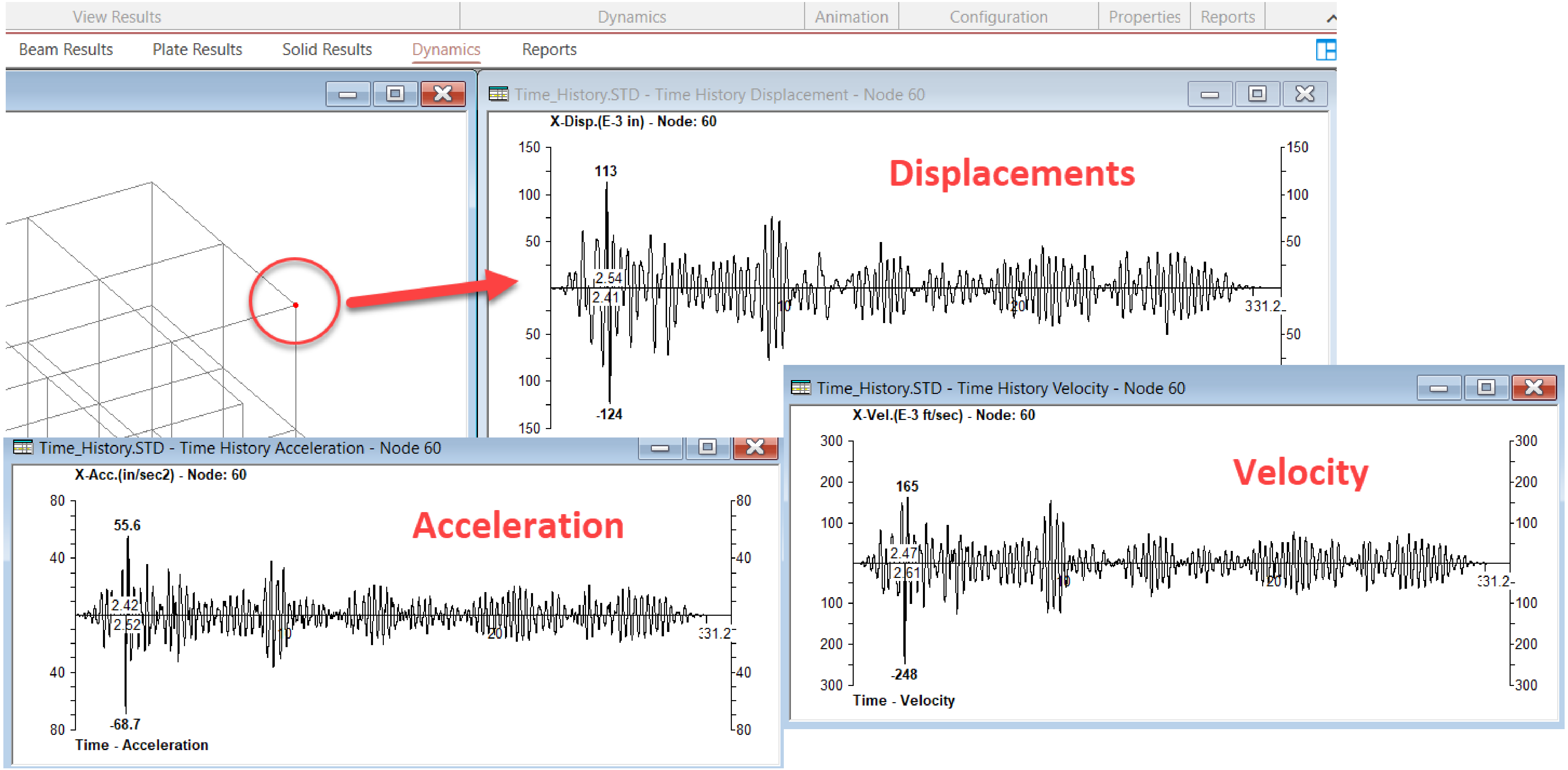
Response History Results



Results at each time instant

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File Edit Format View Help

```
 JOINT      TIME          X-TRANS       Y-TRANS       Z-TRANS       X-ROTAN       Y-ROTAN       Z-ROTAN
DISPLACEMENTS IN INCHES and RADIANS

      1  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
      2  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
      3  0.000000E
      4  0.000000E
      5  0.000000E
```

Time_History.frc - Notepad

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```
    UNITS ARE -- KIP   FEET


    MEMB     TIME    JT      FX        FY       FZ        MX        MY         MZ

    101  0.000000E+00      17  0.000000E+00  9.123727E-06  2.765755E-24 -8.211569E-15 -3.576103E-23  5.094712E-05
                           18  0.000000E+00 -9.123727E-06 -2.765755E-24  8.211569E-15 -2.383781E-23  4.029016E-05
    102  0.000000E+00      18  0.00
                           19  0.00
    103  0.000000E+00      19  0.00
                           20  0.00
    104  0.000000E+00      21  0.00
                           22  0.00
```

```
 REACTION TIME HISTORY
   UNITS ARE -- KIP   FEET

 JOINT          FX            FY            FZ            MX            MY            MZ

 REACTIONS AT TIMESTEP NO.        1 TIME =     0.000000E+00
       1  1.653107E-05  4.341898E-06  0.000000E+00 -2.934160E-10  0.000000E+00 -8.957765E-05
       2  1.828629E-05 -1.136070E-06  0.000000E+00  1.081808E-10  0.000000E+00 -9.529860E-05
       3  1.828629E-05  1.136284E-06  0.000000E+00 -1.246482E-10  0.000000E+00 -9.529860E-05
       4  1.653107E-05 -4.341761E-06  0.000000E+00  2.091795E-10  0.000000E+00 -8.957765E-05
       5  1.653121E-05  4.271208E-06  0.000000E+00 -3.298717E-10  0.000000E+00 -8.957809E-05
       6  1.828634E-05 -1.123463E-06  0.000000E+00  0.000000E+00  0.000000E+00 -9.529875E-05
```


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Thank You !!!

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