

FEAKalc 3D

Lateral Analysis Theory and Methods Manual

Document Revision

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1 Introduction

1.1 Purpose

FEAKalc 3D calculates the lateral response of a building from its three-dimensional structural model. This manual explains the implemented path from floor geometry, structural stiffness and selected mass sources to modal properties, response spectrum actions, wind loads and diaphragm response reports. Its purpose is to make the calculations reproducible and the reported quantities unambiguous.

The building is analysed as an assembly of frame and shell elements. Floor diaphragms remain deformable through their shell membrane stiffness.

The active modal workflow generates load-dependent Ritz vectors. Response spectrum calculations use signed responses recovered for each returned mode, followed by the selected statistical combinations.

Wind generation produces ordinary static diaphragm loads that are distributed to the analysis mesh before solution.

This edition describes the source implementation reviewed on November 2026. Chapters 2–8 describe the calculation methods; Appendix B lists published references and Appendix C records significant numerical settings.

A statement that an equation is implemented is distinct from a statement that a complete building satisfies a design standard. Site parameters, structural classifications, seismic weight, wind coefficients and design acceptance remain engineering inputs and assessments.

1.2 Scope of the analysis

The manual covers semi-rigid diaphragm domains and equilibrium-preserving load distribution; load-derived lumped mass; cyclic Ritz modal analysis; reusable spectrum functions; linear modal response spectrum analysis; the Australian minimum-base-shear comparison; static accidental-torsion corrections; Australian along-wind generation; and interpretation of floor and building responses.

The Australian spectrum generator implements the horizontal AS 1170.4:2024 design-spectrum function. A preserved 2007 curve is a fixed historical reference, not a general generator for that edition.

The wind generator implements the particular overall external-wall procedure described in Chapter 7.

A conventional equivalent-static earthquake case with a generated vertical distribution of seismic floor forces is outside this manual's implemented workflow. The static earthquake calculation in Chapter 5 is a whole-model base-shear benchmark for response spectrum cases; it does not generate an equivalent-static earthquake load pattern.

1.3 Calculation architecture

The user defines mass-source entries, spectrum functions and cases, diaphragm assignments, wind parameters and result presentation. The backend prepares the analysis mesh, assembles stiffness and mass, generates Ritz modes, recovers signed responses and solves static accidental-torsion patterns. The user then evaluates spectrum ordinates, combines modes and directions, applies the selected base-shear scaling and builds response reports.

This separation matters when checking an answer. A correct modal period does not by itself verify the spectrum scale, combination settings, torsion correction or reporting definition. Conversely, changing only a spectrum ordinate can change the response without changing the structural modes.

Model identities and saved settings are used to guard against reusing responses from incompatible inputs.

The response spectrum calculation chain is:

- structural model
- meshed stiffness and lumped mass
- cyclic Ritz basis
- returned modal shapes
- signed response recovery
- spectral modal coefficients
- directional scaling
- modal combination and static torsion envelope
- directional combination
- reported component peaks.

The wind chain is:

- assigned floor geometry and exposure inputs
- height-dependent pressures
- integrated strip force and applied torsion
- diaphragm nodal loads
- static structural solution
- signed response recovery
- floor and drift reporting.

1.4 Coordinates and units

Global Z is upwards. Positive diaphragm Mz is counterclockwise when viewed from positive Z towards the XY plane. Wind angle 0 degrees applies force along positive X; 90 degrees applies force along positive Y. Spectrum excitation axes U1 and U2 rotate together about global Z, while U3 remains vertical.

Quantity	Calculation and report unit
Geometry and spectrum displacement	m
Rotation	rad
Translational mass	kg
Force and moment	KN and KN m
Wind pressure	kPa or KN/m ²
Spectrum acceleration after case scaling	m/s ²
Frequency and period	Hz and s
Shell membrane and transverse shear resultants	KN/m
Shell bending resultants and stresses	KN m/m and MPa

Quantity	Calculation and report unit
Displayed diaphragm displacement and drift	mm and percent

The structural stiffness uses KN and metres, whereas modal mass is in kg. The resulting factor of 1000 must be included when converting the stiffness-to-mass eigenvalue into angular frequency. Spectrum report data retain metres and radians. The ordinary result-pane adapter converts translational spectrum displacements to mm to match static results. Drift CSV data retain m/m.

Throughout this manual, n denotes a node, j a mode, k an excitation direction and i a diaphragm level. K is structural stiffness, M is mass, ϕ is a mode shape, ω is angular frequency, Γ is participation factor, S_a is spectral acceleration and $g = 9.80665 \text{ m/s}^2$. A superscript T denotes transpose.

The statistical modal-combination operator is written C; the directional-combination operator is D. The equations describe the methods set out in this manual; equivalence with another program is not assumed.

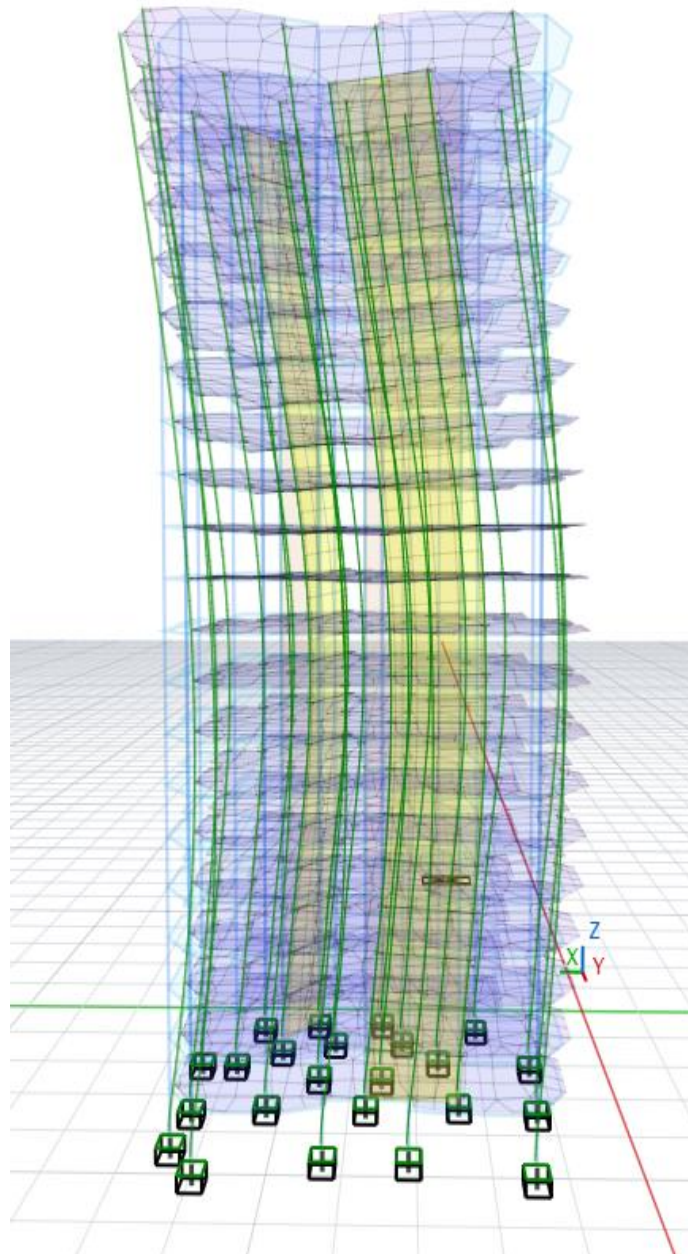


Figure 1.1- Modal Deformed Shape

2 Building model and semi rigid diaphragms

2.1 Structural representation

The analysis mesh contains the frame and shell elements, shared analysis nodes, supports and connection treatments produced by model preparation. Each three-dimensional node carries translations UX, UY, UZ and rotations RX, RY, RZ. Support and analysis-plane restrictions determine the retained free coordinates. The modal calculation uses the assembled structural stiffness for these free coordinates.

Building behaviour therefore depends on member properties, shell thickness and modifiers, releases, connectivity, supports and mesh. A diaphragm name does not repair a disconnected frame joint or replace a floor's membrane stiffness. Wall-edge restraint inheritance and column-to-shell connection treatments are part of the prepared structural model and can affect the periods substantially. They must match the intended physical load path when comparing two models.

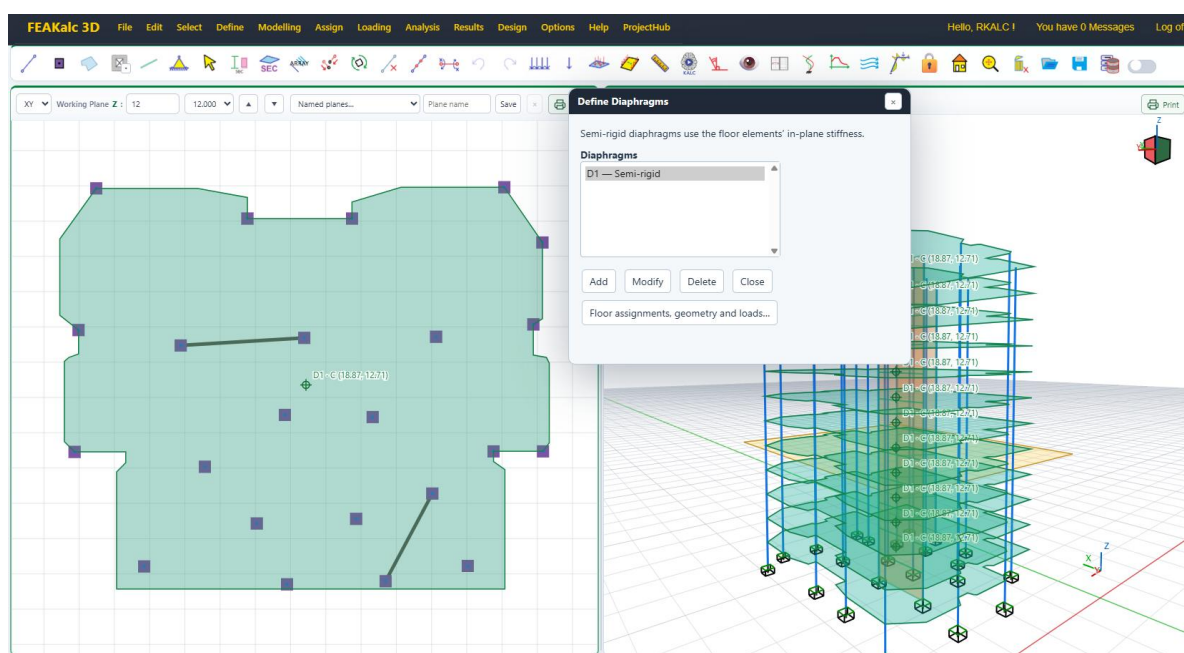


Figure 2.1 – Semi Rigid Diaphragms in FEAkalc 3D

The lateral workflow is linear. It does not introduce a nonlinear material model, a time-history integration or an automatic geometric-stiffness update as part of the modal/spectrum sequence described here.

Stiffness modifiers supplied to the structural model affect that model; the spectrum procedure does not independently infer cracking or structural ductility from the member layout.

2.2 Meaning of a diaphragm assignment

A diaphragm definition is a named semi-rigid property. Assigned horizontal floor shells resolve into one instance for each definition and elevation. A definition may therefore occur at several levels; different definitions can describe separate floor regions at the same elevation.

Assignment adds no rigid link, penalty constraint, coordinate condensation, mass or artificial membrane stiffness. The floor retains its shell deformation and transfers lateral actions through its actual connectivity. Distributed translational masses develop building torsional inertia through their spatial positions. No floor rotational coordinate or additional lumped floor polar mass is created by assigning the diaphragm.

Rigid-floor relations such as $u_x = u_{cx} - \theta_z(y - cy)$ and $u_y = u_{cy} + \theta_z(x - cx)$ are not imposed by this assignment. A floor can warp or deform in its plane, so a single translation and rotation cannot generally represent its entire response. Mean translations reported later are spatial averages of that deformable field.

2.3 Domain resolution and validation

The backend resolves assignments against the surviving analysis mesh after geometry processing, openings and node merging. Openings are excluded from the meshed membrane area. Definition and elevation identify the domain; source and resolved elevations must agree within 0.0001 m, independently of general meshing tolerances.

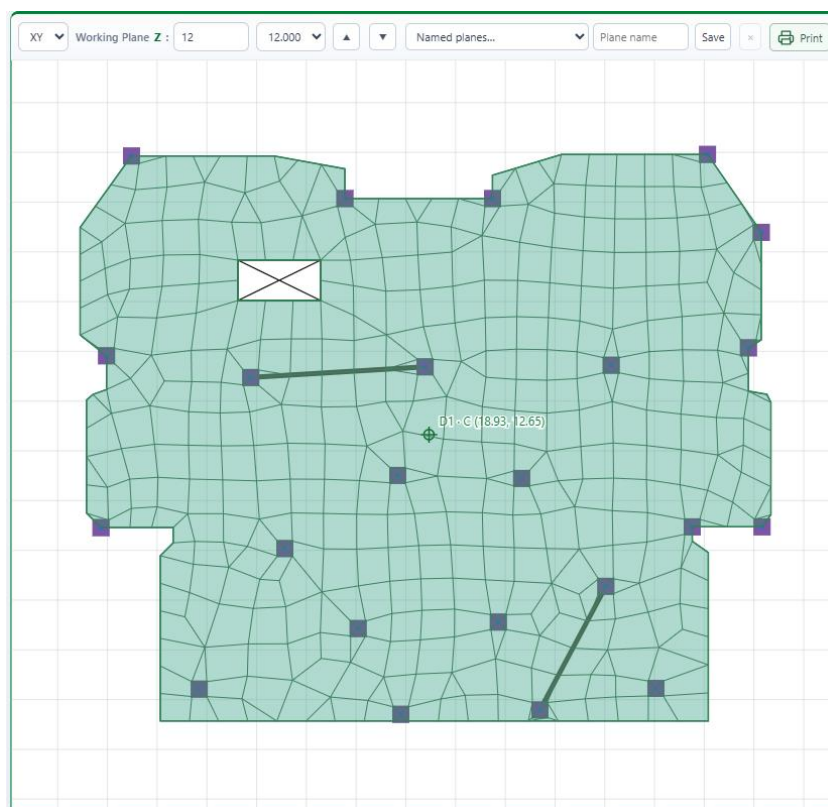


Figure 2.2 – Mesh and Openings with Diaphragm and Centroid

Assigned shells must be horizontal and have positive elastic modulus, thickness and membrane modifier. The domain must be connected through shared element edges. Disconnected islands, including panels touching only at a point, require separate definitions. Positive-area overlaps, non-manifold mesh edges, undefined diaphragm IDs and nodes belonging to distinct resolved domains are rejected.

Enclosed analysis joints at the same level are included in domain membership. An enclosed joint that is not part of the membrane mesh receives zero tributary load area and a connection warning. Its presence inside a floor outline does not establish structural connection. This distinction affects load distribution and the engineer's review of floor-to-frame continuity.

2.4 Area and centroids

An analysis polygon is split into a fan of triangles. For each triangle, one-third of its area is assigned to each of its three vertices. A node's tributary area A_n is the sum of its triangle contributions. The net domain area and geometric centroid are calculated from the same triangles.

$$A = \sum_t A_t, \quad x_c = \frac{\sum_t A_t x_t}{A}, \quad y_c = \frac{\sum_t A_t y_t}{A} \quad (2.1)$$

Here x_t and y_t are triangle-centroid coordinates. Triangulated nodal weighting can differ from simply assigning one-quarter of every quadrilateral area to each corner; the resolved audit is the authority for the current calculation.

The horizontal mass centroid is reported separately. Its nodal weighting mass is the mean of the nodal UX and UY masses, including enclosed joints in the domain. If there is no horizontal mass, a mass centroid is unavailable. The geometric centroid is used for load application and moment reference; the mass centroid is an audit quantity and does not replace it automatically.

$$m_{h,n} = \frac{m_{x,n} + m_{y,n}}{2}, \quad x_m = \frac{\sum_n m_{h,n} x_n}{\sum_n m_{h,n}} \quad (2.2)$$

The corresponding expression gives y_m . Floor mass totals, free modal mass totals and whole-model mass totals have different memberships and must not be treated as interchangeable.

2.5 Applying a force and moment

A diaphragm load row contains F_x , F_y and M_z at a specified elevation and primary static case. Loads can act at the geometric centroid or at an explicit point (a_x , a_y). An explicit application point is transferred to the centroid using the signed cross product:

$$M_c = M_z + (a_x - x_c)F_y - (a_y - y_c)F_x \quad (2.3)$$

Multiple rows are additive. A directly entered M_z is added to the eccentric moment of the application point. Representing the same eccentricity in both entries would double-count it.

For reproducibility, the load distribution first normalises each positive nodal tributary area and finds the weighted nodal centre (x_w , y_w) and squared polar radius J_w :

$$w_n = \frac{A_n}{\sum_n A_n}, \quad x_w = \sum_n w_n x_n, \quad y_w = \sum_n w_n y_n \quad (2.4)$$

$$J_w = \sum_n w_n [(x_n - x_w)^2 + (y_n - y_w)^2] \quad (2.5)$$

The residual torque after distributing the translational force is:

$$\Delta M = M_c - [(x_w - x_c)F_y - (y_w - y_c)F_x] \quad (2.6)$$

The final translational nodal forces are:

$$F_{x,n} = w_n F_x - \frac{\Delta M w_n (y_n - y_w)}{J_w} \quad (2.7)$$

$$F_{y,n} = w_n F_y + \frac{\Delta M w_n (x_n - x_w)}{J_w} \quad (2.8)$$

These forces preserve net F_x , net F_y and the requested moment about the geometric centroid. The correction is a translational force couple; it does not apply concentrated nodal RZ moments. A positive pure torque produces negative X force on the positive-Y side and positive Y force on the positive-X side.

Before assembly, the engine checks the sum of absolute residuals in force and moment against 10^{-7} times $\max(1, |F_x| + |F_y| + |M_c|)$. This is the implemented numerical audit using the stated units, not a dimensionally general engineering acceptance criterion. A zero-area or effectively zero-polar-radius domain cannot distribute a torque.

2.6 Auditing building load transfer

The diaphragm geometry audit records membership, tributary areas, boundaries, geometric and mass centroids, input forces, reference and application points, nodal forces and equilibrium residuals. Use the

resolved mesh audit to check openings and connectivity; source-plan previews alone do not prove the final meshed load path.

A floor assignment can leave global K and M unchanged while changing which nodes receive lateral loads or an accidental-torsion correction. Consequently, equal periods between two software models do not demonstrate equivalent diaphragm load coverage.

Appendix A gives a transparent force-couple example.

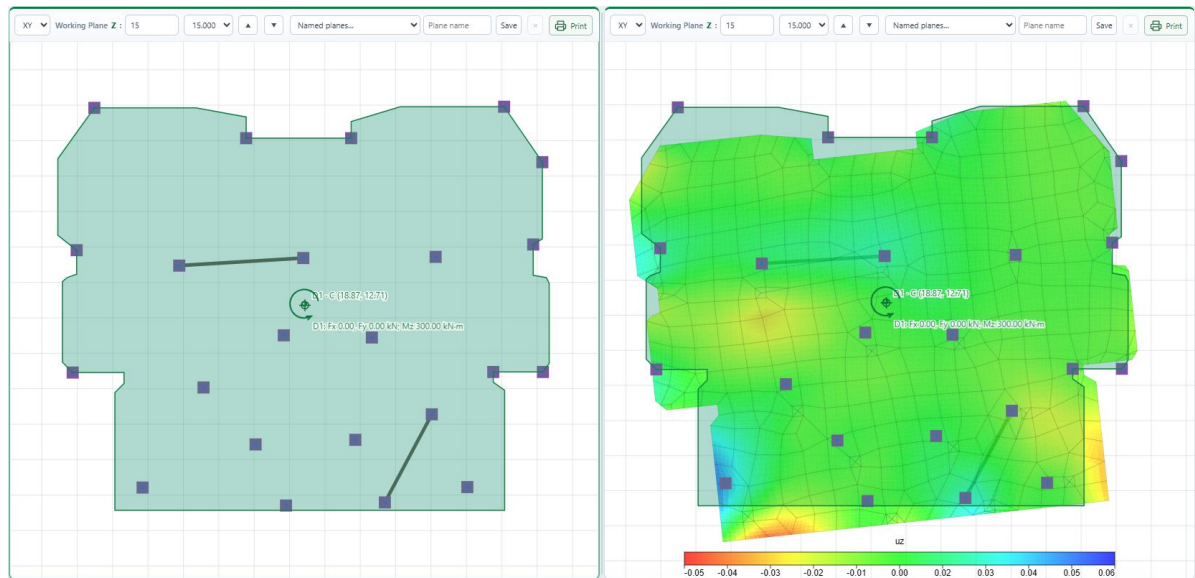


Figure 2.3 – Diaphragm Subject to Torsional Moment (M_z)

3 Mass formulation and modal analysis

3.1 Selected mass source

The mass source selects primary load cases and positive multipliers. For example, Dead × 1.0 plus Live × 0.3 defines the selected load-derived mass; these ratios are user choices and are not automatically inferred from occupancy or code seismic-weight rules. Load combinations are excluded from mass-source matching.

The backend accepts the selected primary-case contributions and converts their represented weight to kg using g. A scalar nodal mass contribution is added equally to UX, UY and UZ. Physical rotary nodal mass is not added by this routine. The three equal translational entries represent the same physical mass acting in different directions; summing MX + MY + MZ would count it three times.

$$m = \frac{1000\alpha W}{g} \quad (3.1)$$

Here W is the represented load in kN and α is the mass-source multiplier. Distribution depends on the load record type, as set out below.

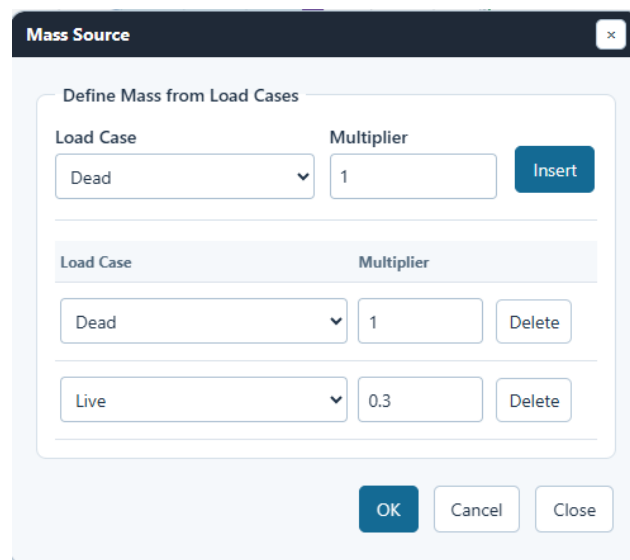


Figure 3.1 – Mass Source in FEAkalc (Define Menu)

3.2 Contribution rules

Frame full-length uniformly distributed loads use the absolute stored intensity, multiplied by member length, with half the resulting mass at each end. Partial trapezoidal loads use the absolute endpoint intensities and their loaded length. Their resultant is located at its trapezoidal centroid and distributed linearly to the member endpoints.

$$W = \frac{w_1 + w_2}{2} L_p, \quad \bar{x} = x_0 + \frac{L_p(w_1 + 2w_2)}{3(w_1 + w_2)} \quad (3.2)$$

For this expression w1 and w2 are nonnegative magnitudes in consistent force-per-length units. The endpoint fractions are $1 - \bar{x}/L$ and $\bar{x}/L$, with the implementation clamping the resultant position to the member length. The stored loaded length is capped by the member length; these rules are an endpoint lumping approximation rather than a consistent distributed mass matrix.

Frame point-load mass is based on the downward global-Z component of the specified local transverse load. Upward or wholly horizontal components do not contribute through this path. Mass is distributed to the two endpoints using the clamped load-position ratio.

In the reviewed source, the P2 and P3 calls pass the XP1 position array as well as the P1 call. Separate P2/P3 positions therefore must not be assumed to control their modal mass distribution in this revision.

Direct frame-end nodal loads contribute only their downward global-Z force. This path also receives frame self-weight assembled into the first primary case. Shell pressures use their absolute magnitude times shell area; resulting mass is divided equally among the shell element's vertices. Resolved shell point/nodal loads contribute their downward global-Z component at the resolved node.

The absolute-value treatment of distributed loads and shell pressure is important: upward distributed loads are not generally subtracted from the mass. The source should represent intended gravity weight, rather than using opposing loads to cancel mass. General horizontal diaphragm Fx/Fy/Mz records do not add mass.

3.3 Self-weight and fallback behaviour

Self-weight enters through the first primary load case when enabled, so its inclusion in modal mass also depends on that case's source multiplier. The frame path uses an explicit material unit weight where supplied; otherwise the defaults are 25 kN/m^3 , with 78.54 kN/m^3 for the recognised steel-modulus case.

The shell-pressure self-weight routine uses 25 kN/m^3 times thickness. Material labels alone should not be assumed to create arbitrary shell density values in this mass path.

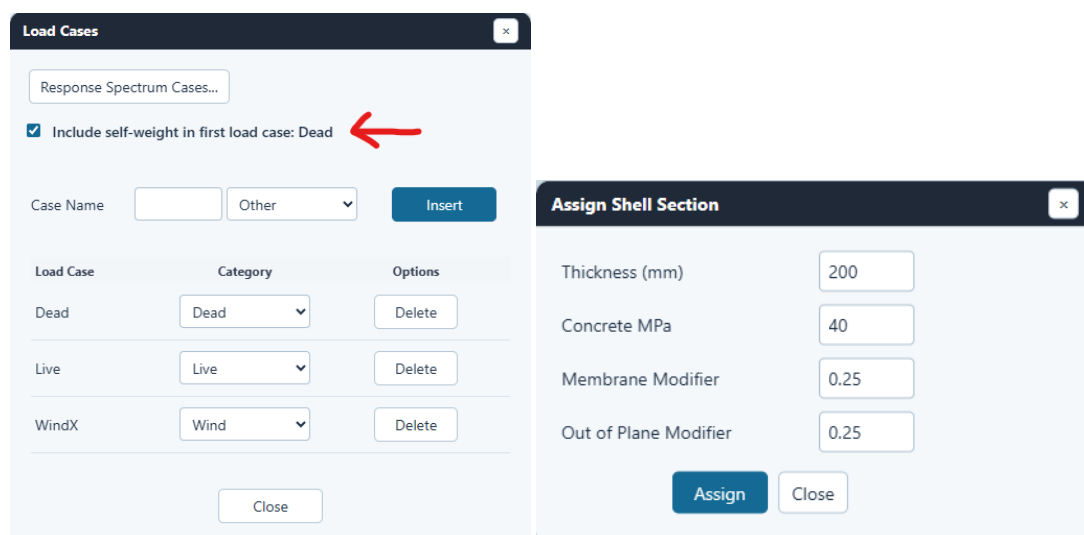


Figure 3.2 – Left: Load Cases Dialog (note self-weight is included in Dead load Case). Right: Shell Section Dialog

Nonpositive multipliers, unknown primary-case names and unusable entries are ignored by the backend mass parser. If no usable source entry is applied and a primary case exists, the backend falls back to the first primary case at multiplier 1.0. Malformed mass-source JSON can also reach this fallback. This is backward-compatible behaviour, not an automatic engineering validation of a seismic mass source.

Review directional mass totals, source multipliers and the spatial mass distribution. A plausible total mass does not establish correct floor distribution, and a validated input form does not remove the need to understand the backend fallback.

3.4 Free coordinates and regularisation

The full assembled mass diagonal is reduced by selecting the same free coordinates used for the reduced stiffness matrix. It is not condensed to floor centres. Restrained translational masses are excluded from the free directional mass used for participation ratios.

Reduced diagonal entries at or below 10^{-12} are replaced by 10^{-12} for numerical solution. This gives otherwise massless free coordinates a very small numerical mass. It is not physical floor rotational inertia. Participation

and recovered inertia are evaluated using the full physical mass entries, so an assumption of exactly unit physical modal mass is avoided in the response calculations.

3.5 Governing modal problem

For an undamped linear system, the free-vibration equation is $M \ddot{u} + K u = 0$, where K denotes stiffness in N/m. The stored stiffness K uses kN/m, giving:

$$K \varphi_j = \lambda_j M \varphi_j, \quad \omega_j = \sqrt{1000 \lambda_j} \quad (3.3)$$

$$f_j = \frac{\omega_j}{2\pi}, \quad T_j = \frac{2\pi}{\omega_j} \quad (3.4)$$

The active application route sets the Ritz branch on. A separate inverse-iteration eigen routine exists in the source but is not the user-selected production method for this route. Returned Ritz periods are eigenvalues of the generated reduced Ritz system; they approximate the relevant vibration properties of the full model and depend on basis size and starting loads.

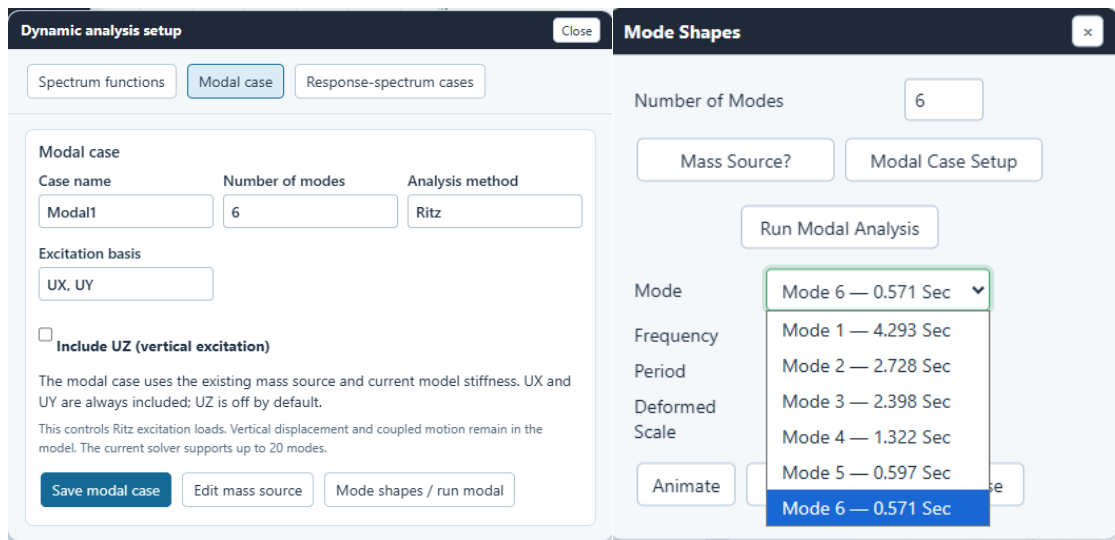


Figure 3.3 – Modal Dialog and Results

3.6 Cyclic Ritz vector generation

UX and UY starting loads are always selected. UZ is added only when vertical excitation is explicitly enabled. For direction k , the initial vector is the reduced mass times its unit translational influence vector:

$$p_{k,1} = M r_k, \quad K y_{k,g} = p_{k,g} \quad (3.5)$$

The solver visits UX, UY and optional UZ cyclically. Each accepted vector is mass-orthogonalised against every previously accepted vector twice, then mass-normalised. Its own direction's next inertia load is:

$$y \leftarrow y - \sum_l v_l (v_l^T M y), \quad v = \frac{y}{\sqrt{y^T M y}}, \quad p_{k,g+1} = M v_{k,g} \quad (3.6)$$

The orthogonalisation expression is applied in two sequential passes; the implementation updates y after each projection. The basis contains exactly the requested number of accepted independent vectors. An incomplete final cycle follows UX, UY, UZ order. A zero or dependent load retires that direction while the others may fill the remaining budget.

A vector is rejected as dependent if its mass norm after orthogonalisation is no greater than 10^{-10} times its original mass norm. If the requested number of independent vectors cannot be generated, the analysis

reports exhaustion instead of returning noise as additional modes. The default request is six modes and the current application limit is twenty.

3.7 Linear solution and numerical controls

The checked-in configuration selects reusable direct factorisation for the Ritz linear systems. The Python worker reconstructs the sparse symmetric matrix and forms diagonal scaling D, with $D_{ii} = 1/\sqrt{|K_{ii}|}$ for a non-negligible diagonal. It factorises $D K D$ using SciPy SuperLU with COLAMD ordering; successive Ritz right-hand sides reuse those factors within the run. The displacement is recovered from $y = D (D K D)^{-1} D p$.

The VB host independently recomputes the diagonally scaled residual. Its squared residual acceptance is $\max(10^{-30}, 10^{-12} \text{ times the squared initial residual})$. Failed direct preparation or validation disables further direct attempts for that modal run and uses the scaled preconditioned conjugate-gradient fallback.

The Ritz PCG fallback uses a relative residual target of 0.01 and an iteration cap $\min(30000, \max(10000, \text{floor}(n\text{-free}/4)))$. It can use a deflated initial guess; failure to form that guess falls back to a zero guess. A non-converged solve is rejected. The 1% linear residual target is a numerical solve setting, not a 1% bound on periods, forces or drift. Direct factors are released after Ritz generation.

3.8 Reduced problem and returned shapes

With V containing the mass-orthonormal Ritz basis, the implementation forms:

$$K_R = V^T K V, \quad M_R = V^T M V \approx I \quad (3.7)$$

It calculates M_R but solves the symmetric eigenproblem of K_R assuming M_R is sufficiently close to identity. A Jacobi rotation method diagonalises K_R . Its absolute off-diagonal stopping threshold is 10^{-10} and its iteration cap is $100 r^2$, where r is the basis size. There is no separate user-facing certification that every requested mode has converged to the full-system eigenproblem.

Eigenvalues are sorted in ascending order and the physical reduced shapes reconstructed as $\phi_j = V a_j$, then mass-normalised again. Shapes are expanded to full coordinates with zero values at eliminated coordinates. Negative reduced eigenvalues are clamped to zero before frequency calculation; a spectrum run requires positive modal frequencies and rejects zero-frequency responses.

The sign and display amplitude of a mode shape are arbitrary. Reversing ϕ reverses Γ , leaving the product $\Gamma\phi$ unchanged. A displayed mode is a relative deformation pattern, not a displacement under a design load.

3.9 Participation and effective mass

For each retained mode and excitation influence vector, the response basis computes generalized mass, participation factor and effective mass:

$$M_j = \phi_j^T M \phi_j, \quad L_{jk} = \phi_j^T M r_k, \quad \Gamma_{jk} = \frac{L_{jk}}{M_j} \quad (3.8)$$

$$M_{eff,jk} = \frac{L_{jk}^2}{M_j}, \quad \eta_{jk} = \frac{M_{eff,jk}}{r_k^T M r_k} \quad (3.9)$$

Cumulative participation is the sum of retained η_{jk}

The denominator is free directional translational mass, not total mass including restrained nodes. For a rotated horizontal excitation with unit vector (v_x, v_y) , the denominator is $v_x^2 M_X + v_y^2 M_Y$.

The modal output tables also evaluate rotational influence vectors about the centre of free translational mass. A global-Z rotational influence has translational components $(-y, x, 0)$, relative to that centre, plus unit

RZ where appropriate. Rotational effective quantities are inertia measures and their ratios; they do not demonstrate that the selected starting loads adequately excite every pure torsional mode.

The spectrum report flags captured directional mass below 90% for review. It does not automatically add modes, perform missing-mass correction or declare code compliance. Check both participation and stability of periods and response when increasing the requested count.

Higher Ritz periods can move as the basis changes; matching mode numbers alone is insufficient when modal character changes.

U1 - retained mass 90.64%

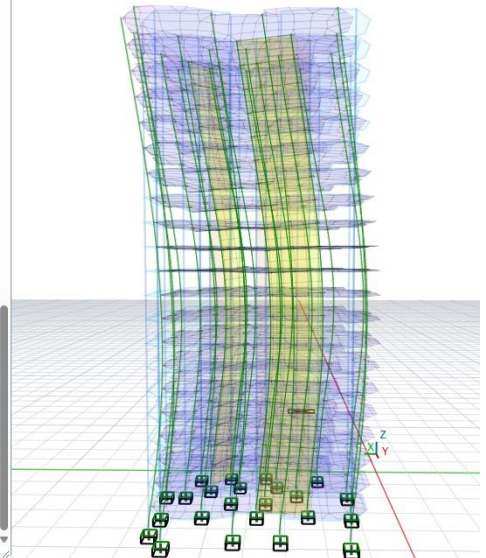
Mode	T (s)	Γ	S_a (m/s ²)	S_d (m)	Effective mass (kg)	Mass (%)	Cumulative (%)	Modal base shear (kN)
1	4.2926	-383.13	0.045386	0.021184	1.4679e+5	1.9086	1.9086	6.6623
2	2.7278	-1124.4	0.11401	0.021489	1.2642e+6	16.437	18.346	144.13
3	2.3984	2015.9	0.14758	0.021505	4.0640e+6	52.840	71.186	599.78
4	1.3217	103.75	0.42280	0.018710	10764	0.13996	71.326	4.5511
5	0.59745	613.32	0.92499	0.0083633	3.7617e+5	4.8909	76.217	347.95
6	0.57102	-1053.1	0.97363	0.0080416	1.1091e+6	14.421	90.638	1079.9

U2 - retained mass 93.56%

Mode	T (s)	Γ	S_a (m/s ²)	S_d (m)	Effective mass (kg)	Mass (%)	Cumulative (%)	Modal base shear (kN)
1	4.2926	1931.2	0.013611	0.0063531	3.7295e+6	48.491	48.491	50.763
2	2.7278	1079.1	0.034191	0.0064444	1.1644e+6	15.140	63.631	39.813
3	2.3984	906.60	0.044260	0.0064493	8.2193e+5	10.687	74.318	36.379
4	1.3217	-761.22	0.12680	0.0056111	5.7946e+5	7.5341	81.852	73.474
5	0.59745	-762.65	0.27740	0.0025081	5.8164e+5	7.5625	89.415	161.35
6	0.57102	-564.51	0.29199	0.0024117	3.1867e+5	4.1434	93.558	93.050

The modal contribution tables show values before optional base-shear scaling. Applied directional factors are shown in the benchmark table and are included once in generated torsion. Missing-mass correction is not applied. Review retained mass, seismic weight and the accidental-torsion audit before design.

[Export complete results \(JSON\)](#)



Spectrum Modal Contributions

Contributions for the actual excitation direction and angle of each spectrum case, before modal and directional combination. Participation factors and modal coefficients depend on mode-shape normalization.

12 rows

Case	Direction	Mode	Period s	Participation factor	S_a m/s ²	Spectral displacement m	Raw modal coefficient	Base-shear scale	Design modal coefficient	Effective mass kg	Mass ratio	Cumulative mass ratio	Raw modal base shear kN
SpecX	U1	1	4.2926476	-383.13484	0.045385944	0.021184202	-8.1164057	1	-8.1164057	146792.31	0.019086036	0.019086036	6.6623073
SpecX	U1	2	2.7278182	-1124.3674	0.11400808	0.021488531	-24.161005	1	-24.161005	1264202.1	0.16437243	0.18345846	144.12926
SpecX	U1	3	2.3984373	2015.9376	0.14758368	0.021504796	43.352328	1	43.352328	4064004.5	0.52840465	0.71186312	599.78074
SpecX	U1	4	1.3217377	103.75062	0.42280433	0.018709849	1.9411584	1	1.9411584	10764.192	0.0013995676	0.71326268	4.5511468
SpecX	U1	5	0.59744697	613.32389	0.92499439	0.008363308	5.1294166	1	5.1294166	376166.19	0.048909386	0.76217207	347.95162
SpecX	U1	6	0.57102209	-1053.1403	0.9736323	0.0080415738	-8.4689053	1	-8.4689053	1109104.4	0.14420652	0.90637859	1079.8599
SpecX	U2	1	4.2926476	1931.1935	0.013611178	0.0063531111	12.269087	1	12.269087	3729508.3	0.48491322	0.48491322	50.763002
SpecX	U2	2	2.7278182	1079.091	0.034190857	0.0064443791	6.9540715	1	6.9540715	1164437.4	0.15140095	0.63631417	39.813112
SpecX	U2	3	2.3984373	906.60251	0.04426013	0.0064492569	5.8469125	1	5.8469125	821928.12	0.10686766	0.74318183	36.378645
SpecX	U2	4	1.3217377	-761.22014	0.1267984	0.0056110563	-4.2712491	1	-4.2712491	579456.1	0.075341279	0.81852311	73.474108
SpecX	U2	5	0.59744697	-762.65049	0.27740447	0.0025081439	-1.9128371	1	-1.9128371	581635.76	0.07562468	0.89414779	161.34836
SpecX	U2	6	0.57102209	-564.51274	0.2919909	0.0024116562	-1.3614107	1	-1.3614107	318674.63	0.041434293	0.93558208	93.050093

Figure 3.4 – Modal Participation

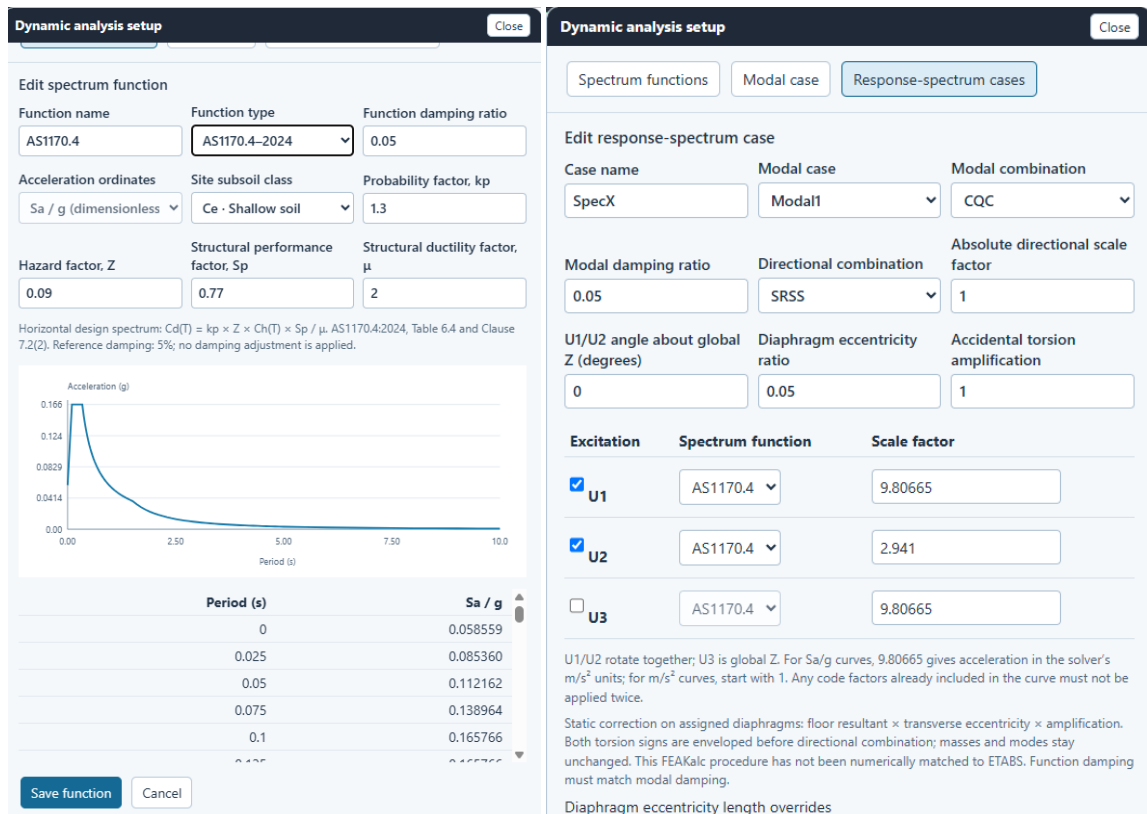
4 Response spectrum functions

4.1 Function and case are different objects

A spectrum function defines acceleration ordinate versus structural period and records its damping basis and units. A response spectrum case selects that function for one or more excitation directions, supplies acceleration scale factors, damping, excitation angle and combination options. Several cases can use one function without duplicating it.

The ordinate used by the solver is pseudo-spectral acceleration consistent with the displacement relation $S_d = S_a/\omega^2$. A function expressed in g requires a case scale containing 9.80665 to obtain m/s^2 ; a function already in m/s^2 normally requires unit scale.

The engine multiplies the ordinate by the entered case scale once. The units label does not insert a second automatic conversion. Any additional directional or design multiplier included in that scale must be recorded explicitly.



The screenshot displays two side-by-side windows from the FEAkalc 3D software. The left window, titled 'Dynamic analysis setup', shows the 'Edit spectrum function' dialog. It includes fields for 'Function name' (AS1170.4), 'Function type' (AS1170.4-2024), 'Function damping ratio' (0.05), 'Acceleration ordinates' (Sa / g), 'Site subsoil class' (Ce - Shallow soil), 'Probability factor, kp' (1.3), 'Hazard factor, Z' (0.09), 'Structural performance factor, Sp' (0.77), and 'Structural ductility factor, μ' (2). Below these fields is a graph of 'Acceleration (g)' vs 'Period (s)' and a table of values.

Period (s)	Sa / g
0	0.058559
0.025	0.085360
0.05	0.112162
0.075	0.138964
0.1	0.165766

The right window, also titled 'Dynamic analysis setup', shows the 'Edit response-spectrum case' dialog. It includes fields for 'Case name' (SpecX), 'Modal case' (Modal1), 'Modal combination' (CQC), 'Modal damping ratio' (0.05), 'Directional combination' (SRSS), 'Absolute directional scale factor' (1), 'U1/U2 angle about global Z (degrees)' (0), 'Diaphragm eccentricity ratio' (0.05), and 'Accidental torsion amplification' (1). Below these fields is a table of excitation, spectrum function, and scale factor.

Excitation	Spectrum function	Scale factor
☒ U1	AS1170.4	9.80665
☒ U2	AS1170.4	2.941
☐ U3	AS1170.4	9.80665

Below the table, there is a note: 'U1/U2 rotate together; U3 is global Z. For Sa/g curves, 9.80665 gives acceleration in the solver's m/s² units; for m/s² curves, start with 1. Any code factors already included in the curve must not be applied twice.' and a warning: 'Static correction on assigned diaphragms: floor resultant × transverse eccentricity × amplification. Both torsion signs are enveloped before directional combination; masses and modes stay unchanged. This FEAkalc procedure has not been numerically matched to ETABS. Function damping must match modal damping.' and a checkbox for 'Diaphragm eccentricity length overrides'.

Figure 4.1 – Spectra Functions and RSA Cases in FEAkalc 3D

4.2 User supplied curves

User curves contain at least two period–acceleration pairs. Periods must be nonnegative and strictly increasing; ordinates must be nonnegative and finite. The parser accepts up to 10000 points. The retained modal period must lie inside the supplied range, including its endpoints. Extrapolation is rejected rather than silently holding the last value or extending a logarithmic branch.

For adjacent supplied points, interpolation is linear in period and acceleration:

$$S(T) = S_a + \frac{T - T_a}{T_b - T_a} (S_b - S_a) \quad (4.1)$$

This is not log-log interpolation. Adequate point density is therefore needed around corners and rapidly changing branches. Damping entered for the function must match the response spectrum case within the run validator's numerical tolerance. The program does not modify the curve for a different damping ratio.

4.3 Australian horizontal function

The generated AS 1170.4:2024 function uses site class Ae, Be, Ce, De or Ee and user inputs k_p , Z , S_p and μ . It evaluates the horizontal design ordinate in g as:

$$C_d(T) = k_p Z C_h(T) \frac{S_p}{\mu} \quad (4.2)$$

The modal spectral shape uses a rising short-period branch, a capped velocity branch and a long-period displacement branch. The following are the implemented coefficients, identified as C_0 , a , C_{max} , C_v and C_{disp} for this manual; they are not additional user inputs.

Site	C_0	a	C_{max}	C_v	C_{disp}
Ae	0.8	15.5	2.35	0.704	1.056
Be	1.0	19.4	2.94	0.880	1.320
Ce	1.3	23.8	3.68	1.250	1.874
De	1.1	25.8	3.68	1.980	2.970
Ee	1.1	25.8	3.68	3.080	4.620

For $0 \leq T \leq 0.1$ s, $C_h = C_0 + aT$. For $0.1 < T \leq 1.5$ s, $C_h = \min(C_{max}, C_v/T)$. For $T > 1.5$ s, $C_h = C_{disp}/T^2$. The precise piecewise inequalities form part of the calculation. Printed coefficients are retained, including Ce's 1.874 long-period coefficient; the software does not alter a coefficient to force exact branch continuity.

Generated curves use 5% damping. Their saved point list supports preview and persistence, but analysis evaluates the analytical function at the actual modal period rather than interpolating the preview points. The generator and parameter validator support Ae–Ee; a special-site or other-damping spectrum must be supplied as a suitable user curve. Generated horizontal Australian functions are rejected for U3 excitation.

These expressions describe the implemented function and the relevant Table 6.4 / Clause 7.2 basis in the supplied standard. They do not select hazard, probability, ductility or performance factors on the engineer's behalf. [R01]

4.4 Preserved 2007 reference function

The saved 2007 reference is a fixed rounded curve with site Ce, $k_p = 1.3$, $Z = 0.09$, $S_p = 0.77$, $\mu = 2$ and 5% damping. Its 23 points extend from 0 to 10 s. It reproduces the retained reference values and is interpolated linearly like a user table.

This function must not be described as a general 2007 spectrum generator. Changing its parameters does not authorise applying the retained points to a different site or damping basis. A function without verified curve points cannot be used for a spectrum run.

5 Response spectrum analysis and base shear scaling

5.1 Excitation vectors and modal response

For case angle θ , U_1 , U_2 and U_3 have global influence directions:

$$r_{U1} = (\cos\theta, \sin\theta, 0), \quad r_{U2} = (-\sin\theta, \cos\theta, 0), \quad r_{U3} = (0, 0, 1) \quad (5.1)$$

The case can contain each direction once, with its own function and positive scale. U_3 requires U_Z starting excitation in the modal case and a suitable user-defined vertical function. Horizontal starting loads do not guarantee an adequate vertical response basis.

For mode j and direction k , the engine evaluates the function, applies its scale and forms the modal displacement coefficient:

$$S_{a,jk} = S_k(T_j)s_k, \quad q_{jk} = \Gamma_{jk} \frac{S_{a,jk}}{\omega_j^2} \quad (5.2)$$

The signed response contribution is the recovered response to shape ϕ_j multiplied by q_{jk} . Directional minimum-base-shear factor f_k , when enabled, multiplies this coefficient before modal and directional response combination.

5.2 Signed structural recovery

The backend recovers each signed mode independently using the ordinary member local axes, stiffness, end releases and shell recovery procedures. Spectrum member recovery has no static gravity or fixed-end load contribution. Frame force diagrams, shell centre/corner resultants, nodal translations and rotations are retained as signed modal fields.

The existing force-recovery routines contain their own force-unit conversion. The spectrum adapter supplies 1000ϕ to those routines while retaining ϕ in metres for deformation and assembling $K\phi$ consistently. This is an implementation boundary conversion, not an extra amplification of the earthquake response.

Support responses include contributions from the structural model's connection penalties and elastic shell foundation springs. Signed base forces and moments are summed within each mode about a stated reference point, then combined. The reference is $(0, 0, z_b)$, where z_b is the lowest restrained or elastic-foundation node elevation; if there is neither, the lowest model elevation is used.

$$M_{b,j} = \sum_n [M_{n,j} + (x_n - x_b) \times F_{n,j}] \quad (5.3)$$

Reference-point transformation is performed on signed responses. Moving a reference after combining separate absolute force and moment peaks would not preserve this relationship. Summing independently combined support maxima does not produce the combined base shear or base moment.

5.3 Inertia and recovered member forces

The backend retains both modal nodal inertia, $\omega_j^2 M_n \phi_j / 1000$, and recovered nodal member-force actions, $K\phi_j$. Both use the appropriate case coefficient when reporting a direction's response. They answer different questions in a finite Ritz approximation.

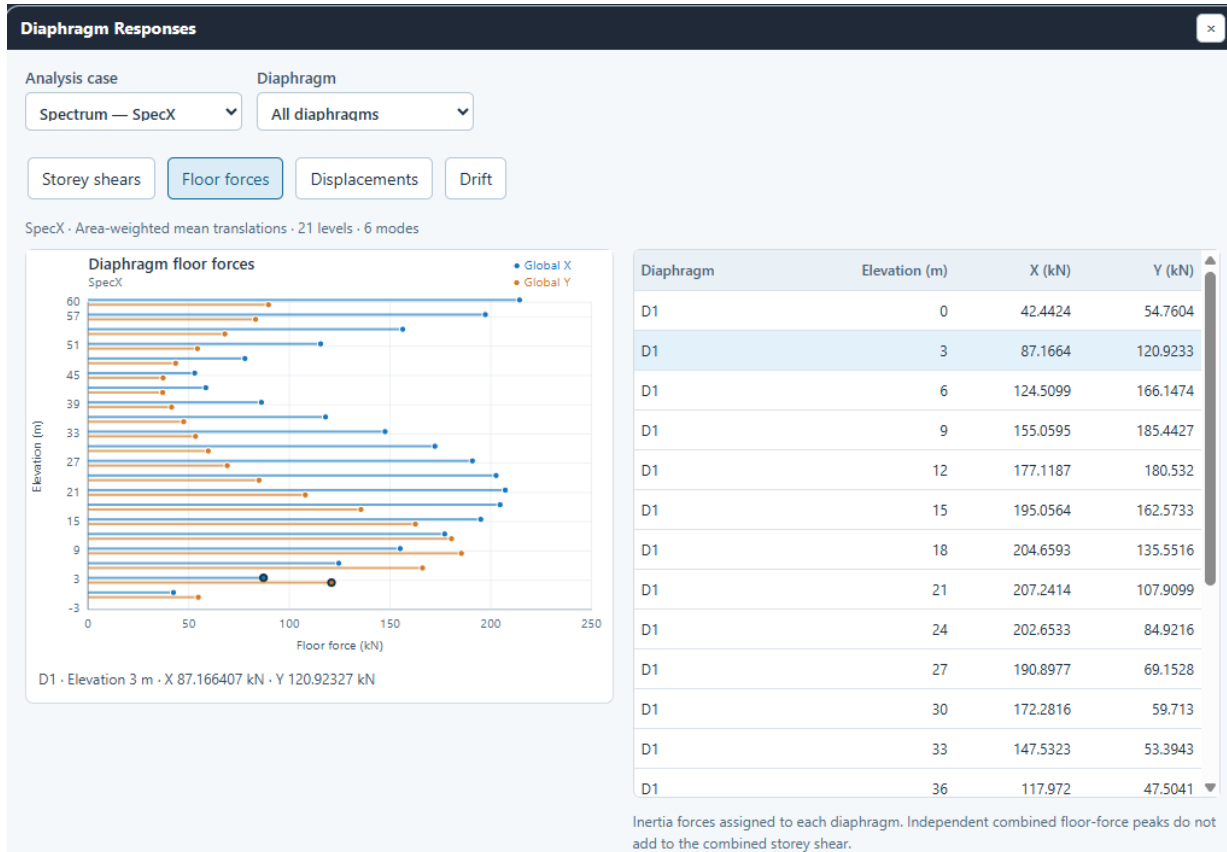


Figure 5.1 – Inertia Forces to Diaphragms from Spectra Case

For an exact full-system eigenvector, the eigen-equation relates these fields. A truncated Ritz shape satisfies its projected reduced problem and need not satisfy that relation at every full-system coordinate. The diaphragm floor-force report therefore uses inertia, while whole-building spectrum storey shear uses recovered member forces and support resultants. Artificially scaling one plot to make its peak equal another would conceal that distinction.

5.4 Modal combinations

For signed modal values R_j of one response component under one excitation direction, SRSS returns:

$$R_{SRSS} = \sqrt{\sum_j R_j^2} \quad (5.4)$$

Absolute sum returns the sum of $|R_j|$. CQC includes equal-damping correlation between each modal pair:

$$R_{CQC} = \sqrt{\sum_i \sum_j \rho_{ij} R_i R_j} \quad (5.5)$$

$$\rho_{ij} = \frac{8\zeta^2(1+r)r^{3/2}}{(1-r^2)^2 + 4\zeta^2r(1+r)^2}, \quad r = \frac{\min(\omega_i, \omega_j)}{\max(\omega_i, \omega_j)} \quad (5.6)$$

The same case damping ζ applies to all pairs. At equal frequencies the correlation is one. Signed modal values are retained in CQC cross terms, so correlated contributions can cancel. Taking absolute modal values before CQC would change the method. The computed square is clamped to zero before its square root to protect against negative numerical roundoff.

The selected damping affects CQC correlation. It does not automatically correct a spectrum function's ordinates. The current function/case damping match is required for that reason.

5.5 Directional combinations and result signs

After modal combination and any static torsion addition within each excitation, directional SRSS returns the square root of the sum of directional response squares. Scaled absolute directional combination returns the largest directional magnitude plus β times the sum of the others, with $0 \leq \beta \leq 1$.

$$R_D = \max_k(R_k) + \beta[\sum_k R_k - \max_k(R_k)] \quad (5.7)$$

This chooses the largest direction separately for each response quantity. It is not one globally selected governing excitation direction. The case does not automatically create every positive/negative directional design combination required for a project.

The combined output is a nonnegative component peak estimate. The ordinary result selector installs positive and negative versions of that envelope for use in explicitly defined design combinations. Those versions do not recover earthquake time, modal phase, simultaneous force vectors or a physical deformed configuration. In particular, concurrent N, M and V for a nonlinear interaction check cannot be inferred merely because their separate peaks occupy the same result row.

5.6 Shell contours and integrated member actions

When a shell contour is smoothed at shared nodes, the program smooths each signed modal field before statistical combination. It does not average already-combined element maxima. For shell-member force resultants, each signed modal field is integrated over the member definition before combination. Signed static-torsion contributions follow the same operation order.

Consequently, displayed element peaks should not be summed into a pier, spandrel or shell-member resultant. A resultant, nodal average or relative displacement is a linear operation that must precede the nonlinear statistical peak operation.

5.7 Australian base shear benchmark

The case can leave the benchmark off, compare only, or scale up to its minimum. Benchmark hazard parameters are taken from a selected generated 2024 function; this selection is independent of the response function. The user enters structural base elevation, height to the uppermost seismic mass and a structural system for each enabled horizontal direction.

The empirical period, reference shear and minimum are:

$$T_a = 1.25 k_t h^{0.75}, \quad V_s = k_p Z C_{h,static}(T_a) \frac{S_p}{\mu} W \quad (5.8)$$

The implemented k_t values are 0.11 for steel moment frames, 0.075 for concrete moment frames, 0.06 for eccentrically braced frames and 0.05 for structural walls/other systems. Below 0.1 s the static branch evaluates at 0.1 s, using the short-period plateau instead of the modal zero-period reduction.

The directional seismic weight is its free translational mass times $g/1000$. For a rotated axis, the mass is $v_x^2 MX + v_y^2 MY$. The routine does not sum three translational mass totals or infer missing seismic-weight components from building usage.

The minimum is 0.7 V_s for height up to and including 50 m, and 0.5 V_s above 50 m. The exact 50 m boundary retains 0.7 as a documented conservative implementation choice. This is the implemented Clause 7.2 benchmark, not an additional multiplication by the separate 80% equivalent-static period rule.

Dynamic analysis setup

Close

☒ U1
 AS1170.4
 9.80665

☒ U2
 AS1170.4
 2.941

☐ U3
 AS1170.4
 9.80665

U1/U2 rotate together; U3 is global Z. For Sa/g curves, 9.80665 gives acceleration in the solver's m/s² units; for m/s² curves, start with 1. Any code factors already included in the curve must not be applied twice.

Static correction on assigned diaphragms: floor resultant × transverse eccentricity × amplification. Both torsion signs are enveloped before directional combination; masses and modes stay unchanged. This FEAkalc procedure has not been numerically matched to ETABS. Function damping must match modal damping.

Diaphragm eccentricity length overrides

AS1170.4:2024 base-shear benchmark

Base-shear check
Scale up to the minimum

Benchmark hazard function
Select AS1170.4:202

Seismic base elevation (m)
0

Height to uppermost seismic mass (m)
60

U1 structural system
Structural walls / otl

U2 structural system
Structural walls / otl

Suggest height from last analysis

Review the base and height before saving. Seismic weight comes from the linked modal mass source, once per excitation direction. The benchmark uses $T_a \approx 1.25 \text{ kt h}^{0.75}$; the minimum is 70% of static shear up to 50 m and 50% above 50 m. Scaling applies to forces and displacements before directional combination. This is a whole-model check; it does not generate static loads or define storeys.

Save case
Cancel

Figure 5.2 – Scaling Spectra to Static Benchmark

AS1170.4:2024 · Clause 7.2 base-shear benchmark

The reference static shear uses $T_a = 1.25 \text{ kt h}^{0.75}$, not a user-entered or modal period. Weight is taken once from the linked modal mass source. Checks are performed before directional combination.

Direction	Weight (kN)	Height (m)	T_a (s)	Static V (kN)	Minimum (kN)	Raw dynamic (kN)	Applied factor	Final dynamic (kN)	Status
U1	75424	63.000	1.3976	3038.6	1519.3	2260.3	1.0000	2260.3	Meets minimum
U2	75424	63.000	1.3976	3038.6	1519.3	401.02	3.7886	1519.3	Meets minimum

Figure 5.3 – FEAkalc Scaling Check

5.8 Applying the factor

The unscaled dynamic base shear V_d is obtained by projecting each signed modal support resultant onto the excitation vector, multiplying by q_{jk} and combining modes. The required factor is:

$$f_k = \max\left(1, \frac{V_{min,k}}{V_{d,k}}\right) \quad (5.9)$$

Compare-only mode reports this requirement but uses factor one. Scale mode multiplies every relevant modal response contribution by f_k before directional combination: translations, rotations, member actions, shell results, support resultants and inertia. The resulting scaled floor force also feeds the accidental-torsion procedure once.

Scaling never reduces a response. A zero dynamic shear cannot be scaled to a positive minimum and is rejected in scale mode. Each run starts from the unscaled basis, so repeated evaluation does not compound a previous scale factor.

The benchmark applies to the whole represented seismic model. Free seismic mass below the chosen base or above the entered top is rejected. It does not isolate a tower from a podium automatically. The output table reports weight, empirical period, reference/minimum shears, unscaled dynamic shear, required/applied factors and final shear. A passed minimum-shear check is not a check of member design, drift, detailing, regularity or overall earthquake-code compliance.

6 Accidental torsion

6.1 Natural torsion and accidental correction

The structural model already develops natural coupled translational/torsional behaviour from its mass and stiffness distribution. The optional accidental-torsion calculation adds a separate static correction on assigned semi-rigid diaphragm domains. It does not move masses, modify K or M, regenerate an eccentric modal basis or create rigid diaphragm constraints.

Only assigned diaphragm domains receive these floor corrections. Mass or structural response outside those domains still participates in the global model, but it is not automatically assigned an accidental floor torque. The current eccentricity ratio range is zero to 0.5; a per-domain, elevation and horizontal-direction absolute-length override can replace the ratio-based length.

Static accidental torsion

For each direction: envelope = modal peak + [signed static correction]. The same torsion sign is applied across the floor stack; both signs are enveloped. Directional combination follows this operation. Lengths: m; forces: kN; torques: kN-m.

Direction	Diaphragm	Elevation	Width	Eccentricity	Floor force	Amplification	Torque
U1	D1	0.0000	22.778	1.1389	40.396	1.1000	50.608
U1	D1	3.0000	22.778	1.1389	82.316	1.1000	103.12
U1	D1	6.0000	22.778	1.1389	118.31	1.1000	148.21
U1	D1	9.0000	22.778	1.1389	148.80	1.1000	186.42
U1	D1	12.000	22.778	1.1389	171.11	1.1000	214.36
U1	D1	15.000	22.778	1.1389	188.58	1.1000	236.26
U1	D1	18.000	22.778	1.1389	196.84	1.1000	246.59
U1	D1	21.000	22.778	1.1389	197.33	1.1000	247.21
U1	D1	24.000	22.778	1.1389	190.42	1.1000	238.56
U1	D1	27.000	22.778	1.1389	176.68	1.1000	221.35
U1	D1	30.000	22.778	1.1389	156.91	1.1000	196.58
U1	D1	33.000	22.778	1.1389	132.14	1.1000	165.55
U1	D1	36.000	22.778	1.1389	103.80	1.1000	130.04
U1	D1	39.000	22.778	1.1389	74.333	1.1000	93.123
U1	D1	42.000	22.778	1.1389	50.167	1.1000	62.849
U1	D1	45.000	22.778	1.1389	48.161	1.1000	60.336
U1	D1	48.000	22.778	1.1389	72.444	1.1000	90.757

Figure 6.1 – Torsion Amplification

6.2 Floor force and transverse width

For a horizontal direction with global unit vector (vx, vy), the transverse coordinate is -vy x + vx y. Width bi is the maximum minus minimum transverse coordinate over that domain's nodes. The eccentricity length ei is the case ratio times bi, unless a length override exists.

For each mode, the signed nodal inertia projected onto the excitation is summed over that diaphragm's membership and multiplied by qjk. The selected modal combination gives a positive floor-force peak. Directional base-shear scaling is included once. The floor torque is then:

$$F_{ik} = f_k C(\{q_{jk} \sum_{n \in i} v_k \cdot f_{n,j}^{inertia}\}_j), \quad T_{ik} = A_t e_{ik} F_{ik} \quad (6.1)$$

At is the user-entered torsional amplification, from 1 to 100; the program does not derive it automatically from a torsional-irregularity check. The floor-force peak is combined separately for each floor. These positive torque peaks form one full-system static load pattern per horizontal excitation direction.

6.3 Full system static correction

Each floor torque is distributed with the equilibrium-preserving translational force couple in Section 2.5, setting net floor F_x and F_y to zero. The backend assembles these nodal loads into the full structure, solves the free-coordinate static system and recovers signed translations, rotations, member/shell forces and support resultants.

This uses the full structural stiffness, rather than projecting a pure-torque response through the retained translational Ritz modes. Direct solution is attempted through the configured static path; the PCG fallback uses a 10^{-8} target and rejects nonconvergence. The nodal load audit verifies the intended torque and zero net correction force.

One signed static pattern is sufficient for the two global signs because the structure is linear. Within each excitation direction, the engine adds the absolute static response to the modal peak for that response component:

$$R_k^{env} = R_k^{modal} + |R_k^{torsion}|, \quad R = D(\{R_k^{env}\}_k) \quad (6.2)$$

This envelopes both signs of the complete static pattern. It does not enumerate arbitrary independent sign permutations at every floor or generate simultaneous signed member-force sets. Signed relative floor translations are formed before taking the absolute torsion contribution for drift.

6.4 Consequences and method boundaries

Floor torques have zero net global horizontal force, but they can redistribute support reactions and local shell/member forces and alter floor displacements. The selected report must be interpreted according to its definition: a translational floor-force sum does not display the applied torque, and a mean translation can remain small despite substantial edge response.

The method intentionally derives torque from separately modal-combined floor inertia peaks. This is generally different from taking differences between adjacent already-combined storey shears. Statistical combination and subtraction do not commute. Equality of a total base torque also does not demonstrate equal local nodal load distribution or equal shell/drift response.

The retained Model 1 investigation identifies both unequal diaphragm assignment coverage in the comparison model and this calculation-order difference. The implementation documented here remains the floor-inertia/force-couple procedure. It is not an assertion of ETABS accidental-torsion equivalence, and the diagnostic alternative was not a production change.

7 Wind generation and static analysis

7.1 Supported wind procedure

The automatic wind feature generates single-direction overall external wall loads for assigned diaphragm levels using the implemented AS/NZS 1170.2:2021 data and procedure. The calculation report identifies the WindKALC origin. Australian regions A0–A5, B1, B2, C and D and terrain categories 1, 2, 2.5, 3 and 4 are available.

Each definition belongs to an existing primary static case classified as Wind. One definition represents one applied force direction. Opposite force directions and opposite torsion signs require appropriate separate cases. User-defined wind loads can also be entered directly as diaphragm Fx, Fy, Mz and application points, bypassing automatic pressure generation.

The generator is not a dynamic wind analysis. Cdyn is a user input; the program does not calculate it from modal periods, damping or mass. It does not automatically generate crosswind, roof, parapet, internal-pressure, friction or local cladding loads. Other shape factors outside the entered coefficients are taken as one. The wind report is a calculation record for this defined scope, not a complete aerodynamic assessment of every building form.

AS/NZS 1170.2:2021 Wind Loads

Wind load case

WindX

One applied-force direction per case: 0° = +X, 90° = +Y. Along-wind only, with user-entered Cdyn. Windward Cp and leeward suction are positive magnitudes.

Wind region

Return period R (years)

Terrain category

Limit state

Force direction (°)

Ground / exposure base Z (m)

Md direction multiplier

Ms shielding multiplier

Mt topographic multiplier

Cdyn (user input)

Cp windward

Cp leeward suction

Kc combination factor

Vr override (m/s, optional)

Torsional eccentricity (% width)

Vr and Mc follow the selected Australian region. C/D use tabulated maximum speeds unless overridden. Md is the user-assessed governing multiplier for this direction's sector. Ground Z defaults to the lowest model elevation; adjust it to the actual exposed ground level.

Calculate / Update

Export calculation report

63 m high - 21 diaphragms / 21 levels

Vr 45 m/s · Mc 1 · Mz,cat(H) 1.1508 · Vdes(H) 51.786 m/s

Along-wind force 2,411.5419 kN · Base overturning moment 80,208.5465 kN-m

Widths/depths and X/Y follow each diaphragm. Edit to override; Auto restores model values. Tributary strips meet at adjacent-level midpoints and extend to the exposure base and highest included level. Exclude non-exposed diaphragms as required.

Eccentricity applies to every included diaphragm: Mz = force × width × percentage. Positive gives counterclockwise Mz; negative gives clockwise. New cases default to 20% above 70 m, otherwise 0%, following Clause 2.5.4 for rectangular enclosed buildings. The value remains user-controlled when geometry or exposure changes. Use separate cases for opposite torsion signs. X/Y overrides add their own eccentric moment.

Use	Z (m)	Diaphragm	Width (m)	Depth (m)	X (m)	Y (m)	Tributary height (m)	WW (kPa)	LW (kPa)	Fx (kN)	Fy (kN)	Mz (kN-m)
☒	60	D1	22.77800000	27.77899999	18.87235204	12.71193502	1.5	1.1561	0.7241	64.2409	0	0
☒	57	D1	22.77800000	27.77899999	18.87235204	12.71193502	3	1.1489	0.7241	127.9878	0	0

Figure 7.1 – Wind Loading Dialog in FEAkalc

7.2 Regional and site speed

Regional speed VR is selected from the implemented region-group and return-period table. Available return periods are 1, 5, 10, 20, 25, 50, 100, 200, 250, 500, 1000, 2000, 2500, 5000 and 10000 years. An optional positive speed override replaces the table value. Coastal interpolation is not automatic; the C/D tabulated maxima are used unless overridden.

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The climate multiplier M_c is 1.05 in B2, C and D and one in other supported regions. M_d , M_s and M_t are entered by the engineer. In particular, M_d represents an assessed governing directional-sector multiplier; the program does not perform an automatic surrounding-sector search.

$$V(z) = V_R M_c M_d M_{z,cat}(z) M_s M_t \quad (7.1)$$

ULS design speed is $\max(30 \text{ m/s}, V(z))$; SLS uses $V(z)$ without that minimum. The pressure constant 0.0006 expresses the adopted velocity-pressure conversion in kPa for speed in m/s. The minimum is applied to the product speed before squaring, rather than to V_R alone.

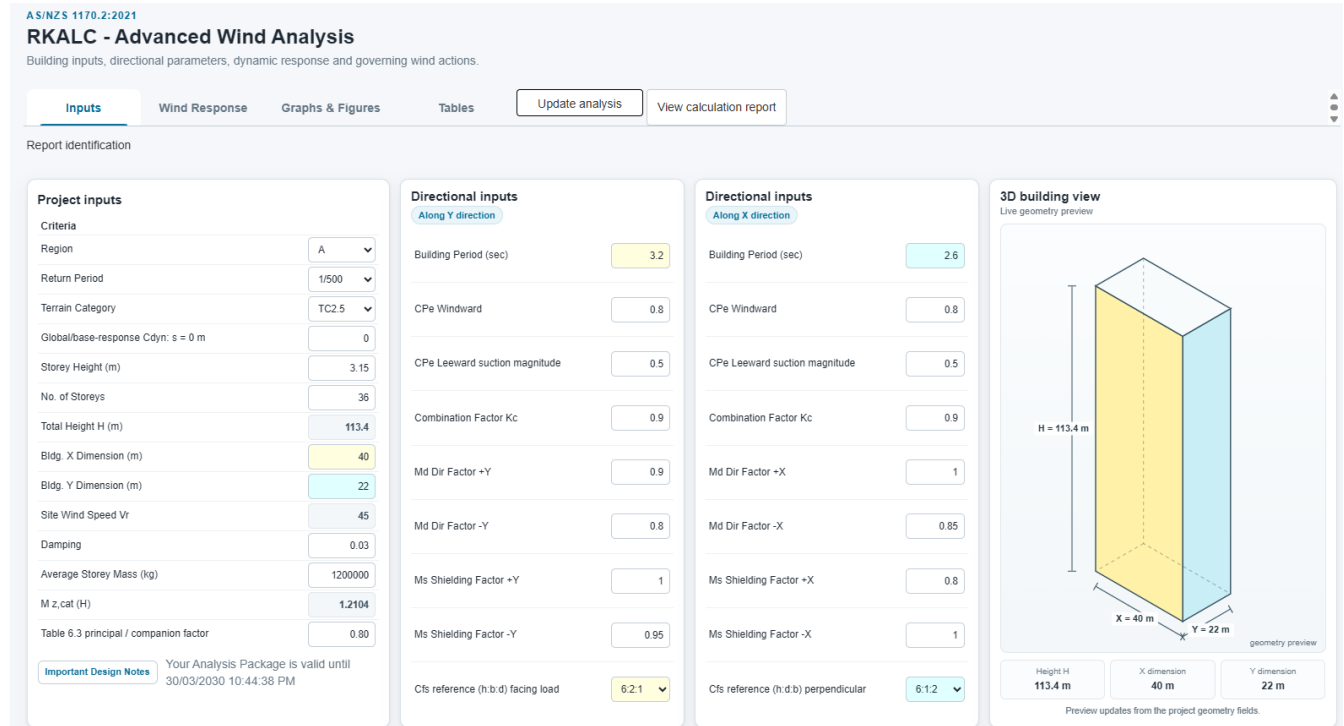


Figure 7.2 – WindKALC Web Application by RKALC for Dynamic Effects

7.3 Terrain interpolation and reference heights

Terrain data are tabulated at 3, 5, 10, 15, 20, 30, 40, 50, 75, 100, 150 and 200 m above the selected exposure ground datum. Between rows the multiplier is linearly interpolated in height. Values below 3 m use the 3 m row. Heights above 200 m are rejected.

For A0, the implementation uses terrain category 2 through 100 m, regardless of the entered terrain category, and 1.24 above 100 m. The A0 rule and breakpoint are applied in the pressure evaluation and integration.

Windward reference speed uses the roof height for buildings of exposed height $H \leq 25 \text{ m}$. Above 25 m it uses the local strip integration height above the exposure base. Leeward reference speed always uses roof height. Ground datum is an engineering input; its initial suggestion comes from the lowest frame/shell geometry and may require correction when basements exist.

7.4 Pressure calculation

The windward and leeward inputs are positive coefficient magnitudes $C_{p,WW}$ and $C_{p,LW}$. Their wall-force contributions act in the same overall along-wind direction and are added, rather than subtracting the positive suction magnitude.

$$p_{WW}(z) = 0.0006 V_{des}(z_{ref})^2 C_{p,WW} K_c C_{dyn} \quad (7.2)$$

$$p_{LW} = 0.0006 V_{des}(H)^2 C_{p,LW} K_c C_{dyn} \quad (7.3)$$

The same user inputs K_c and C_{dyn} apply to both contributions. C_p values are not automatically recalculated from each floor's depth or aspect ratio. Depth is resolved, displayed and can be overridden, but the current force calculation uses the entered C_p values and exposure width. This is particularly important when modelling setbacks or nonrectangular plans.

7.5 Geometry and exposure strips

The source floor domain provides projected transverse width, along-wind depth and geometric-centroid coordinates for each assigned level. Automatic plan geometry follows the source floor domain and openings; the backend later distributes resulting loads on its resolved mesh. Per-level overrides can set width, depth, application coordinates or inclusion.

Only included levels at or above the exposure base are active. Active elevations are sorted, and tributary strips meet at adjacent-elevation midpoints. The lowest strip extends to the exposure base, and the highest ends at the highest included level. A base-level diaphragm, when included, receives the lower half-storey exposure strip. Excluding a level redistributes the strip boundaries to the remaining included elevations.

At one elevation, overlapping projected exposures require explicitly allocated widths for both regions to avoid double-counting the facade. Width changes between levels are represented at the midpoint boundary; this is a geometric exposure approximation and does not calculate flow separation or shielding around irregular building forms.

7.6 Integration and generated actions

For diaphragm level i , using its width b_i and strip bounds z_{i-} and z_{i+} , the resultant is:

$$F_i = b_i \int_{z_{i-}}^{z_{i+}} [p_{WW}(z) + p_{LW}] dz \quad (7.4)$$

Windward pressure is integrated with three-point Gauss quadrature on subintervals split at terrain-table heights. The standard abscissae are 0 and $\pm\sqrt{3/5}$, with weights 8/9 and 5/9, mapped to each subinterval. Leeward pressure is constant over the strip, so its integral is p_{LW} times strip height. Calculations use unrounded values; report formatting does not feed rounded values back into the loads.

With applied force angle θ and signed eccentricity ratio ε_w , the generated actions are:

$$F_{x,i} = F_i \cos\theta, \quad F_{y,i} = F_i \sin\theta, \quad M_{z,i} = F_i \varepsilon_w b_i \quad (7.5)$$

The sign of ε_w directly controls global-Z moment independently of force angle. Reversing the applied force direction while retaining positive ε_w still generates positive M_z . An explicit X/Y application override adds the separate moment from Equation 2.3.

Each strip force is applied at the diaphragm elevation. The report's base moment is the sum $F_i(z_i - z_{base})$ for these applied floor loads. It is not the exact pressure integral of force times continuous height; concentrating strip forces at floors is an explicit structural load approximation. Forces are preserved by integration, while overturning depends on the selected application levels.

7.7 Defaults and torsion

New wind definitions initially use region A2, 500-year return period, terrain 2.5, ULS, angle zero, $M_d = M_s = M_t = C_{dyn} = 1$, $C_{pWW} = 0.8$, $C_{pLW} = 0.5$ and $K_c = 0.9$. These are editable starting values, not a project assessment.

The initial eccentricity is 20% when the suggested exposed height is greater than 70 m and zero otherwise, based on the referenced rectangular-enclosed-building eccentricity provision. Exactly 70 m starts at zero. Saved eccentricity remains user-controlled when height changes. The threshold does not automatically

establish applicability to a particular building, and the dynamic along/crosswind loading sets are not generated.

For the ULS minimum-speed transition within a subinterval, the implemented quadrature is still evaluated numerically; the integration does not explicitly split at every possible minimum-speed crossover. Appendix A's constant-pressure example is exact for that example's inputs.

Kc combination factor

0.9

Vr override (m/s, optional)

Torsional eccentricity (% width)

0.2

Vr and Mc follow the selected Australian region. C/D use tabulated maximum speeds unless overridden. Md is the user-assessed governing multiplier for this direction's sector. Ground Z defaults to the lowest model elevation; adjust it to the actual exposed ground level.

Calculate / Update

Export calculation report

63 m high · 21 diaphragms / 21 levels

Vr 45 m/s · Mc 1 · Mz,cat(H) 1.1508 · Vdes(H) 51.786 m/s

Along-wind force 2,411,5419 kN · Base overturning moment 80,208.5465 kN-m

Widths/depths and X/Y follow each diaphragm. Edit to override; Auto restores model values. Tributary strips meet at adjacent-level midpoints and extend to the exposure base and highest included level. Exclude non-exposed diaphragms as required.

Eccentricity applies to every included diaphragm: Mz = force × width × percentage. Positive gives counterclockwise Mz; negative gives clockwise. New cases default to 20% above 70 m, otherwise 0%, following Clause 2.5.4 for rectangular enclosed buildings. The value remains user-controlled when geometry or exposure changes. Use separate cases for opposite torsion signs. X/Y overrides add their own eccentric moment.

Use	Z (m)	Diaphragm	Width (m)	Depth (m)	X (m)	Y (m)	Tributary height (m)	WW (kPa)	LW (kPa)	Fx (kN)	Fy (kN)	Mz (kN-m)	
☒	60	D1	22.7780000	27.7789999	18.8723520	12.7119350	1.5	1.1561	0.7241	64.2409	0	2.9266	Auto
☒	57	D1	22.7780000	27.7789999	18.8723520	12.7119350	3	1.1489	0.7241	127.9878	0	5.8306	Auto
☒	54	D1	22.7780000	27.7789999	18.8723520	12.7119350	3	1.1393	0.7241	127.3315	0	5.8007	Auto
☒	51	D1	22.7780000	27.7789999	18.8723520	12.7119350	3	1.1297	0.7241	126.678	0	5.7709	Auto
☒	48	D1	22.7780000	27.7789999	18.8723520	12.7119350	3	1.1201	0.7241	126.023	0	5.7400	Auto

Figure 7.3 – Torsion in Wind Loads

7.8 Persistence and manual cases

Automatic definitions retain their parameters, overrides and load ownership. Before analysis and normal persistence, their owned rows are regenerated from current geometry. Invalid exposure geometry prevents analysis with a validation error. This avoids retaining a previously calculated width after a floor changes.

Editing generated rows through a manual diaphragm editor converts the affected wind case to manual loading and retains its current rows. Automatic regeneration then ceases for that case. User-defined rows remain additive and can represent direct engineering load inputs not covered by the automatic wall generator. Both automatic and manual cases ultimately use the same diaphragm load-distribution engine and static structural analysis.

User Defined Wind Loads on Diaphragms

Wind load case

WindX

Global Fx/Fy in kN; Mz in kN-m, positive counterclockwise. X/Y in metres default to the geometric centre. Edit X/Y to move the application point; Centre restores automatic coordinates. Rows for a case add together. Save commits edits across all wind cases; Cancel discards them. Editing an automatically generated case converts it to user-defined loading.

Elevation (m)	Diaphragm	Fx (kN)	Fy (kN)	Mz (kN-m)	X (m)	Y (m)		
60	D1	64.24086135	0	0	18.87235204	12.71193502	Centre	Delete
57	D1	127.9877890	0	0	18.87235204	12.71193502	Centre	Delete
54	D1	127.3315062	0	0	18.87235204	12.71193502	Centre	Delete
51	D1	126.6779780	0	0	18.87235204	12.71193502	Centre	Delete
48	D1	126.0193290	0	0	18.87235204	12.71193502	Centre	Delete
45	D1	125.0027352	0	0	18.87235204	12.71193502	Centre	Delete
42	D1	123.7981370	0	0	18.87235204	12.71193502	Centre	Delete
39	D1	122.6032225	0	0	18.87235204	12.71193502	Centre	Delete

Figure 7.4 – Manual (User Defined) wind loads

8 Building responses and interpretation

8.1 Floor mean displacement

For a diaphragm with positive tributary areas A_n , the signed mean translation in a specified direction is:

$$\bar{u}_i = \frac{\sum_{n \in i} A_n u_n}{\sum_{n \in i} A_n} \quad (8.1)$$

This is an area-weighted spatial mean of the semi-rigid floor field. It is not displacement at the mass centroid, a rigid-floor master-node displacement, maximum node displacement or maximum edge response. Nodes with zero tributary area have zero weight in this mean.

In response spectrum reporting, each mode's signed floor mean is formed before combination. Static-torsion floor means are formed from their signed fields and then enveloped within each direction. In static Wind reporting, the complete signed static displacement field is used, including any other loads present in that case.

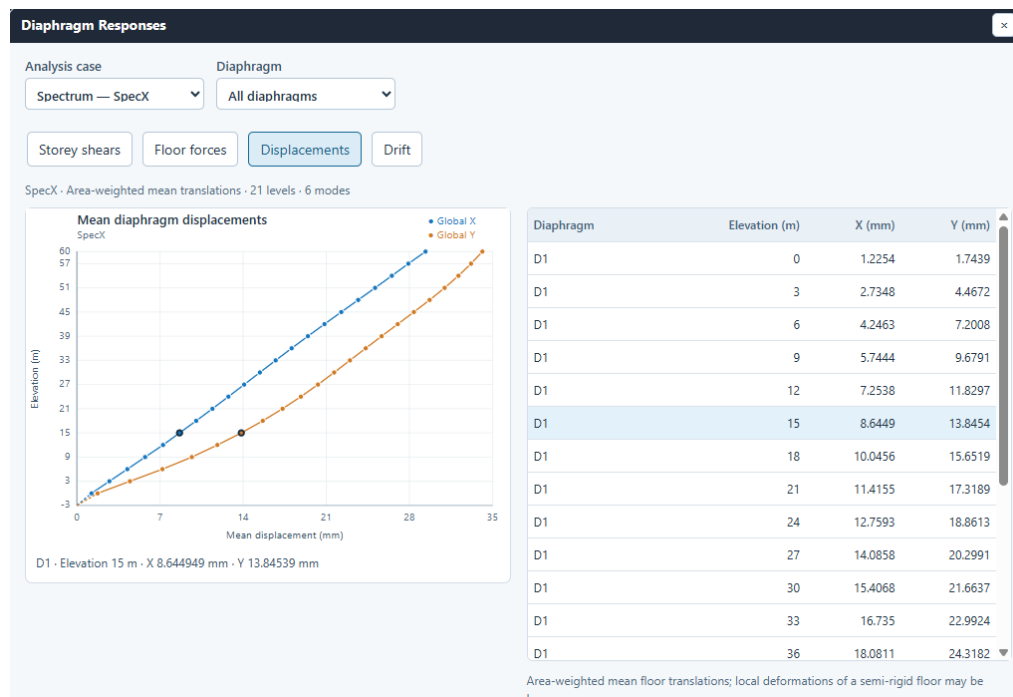


Figure 8.1 – Diaphragm Displacements

8.2 Relative floor displacement and drift

The relative response is upper mean minus lower mean within each signed mode, not the difference between two independently combined floor peaks. The drift ratio uses the actual elevation difference h :

$$\Delta_{i,j} = \bar{u}_{i,j} - \bar{u}_{lower,j}, \quad d_i = \frac{D(\{C(\{q_{jk} f_k \Delta_{i,j}\}_j) + |\Delta_{i,k}^{torsion}|\}_k)}{h_i} \quad (8.2)$$

For static wind, drift is simply the signed difference of the complete analysed floor means divided by h . No additional design-code displacement amplification or acceptance limit is applied by the report. Elastic mean-floor drift must therefore be distinguished from a fully assessed design drift, edge drift or cladding compatibility check.

The lower reference is the immediately preceding assigned elevation. A unique domain with the same definition ID is preferred; otherwise the report uses an unambiguous candidate based on plan bounds.

Ambiguity produces a blank drift and a note, rather than an assumed reference. The first assigned level references the mean displacement of base-support nodes in its plan bounds, using equal support-node weights, including actual spring-support movement.

A zero-height base floor has no drift ratio. Omitting diaphragm assignments at physical floors makes the relative displacement span the full gap between assigned elevations. Assignments should cover every floor where a storey-by-storey report is intended. Mean response alone can conceal torsional edge movement.

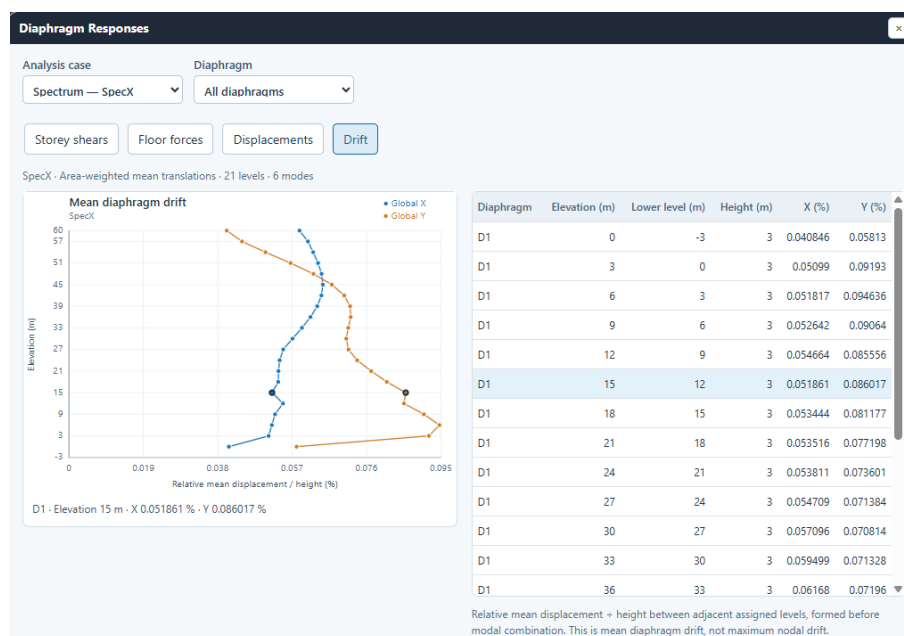


Figure 8.2 - Drifts

8.3 Spectrum floor force

The spectrum floor-force report sums each mode's signed X or Y inertia over the selected diaphragm membership, applies its case coefficient and scaling, and then combines. It includes inertia of enclosed member joints in that membership even where their tributary load weight is zero.

It is a directional inertia resultant for that domain, not a force obtained by subtracting two independently combined building shears. Statistical floor-force peaks cannot be added to obtain a statistically combined storey shear. The pure-torque static correction has zero net horizontal force and does not add a translational floor-force resultant.

8.4 Spectrum whole storey shear

At each assigned elevation, the current recovery sums each signed mode's global nodal member forces $K\phi$ at and above the horizontal cut over the whole building. This includes relevant unassigned nodes and member mass response; the quantity is not filtered to one floor domain.

The base elevation uses the mode's signed support resultant instead of summing $K\phi$ including both ends at supports, which would cancel internal actions. These signed cut/base responses are scaled and combined using the case settings. The base includes any relevant signed static torsion response before the directional envelope, matching the base-resultant reporting path.

Older recovered bases without the separate storey-force field use legacy inertia at upper cuts with an explicit rerun notice. The base still uses support recovery. Such legacy upper cuts must not be described as current recovered member-force cuts. The distinction is especially relevant for truncated Ritz bases.

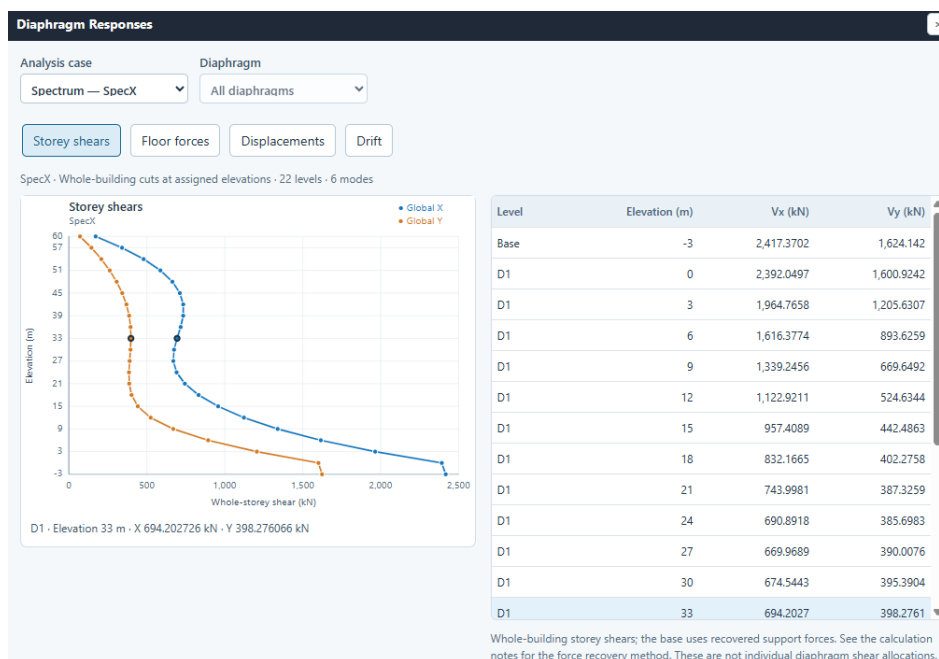


Figure 8.3 – Spectra Whole Storey Shears

8.5 Static wind floor forces and storey shears

Static wind floor forces are algebraic sums of the analysed diaphragm load audit for the selected case, definition and elevation. Opposing loads remain signed; pure torque gives zero translational floor force. The storey-shear plot is the cumulative signed diaphragm-applied force at and above each level and the support base.

This wind plot is an applied-load resultant, not a member section-cut integration. Other frame or shell-surface loads in the static case are excluded from its force plot, although their deformation effects are present in the complete displacement field. The report flags a difference from the total support-action resultant for review rather than silently reallocating those additional loads.

Wind reports use completed saved analysis responses and their load audit, not current editable wind inputs. Their input identity must match the current model.

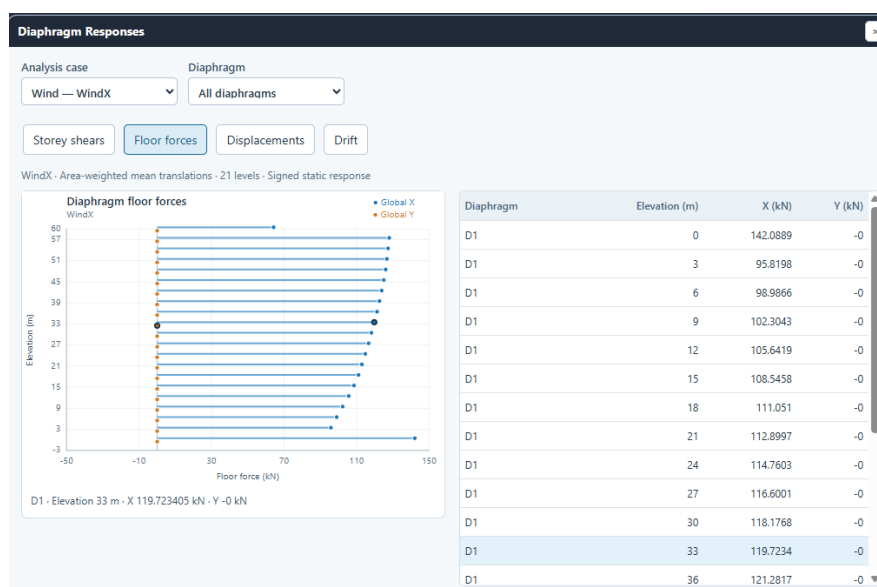


Figure 8.4 – Storey Shears (Wind)

8.6 Reactions and moment references

The existing static reporting convention is load-equivalent support action, $F - Ku$. The physical resisting support action has the opposite sign to the reported load-equivalent resultant. Spectrum output subsequently represents combined magnitudes; its positive and negative display options are envelope signs, not a simultaneous signed support distribution.

Every comparison of overturning or torsion must use the same reference point, axes and force sign. The base-reference metadata records (0, 0, z_b) in metres. Changing z_b changes M_x and M_y through the signed base shear; changing plan origin changes M_z when net horizontal force exists. Equal torsion values with mismatched references can be accidental.

8.7 Model identity and result reuse

Spectrum identity includes structural schedules, supports, material input, analysis plane, mass source, mesh settings, self-weight, modal settings and diaphragm/wind setup. Saved modes are reused only through the applicable identity and settings checks. Changing a response function can reuse an unchanged signed modal basis while recalculating its spectrum responses; changing the structural model or mass source requires compatible modal recovery.

Static Wind reporting has its own analysed-input identity, independent of modal/spectrum settings. Asynchronous report changes are guarded so a superseded result is not installed after inputs change. These checks protect provenance; they do not establish that the original engineering assumptions were correct.

9 Application limits and engineering review

9.1 Limits of the current method

The current workflow is linear, uses a finite load-dependent Ritz basis and reports statistical response spectrum peaks. It provides no automatic missing-mass/rigid-response correction, time-history phase information, nonlinear earthquake response or guaranteed modal convergence. Twenty returned modes are an application limit, not proof of modal sufficiency.

Semi-rigid assignments require connected horizontal floor meshes with membrane stiffness. They do not introduce rigid floors or repair missing connections. The wind generator supplies its specified external-wall actions only; it does not determine full building aerodynamics or dynamic wind response.

The base-shear benchmark and spectrum generator implement specific calculations from their named standard. Their availability does not imply complete compliance assessment. Seismic weight, applicability of response spectrum analysis, torsional allowances, displacement factors, load combinations, strength/detailing and acceptance criteria must be established for the project.

9.2 Reviewing a building model

- Begin with geometry, supports and connectivity.
- Check actual floor openings, wall bases, member-to-floor connections and mesh sensitivity. Inspect the resolved diaphragm audit rather than inferring membership from a name.
- Review total and directional mass, contributions at restrained nodes and floor-by-floor mass distribution.
- Review mode shapes as well as periods.
- Increase the Ritz count and compare the relevant periods, captured mass, member actions and drift. A high captured mass is useful evidence but cannot alone establish local response accuracy.
- Check that vertical response has appropriate UZ excitation and a vertical function when required.
- For spectrum cases:
 - record function units, acceleration scale, damping, angle, enabled directions, modal and directional combinations, base-shear mode and torsion settings.
 - Verify that scales and factors occur once.
 - Inspect a signed/modal quantity before interpreting its combined envelope.
- For wind
 - review the ground datum, included elevations, projected widths and overlap allocation.
 - Establish VR, Md, terrain, shielding, topography, pressure coefficients, Kc and Cdyn for the actual building.
 - Review explicit Mz and application-point eccentricity together.
 - Separate physical pressure resultants from their discretised floor application moments.

9.3 Comparing another program

Match geometry, stiffness modifiers, supports, mass source, mesh, modal method and basis size before interpreting a period difference. Then match spectrum functions, acceleration scales, damping, directions, combination settings, base-shear factors and reference points.

For semi-rigid accidental torsion, compare actual floor area and joint assignments and the generated nodal correction pattern. Point-only assignment and whole-floor mesh assignment can leave the same modal

stiffness but cover different mass for torsion loading. Compare signed resultant forces and moments before local envelopes; equal base torque is not proof of equal force-couple distribution.

Preserve the distinction between a controlled regression test, an analytical benchmark and an independent external software comparison. The checks summarised in Appendix D support the specific implemented operations. They do not certify every building or every provision of a standard.

10 Calculation workflow

10.1 Modal and response spectrum workflow

- Prepare the intended three-dimensional structural model and check supports, releases, floor/wall connectivity and mesh.
- Assign each connected semi-rigid floor domain, including openings and every reporting elevation. Inspect its resolved area, centroids and tributary weights.
- Define the positive load-case mass contributions and review self-weight participation in the first primary case.
- Run the modal analysis with the selected Ritz count and optional UZ excitation.
- Review periods, shapes, participation and response sensitivity to count and mesh before relying on the basis.
- Define reusable spectrum functions with explicit units and damping basis.
- Connect them to response spectrum directions and scales.
- Select combination, minimum-base-shear and accidental-torsion settings.
- Recover signed modal responses, apply the case calculations and review the reported audit and warnings.
- Interpret mean floor displacement, relative drift, floor inertia, storey shear and base reactions using their distinct definitions.
- Define required positive/negative design combinations explicitly, and apply the project's remaining design and displacement assessments.

10.2 Wind workflow

- Assign the connected floor domains and choose the exposure base and included levels.
- Define a Wind primary case, applied direction and either automatic pressure parameters or manual diaphragm actions.
- Review widths, application points, eccentricity and exposure strips.
- Inspect the generated forces and report, then run ordinary static analysis.
- Use the analysed diaphragm load audit to review floor forces and cumulative applied-load shears.
- Use the complete static response for signed mean displacement and drift, checking additional loads in the case and torsional edge effects separately.
- Retain the saved model, analysis settings, generated-load audit and calculation report together.
- After a structural, mass or exposure change, rerun the affected analysis and confirm the new result identity before using previous response plots.

Appendix A Worked calculation examples

A.1 Single degree of freedom spectrum response

Consider an idealised lateral coordinate with mass 1000 kg and stiffness 200 kN/m. This is an analytical illustration, independent of a particular building's mesh. The angular frequency is $\sqrt{(1000 \times 200 / 1000)} = 14.142136$ rad/s; frequency is 2.250791 Hz and period 0.444288 s.

With influence $r = 1$ and mass-normalised shape $\phi = 1/\sqrt{1000}$, the generalized mass is one, $\Gamma = \sqrt{1000}$ and effective mass is 1000 kg. A user spectrum gives 0.2 g at this period and case scale is 9.80665, so $S_a = 1.96133$ m/s².

The physical peak displacement is $S_a/\omega^2 = 0.00980665$ m = 9.80665 mm. The member force is $200 \times 0.00980665 = 1.96133$ kN, equal to $mS_a/1000$. One mode gives 100% participating mass and every available modal combination returns the same magnitude. Multiplying by g a second time would produce an incorrect result.

A.2 Floor force and torque distribution

Consider four equal tributary weights at (-2, -1), (2, -1), (2, 1) and (-2, 1) m. The geometric and weighted centres are (0, 0), with $J_w = 5$ m². Apply $F_x = 100$ kN, $F_y = 0$ and $M_z = 40$ kN m at the centroid.

Node	X m	Y m	F _x kN	F _y kN
1	-2	-1	27	-4
2	2	-1	27	4
3	2	1	23	4
4	-2	1	23	-4

The force sums are 100 kN and zero. The torque sum $\sum(xF_y - yF_x)$ is 40 kN m. If the same F_x acts instead at $a_y = 0.5$ m with no entered torque, the centroid torque is -50 kN m. An additional entered +40 kN m would give -10 kN m; it would not replace the point-eccentricity term.

A.3 Why drift must precede combination

Take two signed modal upper-floor translations of 10 and 8 mm, and lower-floor translations of 9 and -6 mm. With unit modal multipliers and SRSS, the separate upper and lower peaks are 12.806248 and 10.816654 mm. Their difference is only 1.989594 mm.

The signed relative modal translations are 1 and 14 mm. Combining those gives $\sqrt{(1^2 + 14^2)} = 14.035669$ mm. Across a 3 m storey, the relative mean drift is 0.00467856 m/m, or 0.467856%. Subtracting combined absolute floor peaks would not calculate this relative response.

A.4 CQC correlation and signs

At equal frequencies and equal positive damping, $\rho_{12} = 1$. For signed contributions +10 and -8 kN, CQC returns $\sqrt{(100 + 64 - 160)} = 2$ kN. SRSS returns 12.806248 kN and absolute sum returns 18 kN. These differing results are consequences of the selected combination model.

Changing the sign of an eigenvector also changes its participation factor, leaving its physical modal response unchanged. Changing only the sign of a recovered response while retaining Γ would not be that invariant transformation.

A.5 Australian shape evaluation

For site C_e , $k_p = 1.3$, $Z = 0.09$, $S_p = 0.77$ and $\mu = 2$, the multiplier $k_p Z S_p / \mu$ is 0.045045. At $T = 0$, $C_h = 1.3$ and $C_d = 0.0585585$ g.

At $T = 1$ s, $C_h = 1.25$ and $C_d = 0.05630625$ g. At $T = 2$ s, $C_h = 1.874/4 = 0.4685$ and $C_d = 0.0211035825$ g.

The generated function evaluates these analytical values at a mode's actual period. A user table with points only at 1 and 2 s would instead interpolate linearly between them, giving a different ordinate at intermediate periods. Matching values at listed periods therefore does not make the two function representations identical everywhere.

A.6 Directional base shear scaling

Consider a 30 m wall-system benchmark with $k_t = 0.05$, the parameters from Example A.5 and directional seismic weight 10000 kN. The empirical period is $1.25 \times 0.05 \times 30^{0.75} = 0.801163$ s. On the C_e velocity branch, $C_h \approx 1.560231$, giving $V_s \approx 702.806$ kN and $V_{min} \approx 491.964$ kN.

If the unscaled dynamic shear is 400 kN, scale mode uses approximately 1.22991. A 10 mm response from that excitation becomes approximately 12.2991 mm before directional combination. Compare-only mode retains 10 mm and reports the deficiency.

Another enabled direction receives its own factor, rather than sharing this factor after the directions are combined.

A.7 Constant pressure wind example

Take Australian A2, 500 years, terrain category 2, exposure base 0 m, floors at 3 and 6 m and exposed width 10 m. Use the initial ULS coefficients $M_d = M_s = M_t = C_{dyn} = 1$, $C_{pWW} = 0.8$, $C_{pLW} = 0.5$ and $K_c = 0.9$, with zero eccentricity. The roof is below 25 m, so both faces use the roof reference speed.

$V_R = 45$ m/s. Linear terrain interpolation at 6 m gives $M_{z,cat} = 0.928$. Design speed is 41.76 m/s, exceeding the ULS minimum. Total wall pressure is $0.0006 \times 41.76^2 \times (0.8 + 0.5) \times 0.9 = 1.2242161$ kPa.

The strip boundary is 4.5 m. The 3 m floor receives a 4.5 m strip, giving 55.089725 kN; the 6 m floor receives 1.5 m, giving 18.363242 kN. Total force is 73.452967 kN. The applied floor-load base moment is $55.089725 \times 3 + 18.363242 \times 6 \approx 275.448626$ kN m. The exact continuous constant-pressure base moment would be 220.358901 kN m. Their difference illustrates the floor application-height approximation, despite equal total force.

At signed wind eccentricity +0.2, the eccentricity length is 2 m and the floor moments are +110.179450 and +36.726483 kN m. Reversing the force angle alone keeps these global-Z moments positive under the implemented sign rule.

Appendix B Implementation and reference register

B.1 Standards and supporting references

[R01] Standards Australia, AS 1170.4:2024, Structural design actions Part 4 Earthquake actions in Australia.

The implemented horizontal spectrum is associated with Table 6.4 and Clause 7.2; the empirical-period benchmark uses Equation 6.2(7). This manual records the implemented calculation and does not replace the full standard.

[R02] AS/NZS 1170.2:2021, Structural design actions Part 2 Wind actions.

The source generator identifies Tables 3.1(A), 3.3 and 4.1 and Equations 2.2 and 2.4(1); the wind eccentricity default refers to Clause 2.5.4. The wind calculation in this manual is the implemented method. The project's applicable amendment set must be recorded when establishing its design basis.

[R03] Computers and Structures Inc., CSI Analysis Reference Manual, Modal Analysis and Response Spectrum Analysis chapters. <https://docs.csiamerica.com/manuals/etabs/Analysis%20Reference.pdf>.

Provides general background on load-dependent Ritz methods and modal superposition.

FEAKalc-specific methods and numerical controls are described in Chapters 2–8 and Appendix C; they must not be inferred from CSI behaviour.

Appendix C Significant settings and boundaries

Setting	Reviewed behaviour
Active modal method	Cyclic load-dependent Ritz vectors
Mode request	Default 6; supported 1–20
Starting directions	UX/UY; UZ explicitly optional
Ritz basis budget	Exactly requested accepted independent vectors
Orthogonalisation	Two mass-projection passes; dependency ratio 10^{-10}
Reduced mass floor	10^{-12} at nonpositive or smaller entries
Ritz PCG tolerance	Relative target 0.01
Ritz PCG cap	$\min(30000, \max(10000, \text{floor}(\text{nfree}/4)))$
Reduced eigensolve	Jacobi; absolute off-diagonal tolerance 10^{-10} ; cap $100r^2$
Spectrum damping	Function and case must match; generated Australian 5%
User curve range	All retained modal periods covered; no extrapolation
Directional factor	0–1 for scaled absolute directional combination
Spectrum eccentricity	Ratio 0–0.5; per-level/direction length overrides
Torsional amplification	User input 1–100
Diaphragm level tolerance	0.0001 m
Wind exposed height	Greater than 0 and no more than 200 m
Wind reference-height boundary	Roof windward reference through $H = 25$ m
Wind ULS minimum	30 m/s on design product speed
Initial wind eccentricity	20% above 70 m; zero at/below 70 m
Base-shear benchmark boundary	70% through $h = 50$ m; 50% above

These settings describe the reviewed implementation. A numerical limit or initial value is not an engineering criterion unless the relevant calculation explicitly defines it as such.

The checked-in direct-solver configuration is a deployment setting; a different deployed configuration can take the documented PCG path.

Appendix D Verification summary

D.1 Basis and scope

Verification checks compare FEAkalc 3D calculations with analytical solutions, independently calculated numerical expectations and selected building benchmarks. This appendix summarises the checks completed on late October 2026 and the earlier building comparisons retained for this edition. The results are reported here so the reader does not need access to software test scripts or internal development records.

The checks address modal extraction, spectrum functions, response recovery, modal and directional combinations, base-shear scaling, accidental torsion, wind generation and diaphragm reporting. All nine groups of checks completed successfully.

A successful check means that its stated numerical or behavioural expectation was met for the cases examined; it is not a certification of every structural model or every provision of a design standard.

Values below are rounded for readability. Scalar comparison tolerances were $10^{-10} \times \max(1, |\text{reference value}|)$ for response-spectrum checks and $10^{-8} \times \max(1, |\text{reference value}|)$ for wind-generation checks.

These are numerical tolerances in the stated units, not error bounds on a building's response.

D.2 Modal extraction and participation

Controlled systems with known vibration properties were used to check Ritz-vector generation and extraction. The analytical checks recovered the expected frequencies and 100% participation in the fully represented excitation direction. They also confirmed the default horizontal starting directions and the explicit addition of vertical excitation when selected.

One-vector requests, odd and even vector counts, a direction with no starting load, and exhaustion of independent vectors were checked. A direction with no useful load did not prevent the remaining active directions from filling the requested basis. Once no independent vectors remained, the calculation reported that condition instead of accepting dependent numerical noise as additional modes.

The checks also confirmed mass orthogonality and consistency when preparing the scaled linear solution. In the four building runs summarised in Section D.7, the largest reported mass-orthogonality deviation from the identity matrix was 1.23×10^{-14} . This supports the reduced-mass approximation for those runs; it does not establish convergence of every higher mode in an arbitrary building.

D.3 Spectrum functions and structural recovery

The Australian horizontal spectral-shape calculation was compared at 20 periods for each of the five supported site classes, giving 100 tabulated comparisons. Additional checks covered the zero-period ordinates, rising short-period branches, plateau corners, the 1.5 s branch boundary and the long-period coefficients. The retained 23-point Class C reference curve was reproduced within its six-decimal rounding. Scaling of the hazard and performance parameters and the inverse effect of ductility were also checked.

A separate one-coordinate response check used mass $m = 1000$ kg, angular frequency $\omega = 2$ rad/s and a constant spectrum $S_a = 2$ m/s². The equivalent stiffness is 4 kN/m and the period is π s. The expected displacement is $S_a/\omega^2 = 0.5$ m, the effective modal mass is 1000 kg, and both the member force and base-shear magnitude are $mS_a/1000 = 2$ kN. The calculated displacement, member force, inertia resultant, base shear and 100% directional participation met these expectations.

Expressing the same ordinate as 2/9.80665 g and applying a case scale of 9.80665 reproduced the 2 kN result. A case scale of three increased it to 6 kN. These checks confirm once-only acceleration conversion and

linear scaling for the examined response basis. Appendix A provides an additional worked single-degree-of-freedom calculation at a different stiffness and spectral ordinate.

Structural recovery was also checked through an axial cantilever, a bending case with its base at $Z = -3$ m, and a triangular shell membrane case. The checks verified modal participation, frame action and displacement units, support couples, the lowest-base moment reference, and shell membrane-force and stress units. These exercise structural recovery in addition to the spectrum-combination arithmetic.

D.4 Combination order and signs

Simple signed response sets were used to distinguish the available combination methods. For modal values +3 and +4, SRSS must return 5. For -3 and +4, absolute sum must return 7. For two equal-frequency modes with perfectly correlated contributions +2 and -2, CQC must return zero. All three expectations were met, including symmetry of the equal-damping CQC correlation when the two frequencies are interchanged.

For directional magnitudes 10, 4 and 2, scaled absolute combination with factor 0.3 must return $10 + 0.3(4 + 2) = 11.8$. Directional SRSS of 3 and 4 must return 5. These checks passed. Reversing a mode shape and its participation factor together left the physical response unchanged; rotating excitation also changed the participating response as expected.

Support and shell checks addressed the order of operations. Signed support actions were summed within each mode before base-resultant combination. Signed base moments were transferred to the stated base elevation before combination. Signed shell values were averaged before forming nodal contour peaks. The results distinguished these operations from summing support envelopes or averaging independently combined shell maxima, which generally give different answers.

D.5 Scaling torsion and diaphragm reporting

The minimum-base-shear checks covered all four structural-system period coefficients, the static short-period plateau, the 50 m height boundary, directional seismic weight, compare-only operation and independent directional scale factors. They confirmed that scale-up affected displacement, rotation, member and shell actions, support resultants and inertia once, while compare-only operation retained the original response. Zero-shear scaling and incompatible seismic mass elevations were rejected.

Accidental-torsion checks confirmed that signed nodal floor inertia is summed before modal combination, that eccentricity uses width transverse to the excitation, and that length overrides and amplification modify the intended floor torque. Minimum-base-shear scaling reached the torque once. Both signs of the full static correction were enveloped within each direction, and missing diaphragm or correction data were rejected.

Diaphragm-reporting checks verified nonuniform tributary-area weighting, signed relative floor displacement before statistical combination, and the actual moving-support reference at the first level. They also covered unassigned nodes in whole-building shear, the recovered member-force cut at upper levels, the signed support resultant at the base, and explicit treatment of missing or ambiguous lower-floor references. A pure-torque correction added no net global translational floor force.

For static wind reporting, opposing floor loads retained their signs and storey forces were accumulated algebraically. Displacement conversion from mm to m, signed relative drift, nonuniform floor weights and moving supports were checked. These results support the different floor-force and storey-shear definitions in Chapter 8; they do not make combined floor-force peaks additive or turn mean-floor drift into maximum edge drift.

D.6 Wind load generation

Wind-data checks included regional speeds of 45, 57 and 80 m/s for A2, B2 and D respectively at a 500-year return period; climate multipliers of 1.0 for B1 and 1.05 for B2; terrain interpolation; the A0 special rule; and

the lower-height treatment. Invalid exposure overlap and heights above the supported 200 m limit were rejected.

The constant-pressure calculation in Appendix A.7 also provides a numerical reference for the checked wind integration. For A2, terrain category 2, floors at 3 and 6 m, 10 m exposed width and the stated coefficients, roof speed is 41.76 m/s. Pressure is 1.2242161 kPa, the tributary heights are 4.5 and 1.5 m, and the floor forces are 55.089725 and 18.363242 kN. Their sum is 73.452967 kN. The generated total force and tributary-height calculations agreed with the unrounded reference values.

For a building taller than 25 m, variable-height windward pressure was checked against an independent integral of the squared linearly interpolated terrain multiplier, with the pressure interval split at its tabulated heights. Further checks covered changing floor widths, rotated and reversed force directions, manual coefficient and application-point overrides, and linear scaling with the entered dynamic factor.

A low regional-speed override checked the ULS minimum separately from SLS: an unbounded roof speed of 9.28 m/s became 30 m/s in ULS and remained 9.28 m/s in SLS. Wind torsion checks retained the specified global moment sign independently of force reversal. These results verify the implemented external-wall procedure; they do not validate unimplemented crosswind, local cladding or other aerodynamic actions.

D.7 Building modal comparisons

Two building benchmarks were analysed using 1.25 m Smooth Quad slab meshes and rectangular wall meshes. Six- and twelve-vector Ritz runs were generated separately for each model. The following table records the cumulative participating mass obtained in each horizontal direction.

Model	Ritz vectors	Captured UX percent	Captured UY percent
Model 1	6	90.4339	92.4409
Model 1	12	98.6815	98.7464
Model 2	6	91.0111	85.3098
Model 2	12	98.0232	97.4102

For Model 1, six vectors captured more than 90% in both horizontal directions. The corresponding supplied six-vector ETABS result was 90.52% UX and 92.36% UY, compared with FEAkalc values of 90.4339% and 92.4409%. The differences were -0.0861 and +0.0809 percentage points respectively, at the precision of the supplied comparison values.

For Model 2, six vectors captured 85.3098% in UY; increasing to twelve raised this to 97.4102%. This is a direct example of why the default count is not an adequacy guarantee. Increasing the basis also improved UX capture in both models. Each structure still requires its own participation and response-convergence assessment.

These retained results provide model-specific comparative evidence. The building geometry and complete inputs are not reproduced here, so the table is not a fully specified benchmark that can be reconstructed from the percentages alone.

D.8 Interpretation of the evidence

The analytical checks establish the reference quantities and operations examined; building comparisons add evidence for the stated settings. They do not establish accuracy for every geometry, local stress concentration, higher mode or code assessment.

Mass capture does not prove mesh convergence or accidental-torsion equivalence with another program. The checks verify the Chapter 6 procedure. Wind integration verifies total strip force; floor application heights retain the overturning approximation explained in Section 7.6 and Appendix A.7.

Project records should identify the software version, model, mass, mesh, modal count, load inputs and combination settings. Review mesh/modal sensitivity and torsional edge response. Material changes to a method require corresponding verification before earlier evidence is applied to it.

