FEAKalc 3D

Steel Design Manual to AS4100

Document Revision

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First Issue	0	11th August 2026	RK
Combined Actions, Moment Amplification, Shear/Bending Interaction and L-Angle Design	1	1 September 2026	RK

Revision 1 is a full technical update of the original FEAKalc 3D Steel Design Manual. It retains the established design basis, effective-length procedures, section classification, compression, bending, shear and Section 8 material, and extends those procedures to reflect the current steel design engine. The principal additions are AS 4100 Clause 4.4.2 first-order moment amplification and the associated second-order-analysis trigger, the user-controlled major-axis moment modification factor, Clause 5.12.3 shear-bending interaction, the completed Section 8 section/member interaction implementation, and dedicated L-angle design about inclined principal axes.

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1 General Design Basis and Design Actions

1.1 General

The FEAKalc 3D steel design module performs strength and stability checks of structural steel frame members using design actions obtained from the FEAKalc 3D finite element analysis. The current implementation is based on the calculation procedures embodied in the FEAKalc AS 4100 steel design engine and supports the following section families:

- rolled and welded I-sections;
- Parallel Flange Channels (PFC);
- Rectangular and Square Hollow Sections (RHS/SHS);
- Circular Hollow Sections (CHS); and
- equal and unequal L-angle sections where the required angle properties are available.

Design is carried out at the available analysis stations along every member, rather than only at member ends. Each applicable steel design load combination is evaluated independently and the final member result is the envelope of all station checks and all applicable load combinations.

The principal FEAKalc local action convention used by the steel engine is:

$$N^*, \quad M_{22}^*, \quad M_{33}^*, \quad V_2^*, \quad V_3^*, \quad T^*$$

For ordinary I, PFC, RHS/SHS and CHS sections, M_{33} is treated as major-axis bending and M_{22} as minor-axis bending. For L-angles, the local moments are first transformed to the inclined principal axes before amplification and design.

Torsion T^* is transferred to the design result for reporting and traceability, but the present steel engine does not calculate a separate torsional utilisation or a torsion interaction check.

The design-combination operation is intentionally separated from the subsequent steel capacity calculation. FEAKalc first forms the complete station action set for a selected combination and only then passes that station to the steel engine. This means that axial force, the two bending moments, the two shear forces and torsion all correspond to the same physical station and the same load combination. The design engine does not construct a capacity envelope by mixing an axial action from one combination with a bending action from another.

This treatment is important for members whose force distribution changes significantly between combinations. A combination that produces the maximum major-axis moment may not produce the maximum axial compression, and neither of those actions necessarily identifies the governing combined-action check. FEAKalc therefore retains the station-by-station relationship between actions and repeats the full design calculation for every applicable design combination.

1.2 Design Load Combinations

Steel design is performed for the applicable FEAKalc design combinations, conventionally identified by the LC- prefix. For a design action X obtained from n analysis load cases, the combined action is:

$$X^* = \sum_{i=1}^{n} \gamma_i X_i$$

where X_i is the action from analysis load case i and γ_i is its load-combination factor.

Accordingly:

$$N^* = \sum_i \gamma_i N_i$$

$$M_{22}^* = \sum_i \gamma_i M_{22,i}$$

$$M_{33}^* = \sum_i \gamma_i M_{33,i}$$

$$V_2^* = \sum_i \gamma_i V_{2,i}$$

$$V_3^* = \sum_i \gamma_i V_{3,i}$$

$$T^* = \sum_i \gamma_i T_i$$

The combination is formed independently at each station, so the analysed variation of axial force, bending moment, shear and torsion along the member is retained.

The station procedure is also used by the moment-amplification routine. The first and last station values establish the member end-moment relationship where transverse loading is absent, while the complete station set is examined for curvature and associated shear variation. Consequently, station density is not only a reporting matter: it preserves the analysed member action diagram used by several later design checks.

At finalisation, each station carries both its applied actions and the capacities calculated for the section and member. The reported governing station is selected from the calculated utilisation values rather than from a separate search for the largest raw force or moment. This is why the critical station may move when an effective length, lateral-restraint length, moment modification factor or sway amplification is changed even though the first-order finite element actions remain unchanged.

1.3 Design Stations

For a member containing m design stations at distances s_j along the member, the station action vector is:

$$\mathbf{S}_j = \left[N_j^*, M_{22,j}^*, M_{33,j}^*, V_{2,j}^*, V_{3,j}^*, T_j^*\right]$$

The steel design calculation is repeated for every station $j = 1, \ldots, m$.

This station-by-station procedure is important because the governing location may be controlled by a combined-action interaction, moment amplification, shear-bending interaction or a stability capacity, rather than by the largest value of one raw analysis action.

1.4 Design Capacities and Capacity Factor

The FEAKalc steel API returns **design capacities**. The capacity factor is already incorporated into the reported values and must not be applied a second time in subsequent utilisation calculations.

The current design engine uses:

$$\phi = 0.9$$

for the principal steel strength capacities documented in this manual.

For an action S^* and a design capacity ϕR, the corresponding utilisation is:

$$U = \frac{|S^*|}{\phi R}$$

The individual check satisfies the design criterion when:

$$U \leq 1.0$$

1.5 Axial Sign and Action Type

The current engine distinguishes compression and tension from the sign of the station axial force. With the FEAKalc convention:

$$N_c^* = \max(0, -N^*)$$

$$N_t^* = \max(0, N^*)$$

The action type is therefore reported as compression, tension or none.

This distinction is significant in Section 8 because compression uses member buckling capacities, while tension uses gross-section yielding in the present implementation and permits different out-of-plane interaction behaviour.

Revision 1 reporting deliberately retains the unamplified analysis moments as an audit trail. The values displayed as design moments in the strength checks are the amplified actions where Clause 4.4.2 amplification applies; the first-order values remain available separately so the effect of the amplification process can be reviewed.

The amplification is performed before section bending, member bending and Section 8 checks. This order is significant. FEAKalc does not calculate a first-order utilisation and then multiply the utilisation by an amplification factor. Instead, it amplifies the relevant moment action and passes that amplified action through the normal section-capacity, member-stability and interaction calculations.

1.6 First-Order and Amplified Moments

The moments received from the frame analysis are retained as first-order actions:

$$M_{33,1}^*, \qquad M_{22,1}^*$$

Before ordinary-section strength checks, FEAKalc applies the Clause 4.4.2 amplification factors:

$$M_{33}^* = \delta_{mx} M_{33,1}^*$$

$$M_{22}^* = \delta_{my} M_{22,1}^*$$

For angles, the first-order local moments are first resolved to the angle principal axes and the amplification is applied on those principal axes. The complete amplification procedure is given in Part 3.

1.7 Individual Utilisation Checks

At each station the engine retains, as applicable:

$$U_N = \frac{N_c^*}{\phi N_c} \quad \text{or} \quad U_N = \frac{N_t^*}{\phi N_t}$$

$$U_{M33} = \frac{|M_{33}^*|}{\phi M_{bx}}$$

$$U_{M22} = \frac{|M_{22}^*|}{\phi M_{sy}}$$

$$U_{V2} = \frac{|V_2^*|}{\phi V_v}$$

$$U_{V3} = \frac{|V_3^*|}{\phi V_v}$$

For angle sections the two bending utilisations are evaluated about the inclined principal axes rather than the unrotated local 33 and 22 axes.

The global capacity ratio is therefore a true envelope of applicable limit-state checks. It is not a single universal interaction equation. Depending on the station and section family, the governing value may be axial compression, major-axis member bending, minor-axis section bending, local shear, Clause 5.12.3 shear-bending interaction, a Section 8 section interaction, an in-plane member interaction, an out-of-plane member interaction or the powered biaxial member interaction.

The design memo records the check name associated with this maximum. This is an important part of result interpretation because two members with the same numerical capacity ratio may be governed by entirely different physical mechanisms. FEAKalc therefore reports the component ratios and principal capacities in addition to the final PASS or FAIL status.

1.8 Combined Actions and Governing Station

The current engine carries separate Section 8 section-capacity and member-capacity interactions. The combined-action utilisation is:

$$U_{int} = \max(U_{8.3}, U_{8.4})$$

where $U_{8.3}$ is the applicable cross-section interaction and $U_{8.4}$ is the applicable member interaction.

The governing station utilisation is the maximum of every check calculated for that station, including the Clause 5.12.3 shear-bending check where applicable:

$$U_j = \max(U_N, U_{M33}, U_{M22}, U_{V2}, U_{V3}, U_{5.12.3}, U_{8.3}, U_{8.4})$$

The governing station for one load combination is:

$$U_{member,LC} = \max_j U_j$$

and the final member envelope is:

$$U_{member} = \max_{LC} U_{member,LC}$$

The governing station, governing load combination and governing check are retained with the final result.

2 Effective Length, Member Restraint and Buckling Lengths

2.1 General

FEAKalc determines effective lengths independently for the two ordinary member buckling directions:

$$L_{e,22}$$

$$L_{e,33}$$

The values may be established automatically from the three-dimensional frame and shell geometry or replaced by user-defined effective length factors or direct length overrides.

A separate length is used for major-axis lateral-torsional buckling:

$$L_{LTB}$$

For L-angle sections, the steel engine also accepts effective lengths about the inclined principal axes:

$$L_{e,x}^{angle}, \qquad L_{e,y}^{angle}$$

If these angle-specific lengths are not supplied, the current engine conservatively adopts the larger of the ordinary 22 and 33 effective lengths for both angle principal axes.

The physical frame length and the effective buckling lengths are stored separately. The physical length describes the actual finite element object between its end nodes; the effective lengths represent stability restraint conditions and may correspond to a longer continuous chain, a shorter braced segment, or a user-defined value. This separation is retained when the Section 8 interaction length is formed, because that interaction check may use the physical length differently from the standalone flexural-buckling check.

2.2 Physical Member Length

For a frame element with endpoints $\mathbf{x}_1$ and $\mathbf{x}_2$, the physical length is:

$$L = \| \mathbf{x}_2 - \mathbf{x}_1 \|$$

and the member unit vector is:

$$\mathbf{e}_1 = \frac{\mathbf{x}_2 - \mathbf{x}_1}{L}$$

Together with the FEAKalc local 2 and local 3 directions, this defines the local member axes used in restraint recognition.

2.3 Collinear Member Chains

A physical member may consist of several finite element frame objects. Connected frames are considered aligned where the absolute dot product of their unit directions is sufficiently close to unity:

$$\left|\mathbf{e}_{1,a} \cdot \mathbf{e}_{1,b}\right| \approx 1$$

The absolute value allows members defined in opposite node directions to form one continuous chain.

A chain containing q aligned members has physical length:

$$L_{chain} = \sum_{i=1}^{q} L_i$$

unless intermediate frame or shell restraints divide it into shorter unrestrained segments.

The axis-specific restraint test is intended to avoid an unrealistic assumption that any connected member braces both directions equally. A beam connected to a column may provide strong restraint in one transverse direction but little restraint in the orthogonal direction. The implemented component test therefore classifies the connected member according to its dominant projection onto the designed member local axes, after which the collinear chain is split independently for the two buckling directions.

As a result, the same finite element may legitimately receive different automatic effective lengths about its two principal directions. The steel compression routine preserves this distinction all the way through the separate slenderness, compression-reduction and member-capacity calculations.

2.4 Axis-Specific Frame Restraint

FEAKalc does not assume that every intersecting frame restrains both buckling directions. For a connected non-collinear member with direction b, its components on the designed member's local transverse axes are:

$$b_2 = |\mathrm{b} \cdot \mathrm{e}_2|$$

$$b_3 = |\mathrm{b} \cdot \mathrm{e}_3|$$

The implemented restraint test requires the relevant component to be dominant and greater than approximately 0.35. In conceptual form:

22 restraint: $b_2 > b_3$ and $b_2 > 0.35$

33 restraint: $b_3 > b_2$ and $b_3 > 0.35$

The collinear chain is then split independently for the two axes.

2.5 Shell Intersections

Frame-shell intersections are also considered in the automatic restraint procedure. For a frame line:

$$\mathrm{x}(t) = \mathrm{x}_1 + t(\mathrm{x}_2 - \mathrm{x}_1)$$

and a shell plane through x_s with normal n, the plane intersection parameter is:

$$t = \frac{(\mathrm{x}_s - \mathrm{x}_1) \cdot \mathrm{n}}{(\mathrm{x}_2 - \mathrm{x}_1) \cdot \mathrm{n}}$$

A valid intersection is then checked against the actual shell polygon. An interior intersection introduces an additional restraint position in the chain; shell intersections at frame nodes are also recognised.

Interior shell intersections are especially useful for modelling columns that pass continuously through floor levels. The restraint routine can recognise the floor shell as a break in the unrestrained chain even when the frame object itself has not been subdivided at that elevation. End-node shell intersections are also carried into the chain restraint set, allowing adjacent collinear frame objects to be treated consistently.

Automatic effective length is therefore a geometric inference from the FEAKalc analytical model. It should be regarded as a model-derived design input, not as an independent determination of real connection stiffness or construction restraint. Where the actual structural restraint differs from the analytical idealisation, the user override facilities described below take precedence.

2.6 Automatic Effective Lengths

After the applicable restraint points are assembled, the chain is split into unrestrained segments. The automatically determined effective length for a frame is the segment length containing that frame for the particular buckling axis.

This produces two potentially different automatic lengths:

$$L_{e,22}^{auto}$$

and

$$L_{e,33}^{auto}$$

2.7 User Effective-Length Factors

Where a user assigns effective-length factor K, FEAKalc uses the physical frame length as the reference:

$$L_{e,22} = K_{22}L$$

$$L_{e,33} = K_{33}L$$

The reported factors are correspondingly:

$$\beta_{22} = \frac{L_{e,22}}{L}$$

$$\beta_{33} = \frac{L_{e,33}}{L}$$

2.8 Direct Effective-Length Overrides

A direct user length overrides the automatic value for that axis. The effective-length selection can be represented as:

$$L_{e,a} = \begin{cases} L_{e,a}^{override}, & \text{direct length assigned} \\ K_a L, & \text{factor assigned} \\ L_{e,a}^{auto}, & \text{automatic mode} \end{cases}$$

where a is 22 or 33.

The separation between axial buckling length and lateral-torsional buckling length is retained because the restraint mechanisms are different. A member may be laterally restrained along its compression flange while still having a longer flexural-buckling length as a compression member, or the reverse may occur. The dedicated LTB value allows the bending stability check to follow the physical lateral restraint rather than forcing it to use the axial buckling segmentation.

Where no positive LTB length is supplied, the engine uses the major-axis effective length as a practical fallback. This fallback is an implementation default, not a statement that the two physical restraint conditions are always equivalent. The user should assign the actual LTB restraint length where the model geometry alone does not represent it adequately.

2.9 Lateral-Torsional Buckling Length

The LTB length is independent of the axial flexural buckling lengths. Where a positive user-supplied LTB length exists:

$$L_b = L_{LTB}$$

otherwise the current ordinary-section routines use the major-axis effective length as the fallback:

$$L_b = L_{e,33}$$

For an angle, the fallback is the principal-x effective length.

<u>Revision 1 implementation correction: the current steel engine does not impose the previously documented 2.0 m minimum on $L_{e,22}$, $L_{e,33}$ or L_{LTB}. A non-positive effective length is replaced by the physical member length; a negative LTB input is reset to zero and then handled by the fallback rule above.</u>

2.10 Angle Principal-Axis Effective Lengths

For an angle, the request may contain:

$$L_{e,x}^{angle}$$

and

$$L_{e,y}^{angle}$$

If either is omitted, the engine first forms:

$$L_{cons} = \max\left(L_{e,22}, L_{e,33}\right)$$

and adopts:

$$L_{e,x}^{angle} = L_{cons}$$

$$L_{e,y}^{angle} = L_{cons}$$

unless an explicit angle principal-axis length is supplied for that direction.

3 AS4100 First-Order Moment Amplification and Second-Order Requirement

3.1 General

Revision 1 introduces a formal first-order elastic moment-amplification stage before the steel capacity checks. The procedure is based on the current engine implementation of AS 4100 Clause 4.4.2.

For ordinary sections the amplification axes are the major principal x axis associated with M_{33} and the minor principal y axis associated with M_{22}. For angles the complete moment diagram is transformed to the inclined principal axes before the amplification parameters are calculated.

The end-moment ratio is evaluated separately for the two bending axes from the ordered station set. Only the magnitude ratio of the smaller end moment to the larger end moment is required, with the sign then assigned from the curvature condition. Same-curvature end moments produce a negative value under the convention used by the engine, while reverse curvature produces a positive value. The result is bounded so numerical or modelling irregularities cannot take it outside the implemented range.

This quantity is not the same as the user-controlled major-axis moment modification factor used in the lateral-torsional buckling capacity calculation. The end-moment ratio belongs to Clause 4.4.2 action amplification; the major-axis moment modification factor belongs to the Clause 5 member bending capacity. Both appear in the design process, but they modify different parts of the calculation and are retained as separate values in the result.

3.2 End-Moment Ratio β_m

Where no transverse member loading is detected, FEAKalc determines the end-moment ratio from the first and last design stations. Let the two end moments be M_1 and M_2, with:

$$|M_L| = \max(|M_1|, |M_2|)$$

$$|M_S| = \min(|M_1|, |M_2|)$$

The magnitude is:

$$|\beta_m| = \frac{|M_S|}{|M_L|}$$

The current sign convention is positive for reverse curvature and negative for same-curvature end moments. Thus:

$$\beta_m = +\frac{|M_S|}{|M_L|} \quad \text{for opposite-sign end moments}$$

$$\beta_m = -\frac{|M_S|}{|M_L|} \quad \text{for same-sign end moments}$$

with:

$$-1 \le \beta_m \le 1$$

The transverse-load detector uses two independent indicators. First, it examines the associated shear-force values over the ordered stations. A material change in shear is direct evidence that transverse loading acts between the member ends. Second, it compares the interior moment values with the straight line joining the two end moments. A meaningful departure from that line indicates a curved first-order moment diagram even where the shear evidence is numerically small.

When either indicator is present, the engine does not attempt to infer a more favourable end-moment ratio from the measured diagram. It adopts the conservative transverse-loading option used by the implementation. This same transverse-load flag is later used when deciding whether the compact out-of-plane Section 8 alternative is permitted for an I-section.

3.3 Detection of Transverse Member Loading

The engine checks the complete station diagram for evidence of transverse loading. For major-axis bending, M_{33} is paired with V_3; for minor-axis bending, M_{22} is paired with V_2.

A transverse load is detected if the associated shear varies materially along the station set or if an interior moment departs from the straight line joining the end moments by more than the numerical tolerance used by the engine.

Where transverse loading is detected, FEAKalc uses the permitted conservative value:

$$\beta_m = -1.0$$

for the Clause 4.4.2 amplification calculation.

3.4 Moment Distribution Coefficient c_m

For each axis, the implementation calculates:

$$c_m = 0.6 - 0.4\beta_m$$

and limits the value to:

$$0 \le c_m \le 1.0$$

Therefore the implemented expression is:

$$c_m = \min\left(1, \max(0, 0.6 - 0.4\beta_m)\right)$$

3.5 Elastic Buckling Load N_{omb}

For an axis with second moment of area I and effective length L_e, the engine calculates:

$$N_{omb} = \frac{\pi^2 EI}{L_e^2}$$

using:

$$E = 200000 \text{ MPa}$$

The internal result is converted to kN before use in the amplification equation.

For ordinary sections:

$$N_{omb,x} = \frac{\pi^2 EI_x}{L_{e,33}^2}$$

$$N_{omb,y} = \frac{\pi^2 EI_y}{L_{e,22}^2}$$

For angles, I_x and I_y are the inclined principal second moments and the corresponding principal-axis effective lengths are used.

The compressive axial force used in the amplification stage is the maximum compression found anywhere in the member station set for the load combination being designed. This provides one member-level compression demand for the braced amplification calculation while the resulting moment factor is then applied to every station moment about the corresponding axis.

When the axial action approaches the elastic buckling load, the denominator in the amplification expression approaches zero and the calculated factor increases rapidly. The code treats a non-positive denominator as an unstable first-order amplification condition and assigns a deliberately large value so that the subsequent second-order-analysis check cannot be missed.

3.6 Braced Moment Amplification δ_b

Let the maximum compressive axial action in the member station set be:

$$N_c^* = \max_j(0, -N_j^*)$$

For a given axis, the current implementation calculates:

$$\delta_b = \max\left(1, \frac{c_m}{1 - N_c^*/N_{omb}}\right)$$

If $N_c^* \leq 0$, the engine uses:

$$\delta_b = 1.0$$

If $N_{omb} \leq 0$ or the denominator becomes non-positive, the engine assigns a very large amplification value, which subsequently triggers the second-order analysis requirement.

3.7 Sway Amplification δ_s

The steel request may include sway amplification factors supplied by a frame/storey stability calculation:

$$\delta_{sx}$$

and

$$\delta_{sy}$$

A non-positive supplied value defaults to unity. The current engine therefore uses:

$$\delta_s = \max(1, \delta_s^{supplied})$$

If no frame/storey sway amplification is supplied, the steel design result records:

$$\delta_s = 1.0$$

and notes that a non-unity value or a second-order analysis is required for sway behaviour where applicable.

The governing design amplification for an axis is the larger of the braced member term and the supplied sway term. This ensures that a member which is locally sensitive to compression amplification is not relieved by a smaller storey factor, while a member in a sway-sensitive frame is not allowed to ignore the larger global amplification supplied by the frame or storey stability calculation.

Only the bending moments are modified in this first-order amplification step. The original axial force, shear forces and torsion are retained. The amplified moments then become the design moments used by the ordinary-section strength checks and by the Section 8 interaction calculations.

3.8 Governing Moment Amplification

For each principal axis the design amplification is the larger of the braced and sway terms:

$$\delta_m = \max(\delta_b, \delta_s)$$

Thus:

$$\delta_{mx} = \max(\delta_{bx}, \delta_{sx})$$

$$\delta_{my} = \max\left(\delta_{by}, \delta_{sy}\right)$$

The amplified design moments for ordinary sections are:

$$M_{33}^{*} = \delta_{mx} M_{33,1}^{*}$$

$$M_{22}^{*} = \delta_{my} M_{22,1}^{*}$$

Shear, axial force and torsion are not multiplied by these moment factors.

The 1.4 threshold is treated by the current engine as a design-method boundary rather than as another capacity ratio. If any individual braced or sway amplification exceeds the threshold, the software marks the result as requiring second-order elastic analysis. The station is forced to a failing status even if the numerical first-order amplified strength checks would otherwise remain below unity.

The amplified values are still retained in the design result because they are useful for diagnosing why the threshold was exceeded and for comparison with a subsequent second-order analysis. They are explicitly labelled as audit information and are not intended to be accepted as the final compliant design where the second-order flag is active.

3.9 Second-Order Elastic Analysis Trigger

The current engine checks the individual braced and sway amplification values against 1.4. A second-order elastic analysis is flagged as required where any of the following is true:

$$\delta_{bx} > 1.4$$

$$\delta_{by} > 1.4$$

$$\delta_{sx} > 1.4$$

or

$$\delta_{sy} > 1.4$$

When this condition occurs, FEAKalc retains the first-order amplified result for audit but forces the station result to FAIL and identifies the governing reason as the Clause 4.4.1.2 second-order elastic analysis requirement.

The retained amplified result must therefore not be interpreted as a compliant final design when the second-order flag is set.

For angles the sequence is deliberately different from ordinary sections. The local station moment diagram is transformed first, including the complete set of station values used for end-moment and transverse-load assessment. Each principal axis then receives its own end-moment ratio, moment distribution coefficient, elastic buckling load and amplification factor. This avoids applying an amplification derived about the unrotated local axes to a section whose actual flexural principal axes are inclined.

3.10 Angle Moment Amplification

For angle sections, the transformation angle α is measured from the FEAKalc local M_{33} axis towards principal $+x$. The first-order moments are transformed before the amplification parameters are determined:

$$M_{x,1}^{*} = M_{33,1}^{*}\cos\alpha - M_{22,1}^{*}\sin\alpha$$

$$M_{y,1}^{*} = M_{33,1}^{*}\sin\alpha + M_{22,1}^{*}\cos\alpha$$

The complete station moment and shear diagrams are transformed consistently for β_m and transverse-load detection. The design principal moments are then:

$$M_x^* = \delta_{mx} M_{x,1}^*$$

$$M_y^* = \delta_{my} M_{y,1}^*$$

The angle capacity and Section 8 checks are carried out using these amplified principal-axis moments.

4 Section Slenderness, Classification and Effective Section Properties

4.1 General

The FEAKalc design engine evaluates local plate slenderness before calculating compression and bending capacities. The treatment is section-family specific.

The generic yield-stress-modified slenderness form used by the plate-element routines is:

$$\lambda = \frac{b}{t}\sqrt{\frac{f_y}{250}}$$

where b is the relevant plate width, t is the plate thickness and f_y is the applicable yield stress in MPa.

4.2 I-Section Slenderness

For an I-section, the clear web depth is:

$$d_w = d - 2t_f$$

and the web slenderness is:

$$\lambda_w = \frac{d_w}{t_w}\sqrt{\frac{f_{yw}}{250}}$$

The outstanding flange width on one side of the web is:

$$b_o = \frac{b_f - t_w}{2}$$

and the flange slenderness is:

$$\lambda_f = \frac{b_o}{t_f}\sqrt{\frac{f_{yf}}{250}}$$

Separate web and flange yield stresses may be used according to the steel grade/thickness lookup.

The effective-area reduction affects compression through the form factor rather than by modifying the gross section properties used everywhere in the engine. The gross area remains available for section identification and tension yielding, while the effective area is used in the compression section capacity and in the modified member slenderness. A fully effective section therefore retains a form factor of unity; only sections with plate slenderness beyond the implemented limits receive a reduction.

4.3 I-Section Effective Area for Compression

For rolled I-sections the current compression effective-width limits are:

$$\lambda_{w,e} = 45$$

$$\lambda_{f,e} = 16$$

For welded I-sections:

$$\lambda_{w,e} = 35$$

$$\lambda_{f,e} = 14$$

The effective dimensions are limited not to exceed the actual dimensions. In the implementation:

$$d_e = d_w \min\left(1, \frac{\lambda_{w,e}}{\lambda_w}\right)$$

and the total effective flange width represented by the routine is:

$$b_e = (b_f - t_w) \min\left(1, \frac{\lambda_{f,e}}{\lambda_f}\right)$$

The effective area is then calculated from the gross area after subtracting the ineffective portions, and the section form factor is:

$$k_f = \frac{A_e}{A_g}$$

with:

$$0 \le k_f \le 1$$

The classification branch is selected by comparing the web and flange slenderness relative to their respective limiting values. This means the numerically larger raw slenderness does not necessarily control: the comparison is made on a normalised basis. Once the controlling element is identified, the effective section modulus is taken as the compact value, an interpolation between elastic and compact values, or a reduced elastic value according to the branch implemented by the engine.

This effective modulus feeds directly into the section moment capacity and therefore also influences the member LTB capacity and the Section 8 reduced-moment calculations. Section classification is consequently part of the numerical resistance calculation, not merely a descriptive label shown in the memo.

4.4 I-Section Major-Axis Bending Classification

For major-axis bending, the current engine compares the relative web and flange slenderness. The web controls where:

$$\frac{\lambda_w}{115} > \frac{\lambda_f}{16}$$

For web-controlled behaviour:

- compact: $\lambda_w < 82$;
- non-compact: $82 \le \lambda_w < 115$;
- slender: $\lambda_w \ge 115$.

The compact effective modulus is:

$$Z_{e,x} = \min(S_x, 1.5Z_x)$$

For the non-compact web range:

$$Z_{e,x} = Z_x + \frac{115 - \lambda_w}{115 - 82}[\min(S_x, 1.5Z_x) - Z_x]$$

For a slender web:

$$Z_{e,x} = Z_x \frac{115}{\lambda_w}$$

If the flange controls, the compact/non-compact reference values are 9 and 16 for rolled sections and 8 and 14 for welded sections. The current code also retains its explicit high-slenderness branch, which is documented as an implementation detail rather than replaced by a generic textbook classification.

4.5 I-Section Minor-Axis Bending Classification

The minor-axis routine uses separate flange limits. For rolled I-sections:

$$\lambda_{f,c,y} = 9, \qquad \lambda_{f,n,y} = 25$$

For welded I-sections:

$$\lambda_{f,c,y} = 8, \qquad \lambda_{f,n,y} = 22$$

The web non-compact reference remains 115 and the same interpolation concept is used to obtain $Z_{e,y}$.

The PFC calculation remains separate from the I-section procedure because the channel is not doubly symmetric. In particular, the flange is treated as one outstanding plate from the web and the minor-axis effective modulus depends on the direction of bending. The engine calculates right-side and left-side minor-axis effective moduli using the applicable web and flange branches, limits the left-side result so it cannot exceed the right-side result in the current implementation, and adopts the less favourable minor-axis section capacity.

This directional treatment is preserved in the detailed capacity output even though the global station result needs one governing minor-axis capacity. It also explains why PFC sections are excluded from the compact doubly symmetric Section 8 concessions.

4.6 PFC Slenderness and Effective Area

For a PFC:

$$\lambda_w = \frac{d - 2t_f}{t_w}\sqrt{\frac{f_{yw}}{250}}$$

$$\lambda_f = \frac{b_f - t_w}{t_f}\sqrt{\frac{f_{yf}}{250}}$$

The current compression limits are:

$$\lambda_{w,e} = 45$$

$$\lambda_{f,e} = 16$$

The effective area is obtained by reducing the web and both flange outstands as implemented by the PFC routine, then:

$$k_f = \frac{A_e}{A_g}$$

PFC minor-axis bending is direction-sensitive. FEAKalc calculates separate right- and left-side effective moduli and uses the less favourable capacity.

For RHS and SHS sections, both opposite walls participate in the effective-area and shear calculations. The box routine therefore reduces two webs and two flanges when forming the effective compression area. For bending it determines the effective modulus independently about each principal axis, so an RHS can have different major- and minor-axis classifications even though an SHS will often be symmetric in the corresponding properties.

4.7 RHS and SHS Slenderness

For box sections:

$$\lambda_w = \frac{d - 2t_f}{t_w}\sqrt{\frac{f_y}{250}}$$

$$\lambda_f = \frac{b_f - 2t_w}{t_f}\sqrt{\frac{f_y}{250}}$$

The current compression effective-width limits are:

$$\lambda_{w,e} = 40$$

$$\lambda_{f,e} = 40$$

The box effective area is calculated by reducing both webs and both flanges, then:

$$k_f = \frac{A_e}{A_g}$$

For bending, the current effective-modulus routine uses web reference limits 82 and 115, and flange reference limits 30 and 40, with interpolation between the elastic and compact effective moduli.

The CHS branch uses circular-section slenderness measures rather than attempting to create artificial web and flange plates. Equal section properties are assigned about the two principal axes, but the later member compression calculation is still performed with the effective length supplied for each axis. Accordingly, equal section properties do not force equal member capacities when the restraint lengths differ.

4.8 CHS Slenderness and Effective Properties

For CHS sections, the engine calculates:

$$\lambda_c = \frac{D}{t}\sqrt{\frac{f_y}{250}}$$

and:

$$\lambda_E = \frac{D}{t}\frac{f_y}{250}$$

The effective diameter used for the compression form factor is:

$$D_e = \min\left[D\sqrt{\frac{82}{\lambda_E}},\ D\left(\frac{3\times 82}{\lambda_E}\right)^2,\ D\right]$$

The resulting effective CHS wall area gives:

$$k_f = \frac{A_e}{A_g}$$

For bending, the current CHS classification uses:

$$\lambda_E \le 50 \quad \text{compact}$$

$$50 < \lambda_E \le 120 \quad \text{non-compact}$$

$$\lambda_E > 120 \quad \text{slender}$$

with the corresponding compact, interpolated or reduced section modulus.

Where the enriched angle database supplies a form factor, principal properties and direction-sensitive effective moduli, the engine uses those values directly. The fallback geometry calculation is intended to support legacy angle data. It retains the tabulated centroidal second moments parallel to the legs, estimates the missing product of inertia from an idealised two-rectangle angle, and derives the principal properties from that combined information so that rolled-section information already present in the database is not discarded.

4.9 L-Angle Effective Area Factor

The angle routine uses the outstanding portions of the two legs:

$$b_d = d - t_f$$

$$b_b = b_f - t_w$$

The modified leg slendernesses are:

$$\lambda_d = \frac{b_d}{t_w}\sqrt{\frac{f_y}{250}}$$

$$\lambda_b = \frac{b_b}{t_f}\sqrt{\frac{f_y}{250}}$$

Where the angle database supplies k_f, that value is used subject to $0 \le k_f \le 1$. Otherwise FEAKalc uses an effective-width limit of 16 for both outstanding legs:

$$b_{d,e} = b_d \min\left(1, \frac{16}{\lambda_d}\right)$$

$$b_{b,e} = b_b \min\left(1, \frac{16}{\lambda_b}\right)$$

and calculates:

$$A_e = A_g - (b_d - b_{d,e})t_w - (b_b - b_{b,e})t_f$$

$$k_f = \frac{A_e}{A_g}$$

Angle bending does not use the ordinary I/PFC web-flange effective-modulus routine. It uses direction-sensitive effective moduli supplied for the angle principal axes, as described in Part 9.

5 Axial Compression and Tension Capacity

5.1 General

The axial design procedure distinguishes compression and tension. Compression is checked for section slenderness and flexural buckling about the relevant principal axes. Tension is presently checked against gross-section yielding only.

5.2 Modified Member Slenderness

For an effective length L_e, radius of gyration r, form factor k_f and yield stress f_y, the engine calculates:

$$\lambda_n = \frac{L_e}{r}\sqrt{k_f}\sqrt{\frac{f_y}{250}}$$

The section parameter is:

$$\alpha_a = \frac{2100(\lambda_n - 13.5)}{\lambda_n^2 - 15.3\lambda_n + 2050}$$

The adjusted member slenderness is:

$$\lambda = \lambda_n + \alpha_a \alpha_b$$

5.3 Imperfection and Compression Reduction

The imperfection parameter is:

$$\eta = 0.00326(\lambda - 13.5)$$

with:

$$\eta \geq 0$$

The intermediate parameter is:

$$\xi = \frac{(\lambda/90)^2 + 1 + \eta}{2(\lambda/90)^2}$$

and the compression reduction factor is:

$$\alpha_c = \xi\left[1 - \sqrt{1 - \left(\frac{90}{\xi\lambda}\right)^2}\right]$$

The compression routine first establishes the effective section resistance and then applies the member reduction for flexural buckling. The member result is explicitly capped at the effective section resistance, preventing the stability calculation from producing a capacity greater than the reduced cross-section can carry. The calculation is repeated independently about both relevant principal axes and the smaller design capacity governs the standalone compression check.

For ordinary sections those axes correspond to the section principal x and y directions represented by the FEAKalc 33 and 22 bending conventions. For angles the same compression algorithm is called with the inclined principal radii and the angle-specific effective lengths. The angle buckling curve parameter used by the implementation is fixed separately from the ordinary I, PFC, RHS/SHS and CHS branches.

5.4 Section and Member Compression Capacities

The effective section compression capacity is:

$$\phi N_s = 0.9 k_f A_g f_y$$

The member compression capacity for the particular axis is:

$$\phi N_c = \alpha_c \phi N_s$$

subject to:

$$\phi N_c \leq \phi N_s$$

The two ordinary principal-axis capacities are:

$$\phi N_{cx} = f(L_{e,33}, r_x)$$

$$\phi N_{cy} = f(L_{e,22}, r_y)$$

and the governing ordinary-section compression capacity is:

$$\phi N_c = \min(\phi N_{cx}, \phi N_{cy})$$

For angles, the same general calculation is applied about the inclined principal axes using the angle principal radii and principal-axis effective lengths.

These section-family parameters are deliberately documented because they can materially change member compression resistance for otherwise similar geometric slenderness. The PFC branch changes with the effective-area factor, the box branch uses its own fixed parameter, the CHS branch depends on whether the section is fully effective, and the angle branch uses its dedicated value. The manual therefore treats these as implementation-specific inputs to the common compression equation rather than presenting one universal compression curve for all section families.

5.5 Section-Family Buckling Curve Parameter Values

The current implementation adopts the following α_b rules:

Section family	Current FEAKalc α_b rule
I-section	0 generally; welded I-section with $k_f < 1$ uses $+0.5$
PFC	$+0.5$ where $k_f \approx 1$; otherwise $+1.0$
RHS/SHS	-0.5
CHS	-1.0 where $k_f = 1$; otherwise -0.5
L-angle	$+0.5$

These are implementation rules of the current engine and are reported here so the generated capacity can be traced directly to the code path used.

The interaction length is used only for the in-plane Section 8 compression-plus-bending reduction. The standalone member compression capacity continues to use the selected effective length for the corresponding buckling direction. Keeping these calculations separate mirrors the engine data structure, which stores both the standalone axis capacities and the interaction capacities used to reduce the in-plane moments.

5.6 Compression Interaction Lengths

For the Section 8 in-plane interaction checks, the current engine determines an interaction length from the physical and effective member lengths. Conceptually, where both are available:

$$L_8 = \min(L, L_e)$$

with a small positive numerical lower bound applied internally to avoid zero-length calculations.

The compression capacity used in the Section 8 in-plane reduction is then recalculated using this interaction length rather than blindly reusing the standalone axial buckling capacity.

This is an intentional implementation boundary. Because connection geometry, bolt holes, net area, ultimate tensile strength and connection reduction factors are not present in the steel design request, the engine cannot establish a net-section fracture resistance. The reported tension capacity should therefore be read specifically as the gross-yielding design capacity available to the current member check.

5.7 Tension Capacity

For axial tension, the current engine uses gross-section yielding:

$$\phi N_t = 0.9 A_g f_y$$

and the standalone tension utilisation is:

$$U_t = \frac{N_t^*}{\phi N_t}$$

Net-section fracture is **not** included because the current steel design request does not provide the required net area, ultimate tensile strength and connection reduction information. This limitation applies to ordinary sections and angles.

5.8 CHS Compression About Two Axes

Revision 1 corrects the earlier manual wording that described one common CHS compression capacity. Although CHS section properties are equal about the two principal axes, the current engine calculates:

$$\phi N_{cx} = f\left(L_{e,33}, r\right)$$
$$\phi N_{cy} = f\left(L_{e,22}, r\right)$$

and adopts:

$$\phi N_c = \min\left(\phi N_{cx}, \phi N_{cy}\right)$$

Therefore different effective lengths may produce different CHS compression capacities even though the section itself is rotationally symmetric.

6 Bending Capacity and Lateral-Torsional Buckling

6.1 Section Bending Capacity

For an effective section modulus Z_e, the design section moment capacity is:

$$\phi M_s = 0.9 Z_e f_y$$

For ordinary sections:

$$\phi M_{sx} = 0.9 Z_{e,x} f_y$$

$$\phi M_{sy} = 0.9 Z_{e,y} f_y$$

For PFC minor-axis bending, separate left and right capacities are calculated and the lesser value is adopted.

For angles, the section moment capacities use direction-sensitive principal-axis effective moduli.

The member bending calculation distinguishes the cross-section capacity from the lateral-torsional stability capacity. The elastic buckling term combines minor-axis flexural stiffness, St Venant torsional stiffness and warping stiffness over the selected unrestrained length. The resulting stability reduction is then applied to the section moment capacity together with the supplied moment modification factor, and the final member capacity is limited so it cannot exceed the section capacity.

Increasing the unrestrained length reduces the elastic buckling moment and therefore normally reduces the available member moment capacity. Conversely, shortening the lateral restraint length increases the stability resistance until the section moment capacity becomes the upper limit. This distinction is central to interpreting a result where the section is compact and strong but the member still fails the major-axis bending check because of lateral-torsional buckling.

6.2 Major-Axis Member Bending Capacity

For major-axis bending, FEAKalc calculates an elastic buckling moment from the minor-axis flexural stiffness, St Venant torsional stiffness and warping stiffness:

$$M_o = \sqrt{\left(\frac{\pi^2 E I_y}{L_b^2}\right)\left(GJ + \frac{\pi^2 E I_w}{L_b^2}\right)}$$

using:

$$E = 200000 \text{ MPa}$$

$$G = 80000 \text{ MPa}$$

The slenderness reduction parameter used by the current member-moment function is:

$$\alpha_s = 0.6\left[\sqrt{\left(\frac{M_s/0.9}{M_o}\right)^2 + 3} - \frac{M_s/0.9}{M_o}\right]$$

The major-axis member design capacity is:

$$\phi M_b = \alpha_m \alpha_s \phi M_s$$

subject to:

$$\phi M_b \leq \phi M_s$$

The major-axis moment modification factor is supplied by the caller and is no longer hard-wired to unity. This allows the member capacity to reflect the moment distribution assumption selected by the user or the calling design interface. The factor affects the member LTB capacity only; it does not replace the separate Clause 4.4.2 end-moment ratio or the moment distribution coefficient used for action amplification.

For backward compatibility, the engine can read the legacy LTB factor field when the new major-axis field is absent. A non-positive value is not accepted as a physical capacity multiplier and the engine falls back to unity. The actual factor used for the station is recorded in the result notes so the major-axis capacity can be reproduced.

6.3 Moment Modification Factor α_m

Revision 1 replaces the previous manual statement that the member-bending routine always adopts $\alpha_m = 1.0$.

The current request contains a major-axis moment modification factor:

$$\alpha_m = \text{AlphaM33}$$

Where it is not supplied, a legacy request field is accepted for backward compatibility; if neither provides a positive value, the engine adopts:

$$\alpha_m = 1.0$$

The factor is applied directly in the major-axis member moment capacity equation above and is reported in the design notes and governing-check text.

6.4 LTB Length Selection

Where a positive LTB length is supplied:

$$L_b = L_{LTB}$$

Otherwise, ordinary sections use:

$$L_b = L_{e,33}$$

Angles use the principal-x effective length as the fallback.

No 2.0 m minimum LTB length is imposed by the current engine.

For I-sections the major-axis design moment is checked against the member capacity after lateral-torsional buckling, while the minor-axis design moment is checked against the minor-axis section capacity. The current engine does not pass ordinary minor-axis I-section bending through the major-axis LTB function. This is a substantive correction from earlier versions of the manual and aligns the reported minor-axis utilisation with the present code.

6.5 I-Section Bending

For an I-section:

$$\phi M_{sx} = 0.9 Z_{e,x} f_y$$

$$\phi M_{bx} = \min(\alpha_m \alpha_s \phi M_{sx}, \phi M_{sx})$$

The major-axis standalone utilisation is:

$$U_{M33} = \frac{|M_{33}^*|}{\phi M_{bx}}$$

For minor-axis bending, the current engine uses the section capacity directly:

$$\phi M_{by} = \phi M_{sy}$$

and:

$$U_{M22} = \frac{|M_{22}^*|}{\phi M_{sy}}$$

Revision 1 implementation correction: the minor-axis I-section capacity is no longer passed through the LTB member-moment function.

PFC major-axis bending uses the same general member LTB function as the I-section branch, with the channel section properties and selected LTB length. Minor-axis bending remains a directional section-capacity check. The right and left capacities are retained separately for reporting and the smaller value governs the general minor-axis resistance used in the interaction calculation.

6.6 PFC Bending

PFC major-axis bending uses the same member LTB function:

$$\phi M_{bx} = \min(\alpha_m \alpha_s \phi M_{sx}, \phi M_{sx})$$

For minor-axis bending, the engine calculates the right- and left-side effective section capacities:

$$\phi M_{sy,R} = 0.9 Z_{e,y,R} f_y$$

$$\phi M_{sy,L} = 0.9 Z_{e,y,L} f_y$$

and adopts:

$$\phi M_{by} = \min\left(\phi M_{sy,R}, \phi M_{sy,L}\right)$$

No minor-axis LTB reduction is applied in the current PFC routine.

The current box-section branch still evaluates a major-axis member moment capacity through the common member-bending function, using the box torsional properties supplied by the section database. Minor-axis bending is checked against the minor-axis section capacity. The major-axis capacity remains capped at the section capacity, so where the closed section has ample torsional resistance the section capacity will commonly govern.

6.7 RHS and SHS Bending

For RHS/SHS:

$$\phi M_{sx} = 0.9 Z_{e,x} f_y$$

$$\phi M_{sy} = 0.9 Z_{e,y} f_y$$

The current engine still evaluates the major-axis capacity through the general member-moment function, using the supplied LTB length where available. The minor-axis capacity is the section capacity:

$$\phi M_{by} = \phi M_{sy}$$

The current box section database uses:

$$I_w = 0$$

so the warping term in the member-buckling expression is zero.

CHS bending uses the same effective section modulus about both principal directions. The current implementation evaluates the common member-bending function for the major direction and uses the section capacity for the minor direction. Because the section database assigns zero warping constant to CHS, the elastic buckling term contains the flexural and St Venant torsional contributions available to that section representation.

6.8 CHS Bending

CHS uses one effective bending modulus because the section properties are rotationally symmetric:

$$\phi M_s = 0.9 Z_e f_y$$

The current engine calculates major-axis member capacity with the general member-moment function:

$$\phi M_{bx} = \min(\alpha_m \alpha_s \phi M_s, \phi M_s)$$

while the orthogonal minor-axis check uses:

$$\phi M_{by} = \phi M_s$$

The CHS database input uses $I_w = 0$.

Angle bending is checked after the amplified local moments have been transformed to the inclined principal axes. The sign of each principal moment selects the relevant direction-sensitive effective modulus from the angle table. This is essential because an angle has different extreme-fibre distances and therefore different effective moduli for opposite senses of bending about the same principal axis.

6.9 Angle Bending

Angle bending is carried out about the inclined principal axes. For a signed principal moment M_x^*, the engine selects the corresponding direction-sensitive effective modulus:

$$Z_{e,x} = \begin{cases} Z_{e,XC}, & M_x^* < 0 \\ Z_{e,XA}, & M_x^* > 0 \\ \min(Z_{e,XA}, Z_{e,XC}), & M_x^* \approx 0 \end{cases}$$

Similarly:

$$Z_{e,y} = \begin{cases} Z_{e,YD}, & M_y^* < 0 \\ Z_{e,YB}, & M_y^* > 0 \\ \min(Z_{e,YB}, Z_{e,YD}), & M_y^* \approx 0 \end{cases}$$

The section capacities are:

$$\phi M_{sx} = 0.9 Z_{e,x} f_y$$

$$\phi M_{sy} = 0.9 Z_{e,y} f_y$$

Principal-x LTB is calculated with:

$$I_w = 0$$

and the principal minor second moment I_y in the elastic buckling moment. Principal-y bending uses the section capacity.

7 Shear Capacity and Shear-Bending Interaction

7.1 General

FEAKalc checks local shears independently and, for ordinary sections, also checks the major-axis bending plus associated web shear interaction implemented from AS 4100 Clause 5.12.3.

The FEAKalc action pairing used by the current interaction routine is:

$$M_{33}^* \leftrightarrow V_3^*$$

The Clause 5.12.3 interaction is not extrapolated to the angle-specific whole-leg shear model.

For rolled I-sections the present routine uses the overall depth in the web shear area; for welded I-sections it uses the clear depth between flanges. The same modified web slenderness that was calculated during section classification is used to determine whether the slender-web reduction is required. This reuse keeps the shear and section-classification calculations consistent within the current engine.

7.2 I-Section Shear

For an I-section the effective web depth is:

$$d_v = \begin{cases} d - 2t_f, & \text{welded I-section} \\ d, & \text{rolled I-section} \end{cases}$$

The unreduced design web shear capacity is:

$$\phi V_v = 0.9(0.6 f_{yw}) d_v t_w$$

For:

$$\lambda_w > 82$$

it is reduced by:

$$\phi V_v \leftarrow \phi V_v \left(\frac{82}{\lambda_w}\right)^2$$

The same calculated web capacity is presently used for the standalone V_2 and V_3 utilisation checks.

7.3 PFC Shear

The PFC routine uses:

$$\phi V_v = 0.9(0.6 f_{yw}) d t_w$$

with the same slender-web reduction:

$$\left(\frac{82}{\lambda_w}\right)^2$$

where $\lambda_w > 82$.

The box routine calculates the two directional capacities before selecting a single general shear resistance for station finalisation. The geometry factors recognise that the closed section distributes shear through more than one wall. The present reporting then adopts the lesser directional design capacity for both standalone local shear ratios, which is conservative when one direction is materially stronger than the other.

7.4 RHS/SHS Shear

The current box routine calculates directional shear capacities. For the strong direction, the geometry factor is:

$$k_{vx} = \min\left[1, \frac{2}{1.5(2b+d)/(3b+d)+0.9}\right]$$

and:

$$\phi V_{vx} = 0.9(0.6f_y)(d-2t_f)t_w(2k_{vx})$$

For the orthogonal direction:

$$k_{vy} = \min\left[1, \frac{2}{1.5(2d+b)/(3d+b)+0.9}\right]$$

$$\phi V_{vy} = 0.9(0.6f_y)(b-2t_w)t_f(2k_{vy})$$

The corresponding web or flange slenderness reduction is applied where the modified slenderness exceeds 82.

The general shear capacity passed to station finalisation is:

$$\phi V_v = \min(\phi V_{vx}, \phi V_{vy})$$

and that lesser value is currently used for both local standalone shear utilisations.

7.5 CHS Shear

The current CHS expression is:

$$\phi V_v = 0.324 f_y A_g$$

The same capacity is used in the two local shear directions.

7.6 L-Angle Shear

The angle routine calculates one conservative whole-leg design shear capacity from the two legs:

$$\phi V_{v,d} = 0.9(0.6f_y)dt_w$$

$$\phi V_{v,b} = 0.9(0.6f_y)b_f t_f$$

and adopts:

$$\phi V_v = \min(\phi V_{v,d}, \phi V_{v,b})$$

This capacity is used for both local V_2 and V_3 checks. The ordinary I-section web-based shear-bending interaction is not applied to angles.

7.7 Standalone Shear Utilisation

For the applicable general shear capacity:

$$U_{V2} = \frac{|V_2^*|}{\phi V_v}$$

$$U_{V3} = \frac{|V_3^*|}{\phi V_v}$$

The shear-bending check is carried out using the amplified major-axis design moment and the associated local web shear. Below the implemented moment threshold, the full web shear capacity is available. In the intermediate range the available shear resistance reduces linearly according to the implemented Clause 5.12.3 expression. The station utilisation is then the actual shear action divided by this reduced design capacity.

The check is retained independently from the standalone major-axis bending ratio. A station can therefore be controlled by shear-bending interaction even where both the standalone moment ratio and the standalone shear ratio are individually below unity. Conversely, if the design moment is low enough, the interaction check reduces to the normal shear check.

7.8 Clause 5.12.3 Major-Axis Shear-Bending Interaction

For ordinary sections, the design shear capacity available in the presence of M_{33}^* is calculated from the section major-axis capacity ϕM_{sx}.

Where:

$$|M_{33}^*| \leq 0.75\phi M_{sx}$$

FEAKalc uses:

$$\phi V_{vm} = \phi V_v$$

For:

$$0.75\phi M_{sx} < |M_{33}^*| \leq \phi M_{sx}$$

the current engine uses:

$$\phi V_{vm} = \phi V_v \left[2.2 - 1.6\frac{|M_{33}^*|}{\phi M_{sx}}\right]$$

The interaction utilisation is then:

$$U_{5.12.3} = \frac{|V_3^*|}{\phi V_{vm}}$$

The code does not extrapolate the linear shear-reduction expression past the section moment capacity because that extension is not part of the implemented procedure. When the section moment capacity is already exceeded, the major-axis bending check has independently failed. FEAKalc therefore reports the boundary shear reduction and ensures that the combined shear-bending utilisation is not smaller than the section moment ratio.

7.9 Moment Exceeding Section Capacity

The Clause 5.12.3 interpolation is not extrapolated beyond:

$$|M_{33}^*| > \phi M_{sx}$$

When that occurs, FEAKalc retains the boundary reduction:

$$\phi V_{vm} = 0.60\phi V_v$$

and also retains the separate major-axis bending failure. The reported combined shear-bending utilisation is therefore at least the section moment ratio:

$$U_{5.12.3} \geq \frac{|M_{33}^*|}{\phi M_{sx}}$$

This avoids inventing an extension of the Clause 5.12.3 interpolation beyond its implemented range.

8 Combined Actions and Governing Design — AS 4100 Section 8

Section 8 finalisation is performed after the applicable section and member capacities have been calculated. The routine therefore has access to the effective section compression capacity, gross-yield tension capacity, section moment capacities, major-axis member LTB capacity, axis-specific compression capacities and the separate interaction compression capacities. This permits the cross-section and member checks to use the capacities appropriate to their purpose instead of substituting one common denominator into every interaction equation.

The result object retains the section interaction, in-plane major-axis interaction, in-plane minor-axis interaction, out-of-plane major-axis interaction and overall member interaction separately. The global interaction utilisation is simply the larger of the applicable section and member values; the underlying components remain visible for verification.

8.1 General

FEAKalc separates cross-section interaction from member-stability interaction. The capacities used in Section 8 are design capacities with ϕ already incorporated.

The current calculation also distinguishes compression from tension and retains the standalone axial, bending, shear and Clause 5.12.3 checks in the governing station envelope.

For ordinary sections define:

$$n_s = \frac{N^*}{\phi N_s}$$

using the compression or tension section capacity appropriate to the axial action.

8.2 General Reduced Section Moments

The general reduced section moments are based on the linear axial reduction:

$$r_N = \max\left(0,1 - \frac{N^*}{\phi N_s}\right)$$

$$\phi M_{rx} = \phi M_{sx} r_N$$

$$\phi M_{ry} = \phi M_{sy} r_N$$

These general values are then replaced by the compact-section alternatives where the section family, compactness and axial condition satisfy the current FEAKalc eligibility rules.

Eligibility is evaluated at the section-family and axis-classification level. Compactness alone is not enough. The engine applies the compact alternatives only to the section families expressly represented by its implementation rules and only when the branch-specific conditions are satisfied. PFCs and angles therefore remain on the general equations even if their individual plate elements would otherwise be described as compact, and CHS also remains on the general Section 8 path in the current implementation.

8.3 Compact-Section Eligibility

The current compact alternatives are applied only to compact doubly symmetric I-sections and compact RHS/SHS sections where the clause-specific conditions are satisfied.

PFC and L-angle sections are excluded. CHS uses the general Section 8 equations in the present implementation.

For the powered compact biaxial section interaction, both principal bending classifications must be compact and the applicable reduced moments must have been obtained from the compact alternatives.

8.4 Compact Major-Axis Reduced Section Moment

For an eligible compact major-axis section under tension, zero axial force or compression with $k_f = 1$, the current implementation uses:

$$\phi M_{rx} = \min\left[\phi M_{sx}, 1.18\phi M_{sx}\left(1 - \frac{N^*}{\phi N_s}\right)\right]$$

For an eligible compact compression member with $k_f < 1$, the code uses a web-slenderness modification. Let λ_{wy} denote the compression web reference adopted for the section family. The implemented factor is:

$$k_w = 1 + 0.18\frac{82 - \lambda_w}{82 - \lambda_{wy}}$$

and:

$$\phi M_{rx} = \min\left[\phi M_{sx}, \phi M_{sx}\left(1 - \frac{N^*}{\phi N_s}\right)k_w\right]$$

when the denominator is valid.

8.5 Compact Minor-Axis Reduced Section Moment

For a compact doubly symmetric I-section the current implementation uses:

$$\phi M_{ry} = \min\left[\phi M_{sy}, 1.19\phi M_{sy}\left(1 - \left(\frac{N^*}{\phi N_s}\right)^2\right)\right]$$

For compact RHS/SHS:

$$\phi M_{ry} = \min\left[\phi M_{sy}, 1.18\phi M_{sy}\left(1 - \frac{N^*}{\phi N_s}\right)\right]$$

The general biaxial section interaction uses section capacities rather than member buckling capacities. This distinction was one of the principal corrections introduced in Revision 1 and is retained in Revision 1. Flexural buckling under axial compression and lateral-torsional buckling under major-axis bending are checked separately through the member equations and the standalone member capacities.

For uniaxial bending with axial force, the section interaction is evaluated against the reduced moment capacity for the active axis. Where there is no bending, the section interaction reduces to the axial section ratio. This branching avoids unnecessary biaxial terms and follows the actual action state at each station.

8.6 Clause 8.3 Section Interaction

For biaxial bending where the compact powered alternative is not used, FEAKalc evaluates the general section interaction:

$$U_{8.3} = \frac{N^*}{\phi N_s} + \frac{|M_{33}^*|}{\phi M_{sx}} + \frac{|M_{22}^*|}{\phi M_{sy}}$$

For uniaxial bending with axial force, the current implementation uses the appropriate reduced moment:

$$U_{8.3} = \frac{|M_{33}^*|}{\phi M_{rx}}$$

or:

$$U_{8.3} = \frac{|M_{22}^*|}{\phi M_{ry}}$$

When no bending is present:

$$U_{8.3} = \frac{N^*}{\phi N_s}$$

The powered compact interaction is reported exactly as the left-hand side evaluated by the engine. Earlier comparison exercises showed that taking an exponent root changes the numerical meaning of the Standard expression and understates the actual unity-limit value. The current engine therefore stores and reports the powered sum itself as the utilisation.

8.7 Compact Biaxial Section Interaction

For an eligible compact biaxial section, the exponent is:

$$\gamma = \min\left(2.0, 1.4 + \frac{N^*}{\phi N_s}\right)$$

and the current engine evaluates:

$$U_{8.3} = \left(\frac{|M_{33}^*|}{\phi M_{rx}}\right)^{\gamma} + \left(\frac{|M_{22}^*|}{\phi M_{ry}}\right)^{\gamma}$$

The **left-hand side itself** is the reported utilisation and has a unity limit. FEAKalc does not take a γ-th root of the powered sum.

8.8 In-Plane Member Interaction — Compression

For compression, the ordinary in-plane reduced capacities are:

$$\phi M_{ix} = \phi M_{sx} \max\left(0, 1 - \frac{N_c^*}{\phi N_{cx,8}}\right)$$

$$\phi M_{iy} = \phi M_{sy} \max\left(0, 1 - \frac{N_c^*}{\phi N_{cy,8}}\right)$$

where $\phi N_{cx,8}$ and $\phi N_{cy,8}$ are recalculated using the Section 8 interaction lengths described in Part 5.

The compact in-plane alternative uses the member end-moment parameter for the corresponding axis and the interaction compression capacity calculated with the Section 8 interaction length. It is applied independently about the major and minor axes when each axis is eligible. The result is always capped by the reduced section moment, preserving the section-capacity limit even where the compact member expression would otherwise return a larger value.

8.9 Compact In-Plane Alternative

For a compact eligible I or RHS/SHS section with $k_f = 1$, the current engine may replace the general in-plane moment with the compact alternative.

Define:

$$r = \max\left(0, 1 - \frac{N_c^*}{\phi N_{c,8}}\right)$$

and:

$$q = \left(\frac{1+\beta_m}{2}\right)^3$$

The compact in-plane capacity is:

$$\phi M_i = \phi M_s\left[(1-q)r + 1.18q\sqrt{r}\right]$$

subject to the upper limit:

$$\phi M_i \le \phi M_r$$

The appropriate β_m from the complete member moment diagram is used separately for the two axes.

8.10 General Out-of-Plane Major-Axis Capacity — Compression

For compression plus major-axis bending, the general out-of-plane reduced capacity is:

$$\phi M_{ox} = \phi M_{bx} \max\left(0, 1 - \frac{N_c^*}{\phi N_{cy}}\right)$$

The major-axis capacity used in the compression-member biaxial interaction is:

$$\phi M_{cx} = \min(\phi M_{ix}, \phi M_{ox})$$

This branch is intentionally narrower than the general out-of-plane calculation. In addition to requiring a compact doubly symmetric I-section and a fully effective compression area, the engine requires no meaningful detected transverse loading in the major bending plane and a positive out-of-plane restraint length. The torsional buckling capacity is then calculated from the section torsional and warping properties and used with the member compression ratio in the compact stability expression.

If any eligibility condition is not satisfied, the engine simply retains the general out-of-plane reduced major-axis capacity. The design therefore remains complete without the concession; the compact branch can only improve the capacity when the implementation conditions permit it.

8.11 Compact I-Section Out-of-Plane Alternative

The compact Clause 8.4.4.1 alternative is restricted in the current engine to a compact doubly symmetric I-section with $k_f = 1$, no detected major-axis transverse load and a positive out-of-plane restraint length.

The design torsional buckling capacity is calculated as:

$$\phi N_{oz} = 0.9\frac{GJ + \pi^2 E I_w / L_z^2}{(I_x + I_y)/A_g}$$

Define:

$$n_{cy} = \frac{N_c^*}{\phi N_{cy}}$$

$$n_{oz} = \frac{N_c^*}{\phi N_{oz}}$$

The current engine forms:

$$\frac{1}{\alpha_{bc}} = \frac{1-\beta_m}{2} + \left(\frac{1+\beta_m}{2}\right)^3 (0.4 - 0.23n_{cy})$$

and hence:

$$\alpha_{bc} = \left[\frac{1-\beta_m}{2} + \left(\frac{1+\beta_m}{2}\right)^3 (0.4 - 0.23n_{cy})\right]^{-1}$$

The compact out-of-plane capacity is:

$$\phi M_{ox} = \alpha_{bc}\phi M_{bx}\sqrt{(1 - n_{cy})(1 - n_{oz})}$$

subject to:

$$\phi M_{ox} \le \phi M_{rx}$$

If transverse major-axis loading is detected, this compact out-of-plane branch is not used.

For biaxial compression and bending, the major-axis denominator is the lesser of the applicable in-plane and out-of-plane major-axis capacities, while the minor-axis denominator is the in-plane minor-axis capacity. The powered sum is again treated as the actual unity-limit interaction value. This allows out-of-plane LTB to control the major-axis part of the biaxial interaction even where the in-plane major-axis reduction is comparatively mild.

8.12 Compression Member Biaxial Interaction

For simultaneous major- and minor-axis bending under compression, the current engine uses:

$$U_{8.4} = \left(\frac{|M_{33}^*|}{\phi M_{cx}}\right)^{1.4} + \left(\frac{|M_{22}^*|}{\phi M_{iy}}\right)^{1.4}$$

Again, the powered left-hand side itself is the utilisation with a unity limit; no exponent-root normalisation is applied.

For compression plus major-axis bending only:

$$U_{8.4} = \max\left(\frac{|M_{33}^*|}{\phi M_{ix}}, \frac{|M_{33}^*|}{\phi M_{ox}}\right)$$

For compression plus minor-axis bending only:

$$U_{8.4} = \frac{|M_{22}^*|}{\phi M_{iy}}$$

Tension is treated separately from compression because there is no compression-member flexural-buckling reduction. The in-plane capacities follow the reduced section moments, while axial tension can increase the available out-of-plane major-axis LTB capacity in the implemented expression. That increase is limited by the reduced section moment so tension cannot raise the member capacity above the cross-section resistance available under the same axial action.

8.13 Tension Member In-Plane and Out-of-Plane Interaction

For axial tension, the in-plane capacities are governed by the Section 8.3 reduced section capacities:

$$\phi M_{ix} = \phi M_{rx}$$

$$\phi M_{iy} = \phi M_{ry}$$

The current out-of-plane major-axis capacity is permitted to increase with tension, but is limited by the reduced section moment:

$$\phi M_{ox} = \min\left[\phi M_{bx}\left(1 + \frac{N_t^*}{\phi N_t}\right), \phi M_{rx}\right]$$

The major-axis tension interaction capacity is:

$$\phi M_{tx} = \min(\phi M_{rx}, \phi M_{ox})$$

8.14 Tension Member Biaxial Interaction

For simultaneous biaxial bending under tension:

$$U_{8.4} = \left(\frac{|M_{33}^*|}{\phi M_{tx}}\right)^{1.4} + \left(\frac{|M_{22}^*|}{\phi M_{ry}}\right)^{1.4}$$

For tension plus major-axis bending only, the governing member term is the larger of the in-plane and out-of-plane major-axis ratios.

8.15 Pure Bending

Where axial force is negligible, the Section 8.4 compression/tension member equations are not invoked. For biaxial pure bending, the applicable Clause 8.3 section interaction is retained, together with the standalone Clause 5 member bending checks.

The combined-action value is only one component of station finalisation. FEAKalc then compares it with the standalone compression or tension ratio, major- and minor-axis bending ratios, both shear ratios and the major-axis shear-bending interaction. The named governing check is selected from this complete set. This is why the global capacity ratio should be interpreted as an envelope of design requirements, not as a synonym for Section 8 interaction.

8.16 Overall Combined-Action Utilisation

The combined-action utilisation is:

$$U_{int} = \max(U_{8.3}, U_{8.4})$$

This value is retained together with the component in-plane and out-of-plane utilisations for audit.

The final station utilisation remains the maximum of the interaction and all standalone checks. Accordingly, a member may fail standalone LTB, shear, shear-bending or axial buckling even where its Section 8 interaction is below unity.

9 L-Angle Principal-Axis Design Procedure

The dedicated angle branch was introduced because using the centroidal axes parallel to the legs can misrepresent both buckling and bending. The section has a non-zero product of inertia, so its flexural principal axes are rotated. The current procedure therefore establishes or reads the principal properties, transforms the complete first-order moment diagram, applies Clause 4.4.2 amplification about the principal axes, and then carries out compression, bending, shear and Section 8 checks in that principal-axis system.

The ordinary result fields for major- and minor-axis bending are retained for compatibility with the existing steel-results interface. For an angle, however, those fields represent principal-x and principal-y bending rather than the original unrotated local 33 and 22 axes. The detailed angle fields in the result preserve the principal angle, transformed actions, selected effective moduli and principal-axis utilisations so the distinction is explicit in the memo.

9.1 General

L-angles are not treated as ordinary doubly symmetric sections. Their centroidal axes parallel to the legs are generally not principal axes because the product of inertia is non-zero. FEAKalc therefore uses a dedicated angle design path.

The preferred angle database input includes:

- principal second moments I_x and I_y;
- principal radii r_x and r_y;
- product of inertia I_{xy};
- principal-axis angle α;
- form factor k_f; and
- direction-sensitive effective moduli $Z_{e,XA}$, $Z_{e,XC}$, $Z_{e,YB}$ and $Z_{e,YD}$.

When enriched principal properties are available in the angle database, they are preferred and no geometric reconstruction is needed. For legacy data, the engine retains the tabulated centroidal second moments parallel to the legs because those values may include rolled-section effects. It calculates only the missing product of inertia from an idealised two-rectangle representation, then combines that product with the tabulated second moments to obtain the principal values and principal-axis rotation.

The derived principal radii are obtained from the principal second moments and the tabulated gross area. The calculation rejects a non-positive minor principal second moment, because such a result would indicate invalid geometry or inconsistent section data. The stored principal angle is treated by magnitude for the transformation convention used by FEAKalc.

9.2 Principal Properties from Legacy Angle Data

Where enriched principal properties are not available, the current engine retains the tabulated centroidal I_n and I_p values parallel to the angle legs and estimates only the missing product of inertia from an ideal two-rectangle angle geometry.

For the ideal vertical leg, horizontal leg and overlapping corner rectangle, the areas are:

$$A_1 = t_w d$$

$$A_2 = b_f t_f$$

$$A_3 = t_w t_f$$

The ideal area is:

$$A_i = A_1 + A_2 - A_3$$

The ideal centroid is calculated from the component first moments and the product of inertia is obtained from the parallel-axis terms:

$$I_{xy} = A_1(x_1 - \bar{x})(y_1 - \bar{y}) + A_2(x_2 - \bar{x})(y_2 - \bar{y}) - A_3(x_3 - \bar{x})(y_3 - \bar{y})$$

The current engine then retains the tabulated I_n and I_p and calculates the principal values:

$$I_{avg} = \frac{I_n + I_p}{2}$$

$$R_I = \sqrt{\left(\frac{I_n - I_p}{2}\right)^2 + I_{xy}^2}$$

$$I_x = I_{avg} + R_I$$

$$I_y = I_{avg} - R_I$$

The principal-axis angle is:

$$\alpha = \frac{1}{2}\tan^{-1}\left(\frac{2|I_{xy}|}{I_n - I_p}\right)$$

and the principal radii are:

$$r_x = \sqrt{\frac{I_x}{A_g}}$$

$$r_y = \sqrt{\frac{I_y}{A_g}}$$

This fallback is intended to preserve rolled-radius effects embedded in the tabulated I_n and I_p rather than replacing the complete section properties by a sharp-corner idealisation.

The transformation is applied to every station, not only to the governing station. This is required because the angle amplification process needs the complete principal-axis moment diagram to establish end-moment ratios and to detect transverse loading. The corresponding shear components are transformed in the same orthogonal system for the limited purpose of transverse-load detection in each principal bending plane.

After amplification, the principal moments are transformed back to an equivalent local pair only for compatibility with the general steel-results fields and reporting. The actual angle strength and interaction checks continue to use the signed principal-axis moments.

9.3 Principal Moment Transformation

Using the FEAKalc convention, the local first-order moments are transformed as:

$$M^*_{x,1} = M^*_{33,1}\cos\alpha - M^*_{22,1}\sin\alpha$$

$$M^*_{y,1} = M^*_{33,1}\sin\alpha + M^*_{22,1}\cos\alpha$$

After Clause 4.4.2 amplification:

$$M^*_x = \delta_{mx} M^*_{x,1}$$

$$M^*_y = \delta_{my} M^*_{y,1}$$

For compatibility with the ordinary steel-results UI, the amplified principal pair can be transformed back to an equivalent local pair:

$$M_{33}^{*} = M_{x}^{*}\cos\alpha + M_{y}^{*}\sin\alpha$$

$$M_{22}^{*} = -M_{x}^{*}\sin\alpha + M_{y}^{*}\cos\alpha$$

but the angle strength checks themselves remain on the principal axes.

The sign of the principal-x moment selects Load A or Load C data, while the sign of the principal-y moment selects Load B or Load D data. Where a principal moment is essentially zero, the engine conservatively adopts the smaller of the two available effective moduli for that axis. The selected effective modulus is stored in the result, providing a direct audit trail from bending direction to section capacity.

9.4 Direction-Sensitive Angle Bending

The sign of the amplified principal moment selects the angle capacity-table direction. Principal-x bending uses Load A or C, and principal-y bending uses Load B or D.

The design capacities are:

$$\phi M_{sx} = 0.9 Z_{e,x} f_y$$

$$\phi M_{sy} = 0.9 Z_{e,y} f_y$$

where the applicable Z_e is chosen from A/C or B/D according to the sign of the principal moment.

Angle compression uses the same common compression reduction formulation as the other section families but with the angle form factor, inclined principal radii, angle principal effective lengths and the dedicated angle buckling-curve parameter. The two principal-axis capacities are calculated independently and the smaller value governs the standalone axial compression check.

9.5 Angle Compression

The angle compression calculation uses:

$$\alpha_b = +0.5$$

with the angle form factor k_f, principal radii and principal-axis effective lengths.

Thus:

$$\phi N_{cx} = f\left(A_g, r_x, f_y, k_f, L_{e,x}^{angle}, \alpha_b = 0.5\right)$$

$$\phi N_{cy} = f\left(A_g, r_y, f_y, k_f, L_{e,y}^{angle}, \alpha_b = 0.5\right)$$

and:

$$\phi N_c = \min\left(\phi N_{cx}, \phi N_{cy}\right)$$

The principal-x angle bending capacity is passed through the common member-bending function. The engine uses the minor principal second moment in the elastic buckling expression and sets the warping constant to zero for the angle LTB calculation. A supplied LTB length is used where available; otherwise the principal-x effective length is the fallback. Principal-y bending is checked against its direction-sensitive section capacity.

9.6 Angle Lateral-Torsional Buckling

For principal-x bending, the current engine uses the ordinary member-moment function with:

$$I_y = I_{y,principal}$$

$$I_w = 0$$

and either the supplied LTB length or the principal-x effective length.

Therefore:

$$M_o = \sqrt{\left(\frac{\pi^2 EI_y}{L_b^2}\right)(GJ)}$$

and:

$$\phi M_{bx} = \min(\alpha_m \alpha_s \phi M_{sx}, \phi M_{sx})$$

Principal-y bending uses:

$$\phi M_{by} = \phi M_{sy}$$

Angles remain on the general Section 8 section-capacity path and are never marked as eligible for the compact doubly symmetric concessions. Under biaxial bending the current angle routine uses the general axial-plus-biaxial section relationship. Under uniaxial bending with axial force it uses the appropriate reduced principal-axis section moment, consistent with the ordinary-section branching logic.

9.7 Angle Section Interaction

Angles are excluded from the compact doubly symmetric Section 8 concessions. The current angle section interaction uses the general reduced section moments.

For biaxial bending:

$$U_{8.3} = \frac{N^*}{\phi N_s} + \frac{|M_x^*|}{\phi M_{sx}} + \frac{|M_y^*|}{\phi M_{sy}}$$

For one principal bending axis, the appropriate reduced section moment is used.

For compression, separate interaction compression capacities are recalculated about the principal axes using the Section 8 interaction lengths. These capacities reduce the in-plane principal-x and principal-y moments. The out-of-plane principal-x capacity is based on the angle member LTB capacity reduced by the axial compression ratio about the minor principal direction, and the biaxial member interaction uses the same powered form as the general compression-member calculation.

9.8 Angle Member Interaction — Compression

For compression, the in-plane angle capacities are:

$$\phi M_{ix} = \phi M_{sx} \max\left(0{,}1 - \frac{N_c^*}{\phi N_{cx,8}}\right)$$

$$\phi M_{iy} = \phi M_{sy} \max\left(0{,}1 - \frac{N_c^*}{\phi N_{cy,8}}\right)$$

The out-of-plane principal-x capacity is:

$$\phi M_{ox} = \phi M_{bx} \max\left(0{,}1 - \frac{N_c^*}{\phi N_{cy}}\right)$$

and:

$$\phi M_{cx} = \min(\phi M_{ix}, \phi M_{ox})$$

For biaxial compression plus bending:

$$U_{8.4} = \left(\frac{|M_x^*|}{\phi M_{cx}}\right)^{1.4} + \left(\frac{|M_y^*|}{\phi M_{iy}}\right)^{1.4}$$

For tension, the principal in-plane capacities reduce with the gross-yield axial ratio through the section interaction. The out-of-plane principal-x capacity can increase according to the implemented tension-plus-LTB expression but remains limited by the reduced section moment. As elsewhere in the engine, the axial tension resistance is gross yielding only; connection-dependent net-section fracture is outside the current angle design input.

9.9 Angle Member Interaction - Tension

For tension, the gross yielding capacity is:

$$\phi N_t = 0.9 A_g f_y$$

The reduced section moments are used in-plane. The out-of-plane principal-x capacity is:

$$\phi M_{ox} = \min\left[\phi M_{bx}\left(1 + \frac{N_t^*}{\phi N_t}\right), \phi M_{rx}\right]$$

and the biaxial powered interaction uses the same 1.4 exponent as the ordinary tension-member implementation.

Net-section fracture remains outside the present angle design scope.

The angle shear check is intentionally conservative and simple: the design capacity of each whole leg is calculated and the smaller value is adopted for both local shear components. The ordinary web-based Clause 5.12.3 shear-bending routine is not transferred to angles because the current angle implementation does not define an equivalent web shear model for that interaction.

Station finalisation then compares angle axial capacity, principal-x bending, principal-y bending, Section 8 section interaction, Section 8 member interaction and both shear checks. The governing name explicitly identifies angle principal-axis bending where that check controls.

9.10 Angle Shear and Governing Result

The angle standalone shear check uses the lesser whole-leg design shear capacity for both local shear components. No I-section-type M_{33}-V_3 shear-bending extrapolation is applied to angle sections.

The final angle station utilisation is the maximum of:

- axial compression or gross-yield tension;
- principal-x bending;
- principal-y bending;
- Section 8.3 angle section interaction;
- Section 8.4 angle member interaction; and
- local V_2 and V_3 shear checks.

10 Design Scope, Reporting and Interpretation

10.1 Current Supported Design Scope

The current FEAKalc steel engine supports I-sections, PFCs, RHS/SHS, CHS and L-angle sections, with station-by-station and load-combination-by-load-combination checks for the design actions and interactions described in this manual.

The workflow is:

- 3D finite element analysis
- Design load-combination actions at member stations
- Effective lengths and restraint lengths
- Clause 4.4.2 moment amplification / second-order trigger
- Section slenderness and effective properties
- Axial, bending and shear capacities
- Clause 5.12.3 and Section 8 interactions
- Station and load-combination envelope

Revision 1 adds a more complete audit trail for stability and interaction calculations. The station result can retain first-order and amplified moments, end-moment ratios, moment distribution coefficients, elastic buckling loads, braced and sway amplification factors, the second-order-analysis flag, Section 8 component utilisations, compact-concession flags, the major-axis moment modification factor, shear-bending capacity and reduction factor, and the angle principal-axis data where applicable.

The intention is that the reported global capacity ratio can be traced back to both the applied action and the specific capacity used in its denominator. The design notes generated by the engine include a breakdown of standalone ratios, relevant design capacities, the evaluated Section 8 equations, other interaction components and an ordered list of all applicable governing checks.

10.2 Result Traceability

For each station the current engine can retain, as applicable:

- first-order and amplified moments;
- β_m, c_m, N_{omb}, δ_b, δ_s and δ_m for each axis;
- section classification and k_f;
- axial, section moment, member moment and shear capacities;
- Clause 5.12.3 reduced shear capacity and factor;
- Section 8.3, in-plane, out-of-plane and member interaction utilisations;
- compact Section 8 concession eligibility and use;
- α_{bc} and ϕN_{oz} where the compact I-section out-of-plane alternative is used;
- α_m used for major-axis LTB capacity;
- angle principal properties, direction-sensitive effective moduli and transformed actions; and
- governing check and overall utilisation.

This audit trail is deliberately more detailed than a single global ratio so the reported result can be traced back to the implemented equation and capacity branch.

The global capacity ratio is obtained from the maximum of the check dictionary assembled for the station. The dictionary is action-state dependent: compression stations include the applicable in-plane and out-of-plane compression-member terms, tension stations include the tension member terms, and pure-bending stations retain the Clause 5 member checks together with the applicable Section 8 section interaction. The shear-bending term is included for ordinary sections independently of whether Section 8 governs.

After each station has been finalised, the member result selects the station with the largest utilisation. FEAKalc then envelopes the member result across the applicable steel design load combinations on the client side. The final reported value therefore represents the maximum of check type, station location and load combination.

10.3 Global Capacity Ratio

The reported global capacity ratio is the maximum of all applicable checks at the governing station. It is not a simple sum of axial and bending utilisation ratios.

For an ordinary station, the set may be represented as:

$$U_{global} = \max(U_N, U_{M33}, U_{M22}, U_{V2}, U_{V3}, U_{5.12.3}, U_{8.3}, U_{8.4}, \dots)$$

For an angle, U_{M33} and U_{M22} in the existing results UI correspond to principal-x and principal-y bending utilisations.

10.4 PASS/FAIL Classification

A station and final member pass when:

$$U_{global} \leq 1.0$$

and fail where:

$$U_{global} > 1.0$$

A separate forced FAIL is also applied when the Clause 4.4.1.2 second-order elastic analysis trigger is reached, even if the numerically retained first-order amplified capacity ratios would otherwise be below unity.

These limitations should be read together with the detailed procedure rather than as defects hidden from the result. Torsion is carried through the action data but is not presently checked as a separate resistance. Tension capacity is gross yielding only. The ordinary shear-bending implementation addresses major-axis moment with its associated web shear and is not generalised to angle whole-leg shear. The automatic effective-length routine infers restraint from analytical geometry and cannot establish real semi-rigid connection stiffness that has not been represented by the model or user input.

The Clause 4.4.2 sway amplification values are inputs from a frame or storey stability assessment when required. Where no non-unity values are supplied, the steel engine records unity and notes the assumption. If any braced or sway amplification exceeds the implemented 1.4 threshold, a compliant final result requires second-order elastic analysis; the retained first-order amplified result is diagnostic only.

10.5 Current Implementation Boundaries

The current implementation boundaries relevant to interpretation are:

- torsion T^* is transferred and reported but is not checked as a separate torsional capacity or combined torsion interaction;
- tension capacity presently uses gross-section yielding only; net-section fracture requires connection and net-area data that are not supplied to the current engine;
- the compact Section 8 alternatives are restricted to the section families and conditions described in Part 8; PFC and angle sections are excluded and CHS remains on the general Section 8 equations;
- the Clause 5.12.3 shear-bending check is implemented for major-axis M_{33} with associated local V_3 in the ordinary-section finalisation path;
- the angle shear model uses the lesser whole-leg capacity and does not apply the ordinary I-section web-based shear-bending model;

- the current I and PFC standalone shear routines use one calculated web shear capacity for both local shear utilisation checks;
- the current RHS/SHS routine adopts the lesser calculated directional shear capacity for station finalisation;
- the major-axis moment modification factor α_m is supplied by the request and defaults to 1.0 only when no positive value is available;
- a sway amplification greater than unity must be supplied by the frame/storey stability calculation where required; otherwise $\delta_s = 1.0$ is recorded; and
- when a braced or sway amplification exceeds 1.4, the first-order amplified result is retained for audit only and a second-order elastic analysis is required.

Engineering review should therefore consider whether the model represents the actual bracing, floor restraint, continuity, connection behaviour and lateral restraint of the member. A numerically precise capacity ratio does not compensate for an incorrect effective length, LTB length, sway factor, section property or load combination. The design memo is intended to make those governing inputs visible so they can be checked against the structural arrangement.

10.6 Engineering Judgement

The design result depends on the structural model, assigned section, material properties, effective lengths, LTB restraint, angle principal-axis data, moment modification factor, sway amplification and load combinations.

Automatic restraint inference reflects the geometry represented in the FEAKalc model. The designer remains responsible for confirming that actual connections and restraints provide the assumed behaviour, and for considering design matters not represented by the present steel member engine, including connection design, local detailing, net-section effects, torsion interaction, construction sequence and other project-specific requirements.

The following appendix is a compact index of the principal equations already developed in the main body. It is not a substitute for the section-family discussion, branch eligibility conditions or implementation limitations. In particular, the same symbol can represent a different principal axis for angle sections, and the Section 8 compact alternatives must only be used where the eligibility rules in Part 8 are satisfied.

Appendix A - Implementation Equation Summary

The following compact summary identifies the principal equation sequence used by the current engine.

A.1.Moment Amplification

$$\beta_m \rightarrow c_m = \min[1, \max(0,0.6 - 0.4\beta_m)]$$

$$N_{omb} = \frac{\pi^2 EI}{L_e^2}$$

$$\delta_b = \max\left(1, \frac{c_m}{1 - N_c^*/N_{omb}}\right)$$

$$\delta_m = \max(\delta_b, \delta_s)$$

$$M^* = \delta_m M_1^*$$

If $\delta_b > 1.4$ or $\delta_s > 1.4$, second-order elastic analysis is required.

A.2 Compression

$$\lambda_n = \frac{L_e}{r}\sqrt{k_f}\sqrt{\frac{f_y}{250}}$$

$$\alpha_a = \frac{2100(\lambda_n - 13.5)}{\lambda_n^2 - 15.3\lambda_n + 2050}$$

$$\lambda = \lambda_n + \alpha_a\alpha_b$$

$$\eta = \max[0,0.00326(\lambda - 13.5)]$$

$$\xi = \frac{(\lambda/90)^2 + 1 + \eta}{2(\lambda/90)^2}$$

$$\alpha_c = \xi\left[1 - \sqrt{1 - \left(\frac{90}{\xi\lambda}\right)^2}\right]$$

$$\phi N_s = 0.9k_f A_g f_y$$

$$\phi N_c = \min(\alpha_c \phi N_s, \phi N_s)$$

A.3 Major-Axis Bending

$$\phi M_s = 0.9Z_e f_y$$

$$M_o = \sqrt{\left(\frac{\pi^2 EI_y}{L_b^2}\right)\left(GJ + \frac{\pi^2 EI_w}{L_b^2}\right)}$$

$$\alpha_s = 0.6\left[\sqrt{\left(\frac{M_s/0.9}{M_o}\right)^2 + 3} - \frac{M_s/0.9}{M_o}\right]$$

$$\phi M_b = \min(\alpha_m \alpha_s \phi M_s, \phi M_s)$$

A.4 Shear-Bending

$$\phi V_{vm} = \begin{cases} \phi V_v, & |M^*| \leq 0.75\phi M_s \\ \phi V_v\left(2.2 - 1.6|M^*|/(\phi M_s)\right), & 0.75\phi M_s < |M^*| \leq \phi M_s \end{cases}$$

A.5 Section 8 Powered Interactions

Compact eligible section:

$$U_{8.3} = \left(\frac{|M_x^*|}{\phi M_{rx}}\right)^{\gamma} + \left(\frac{|M_y^*|}{\phi M_{ry}}\right)^{\gamma}$$

$$\gamma = \min\left(2{,}1.4 + \frac{N^*}{\phi N_s}\right)$$

Biaxial member interaction:

$$U_{8.4} = \left(\frac{|M_x^*|}{\phi M_{cx}}\right)^{1.4} + \left(\frac{|M_y^*|}{\phi M_{iy}}\right)^{1.4}$$

In both cases, FEAKalc reports the powered left-hand side directly with a unity limit.

A useful verification exercise should reproduce not only the final global capacity ratio but also the intermediate values that lead to it. For ordinary sections this includes section slenderness, effective section properties, axis compression capacities, section moment capacities, major-axis member bending capacity, moment-amplification metadata, Section 8 component interactions and the Clause 5.12.3 shear-bending check where active. For angles it additionally includes principal properties, transformed actions and the direction-sensitive effective modulus selected for each principal axis.

Appendix B — Verification Checklist

A practical verification of a steel member result should confirm the following items against the design memo and model inputs:

1. the correct section family and steel properties were retrieved;
2. the physical and effective lengths correspond to the intended restraint condition;
3. any LTB length override is appropriate to the actual compression-flange restraint;
4. for angles, the principal angle, radii and A/C/B/D effective moduli are present and plausible;
5. first-order moments have been amplified using the reported β_m, c_m, N_{omb}, δ_b and δ_s values;
6. the second-order analysis flag is not triggered, or a compliant second-order analysis has been used where it is;
7. section slenderness, k_f and bending classifications correspond to the section geometry;
8. axial capacities about both principal axes are reviewed;
9. major-axis α_m and LTB length are checked against the design assumptions;
10. the Clause 5.12.3 M_{33}-V_3 interaction is reviewed where major bending is high;
11. the Section 8.3 and Section 8.4 interaction values are both reviewed; and
12. the governing station and governing load combination correspond to the final reported global capacity ratio.

The FEAKalc steel design memo is intended to provide the values required for this traceability review.

Verification should normally confirm the following items for at least one representative member of each section family:

- the section database properties and material yield stresses transferred to the design engine;
- automatic and user-overridden effective lengths, together with the LTB restraint length;
- first-order station actions and the amplified design moments used by the strength checks;
- section classification, effective area factor and effective bending modulus;
- standalone compression, tension, major-axis bending, minor-axis bending and shear capacities;
- the Section 8 section and member interaction values, including any compact-section concession actually used;
- the Clause 5.12.3 major-axis shear-bending result for ordinary sections where applicable;
- the second-order-analysis flag whenever a braced or sway amplification exceeds the implemented threshold; and
- for L-angles, the principal-axis properties, transformed moments, selected A/C and B/D effective moduli and principal-axis governing checks.

The objective of the verification is to demonstrate that the reported global capacity ratio is the maximum of the same individual checks that can be independently reconstructed from the documented design actions and capacities.

Appendix C - Section-Family Design Sequence

This appendix restates the current design flow by section family. It is intended as a code-review and verification aid: the detailed equations, eligibility conditions and limitations remain those given in the main body of the manual.

C.1 I-Sections

The I-section branch first validates the section dimensions and properties, then establishes the major- and minor-axis effective lengths and the separate lateral-torsional buckling length. Web and flange slenderness are calculated using the applicable web and flange yield stresses. These values determine the compression form factor and the effective section moduli for major- and minor-axis bending. Rolled and welded sections follow the separate compression and flange-classification limits documented in Part 4.

Compression capacities are calculated independently about the two principal axes and the smaller value is retained as the standalone compression capacity. Major-axis section capacity is converted to a member capacity using the LTB routine and the supplied major-axis moment modification factor. Minor-axis bending is checked against the minor-axis section capacity. Web shear is calculated from the current rolled or welded web depth rule and reduced for a slender web where required.

Station finalisation then uses the amplified design moments. It evaluates standalone axial, major-axis bending, minor-axis bending and shear checks; the major-axis shear-bending interaction; Section 8 section interaction; the applicable in-plane member interactions; and the out-of-plane major-axis interaction. Compact I-section alternatives are used only when the branch-specific conditions are satisfied. The maximum of all applicable values becomes the station capacity ratio.

C.2 Parallel Flange Channels

The PFC branch uses the channel-specific flange slenderness and effective-area rules. Major-axis bending classification follows the web-versus-flange comparison used by the channel routine, while minor-axis bending is treated directionally. Separate right-side and left-side effective moduli are calculated and the less favourable section capacity is retained for the general minor-axis check.

The PFC compression buckling parameter depends on whether the effective-area factor is unity. Axis compression capacities are calculated separately and the smaller value governs. Major-axis member bending uses the common LTB function with the channel minor-axis second moment, torsional constant, warping constant and selected LTB length. Minor-axis bending is a section-capacity check and does not use the major-axis LTB reduction.

PFC sections remain outside the compact doubly symmetric Section 8 concessions. The general section and member interaction rules therefore apply. The channel web shear capacity is used for both local standalone shear components in the current finalisation routine, and the ordinary major-axis shear-bending interaction remains active because the branch uses the common ordinary-section finalisation procedure.

C.3 RHS and SHS

The box-section branch calculates modified slenderness for the flat web and flange portions, reduces both opposite webs and both opposite flanges where required, and forms the compression effective-area factor. Effective section moduli are calculated separately about the two principal axes using the box-section web and flange classification limits.

Compression uses the box-section buckling parameter about both axes. Major-axis section bending is passed through the common member-bending routine, with a supplied LTB length where available and the major-axis effective length as fallback. Minor-axis bending uses the corresponding section capacity. The closed-section shear calculation determines separate strong- and weak-direction capacities with the current geometry factors and adopts the smaller value for general station finalisation.

Compact RHS and SHS sections are eligible for the implemented compact Section 8 alternatives where the axis compactness and action-state conditions are satisfied. The compact major- and minor-axis reduced section moments, powered biaxial section interaction and compact in-plane member alternative are therefore available to this family. The final capacity ratio still includes the standalone capacities and major-axis shear-bending interaction independently of those concessions.

C.4 Circular Hollow Sections

The CHS branch uses circular slenderness and effective-diameter relationships rather than web and flange plate elements. The resulting effective wall area provides the compression form factor, while the CHS bending classification provides one effective section modulus that is used about both principal directions because the section properties are equal.

Member compression is nevertheless calculated independently about the two axes using their respective effective lengths, so the two capacities can differ when restraint differs. The major-axis member-bending capacity uses the common stability routine with the CHS properties and the selected LTB or fallback length; the minor-axis check uses the section capacity. The section-area-based CHS shear expression provides the common shear resistance.

CHS remains on the general Section 8 interaction equations in the present engine rather than the compact alternatives implemented for doubly symmetric I-sections and RHS/SHS. This is an explicit software implementation rule. The station result is otherwise finalised through the common ordinary-section path, including moment amplification and the major-axis shear-bending check.

C.5 L-Angles

The angle branch first obtains the inclined principal properties from the enriched angle database or, where necessary, reconstructs them from the legacy centroidal properties and idealised product of inertia. Angle-specific principal-axis effective lengths are used where supplied; otherwise the engine conservatively adopts the larger ordinary effective length for each principal direction.

The complete first-order local moment diagram is transformed to the principal axes before moment amplification. The transformed station set is used to obtain the end-moment ratio, transverse-load condition, moment distribution coefficient and elastic buckling load for each principal axis. The resulting amplified principal moments determine the bending direction and therefore select the appropriate A or C effective modulus about principal x and B or D effective modulus about principal y.

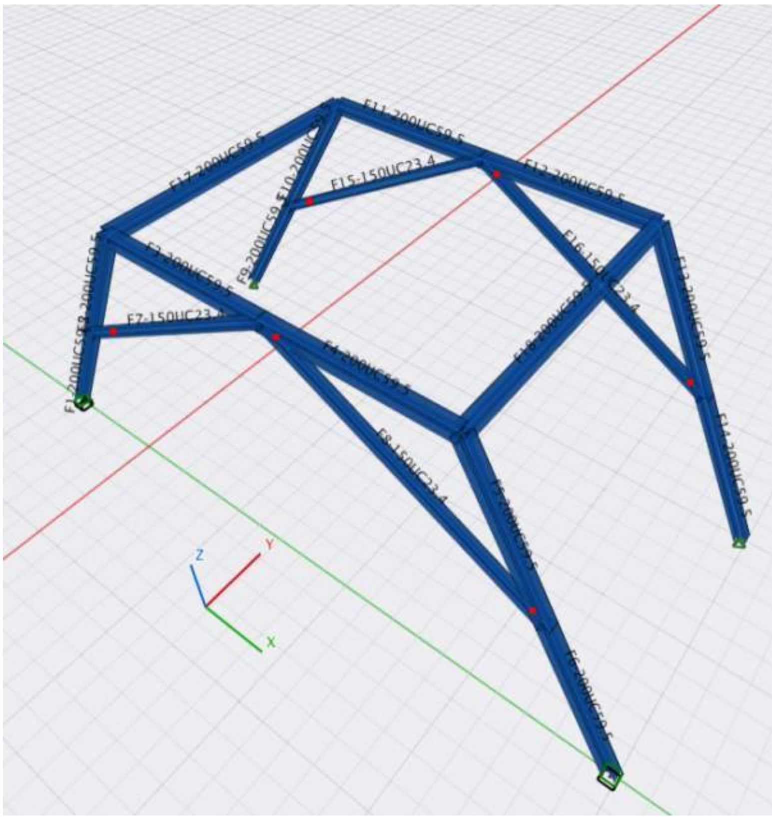
Compression is calculated about the two inclined principal axes using the angle form factor and the angle buckling parameter. Principal-x bending uses the common member-bending routine with zero warping constant and the minor principal second moment; principal-y bending uses the direction-sensitive section capacity. The angle Section 8 checks use the general, non-compact-concession path, and angle shear uses the smaller whole-leg capacity for both local shear components. The final station result compares all of these principal-axis and shear checks directly.

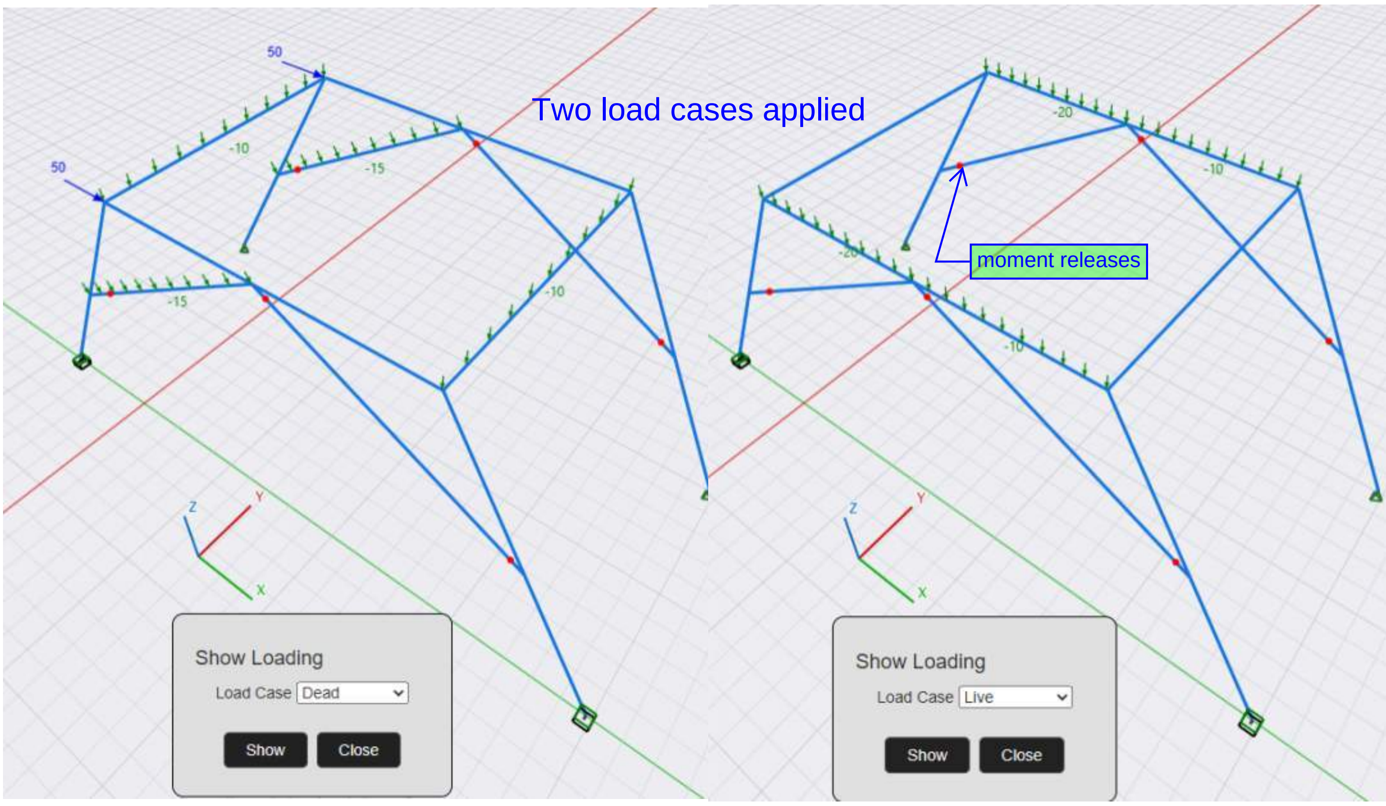
Appendix D – Verification Example

Verification example - FEAKalc 3D vs. ETABS

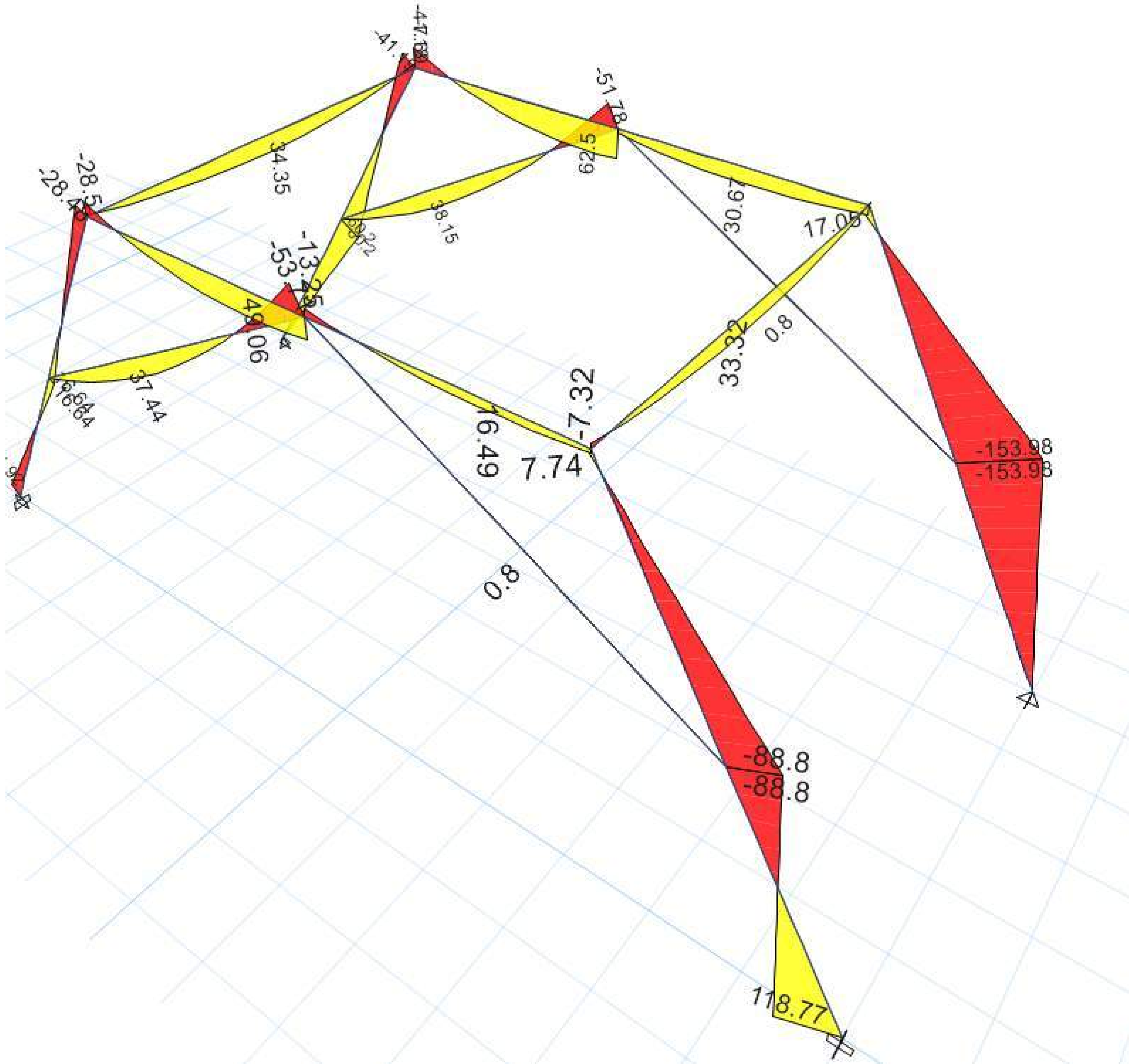
Verification Statement

This example compares FEAKalc 3D directly with ETABS for a representative steel space frame. Independent agreement is demonstrated for structural displacements, internal force distributions and support reactions, providing confidence that FEAKalc accurately reproduces established finite element solutions for three-dimensional frame analysis. The comparison validates the underlying finite element implementation rather than a single numerical result, showing consistent behaviour across the entire structural model





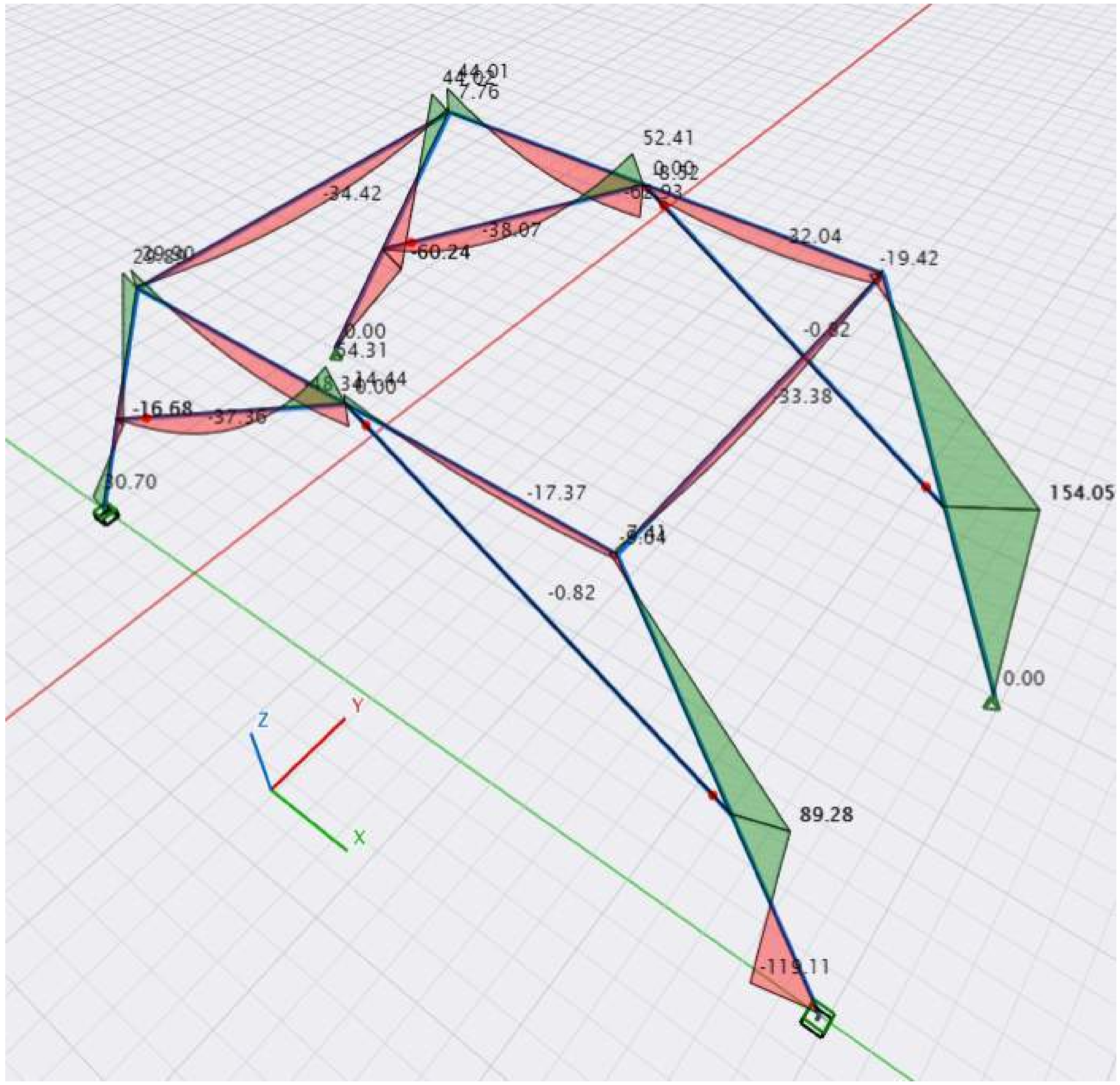
ETABS



Bending Moment Diagram M33

Load Combo : 1.2DL + 1.5LL

FEAKalc 3D

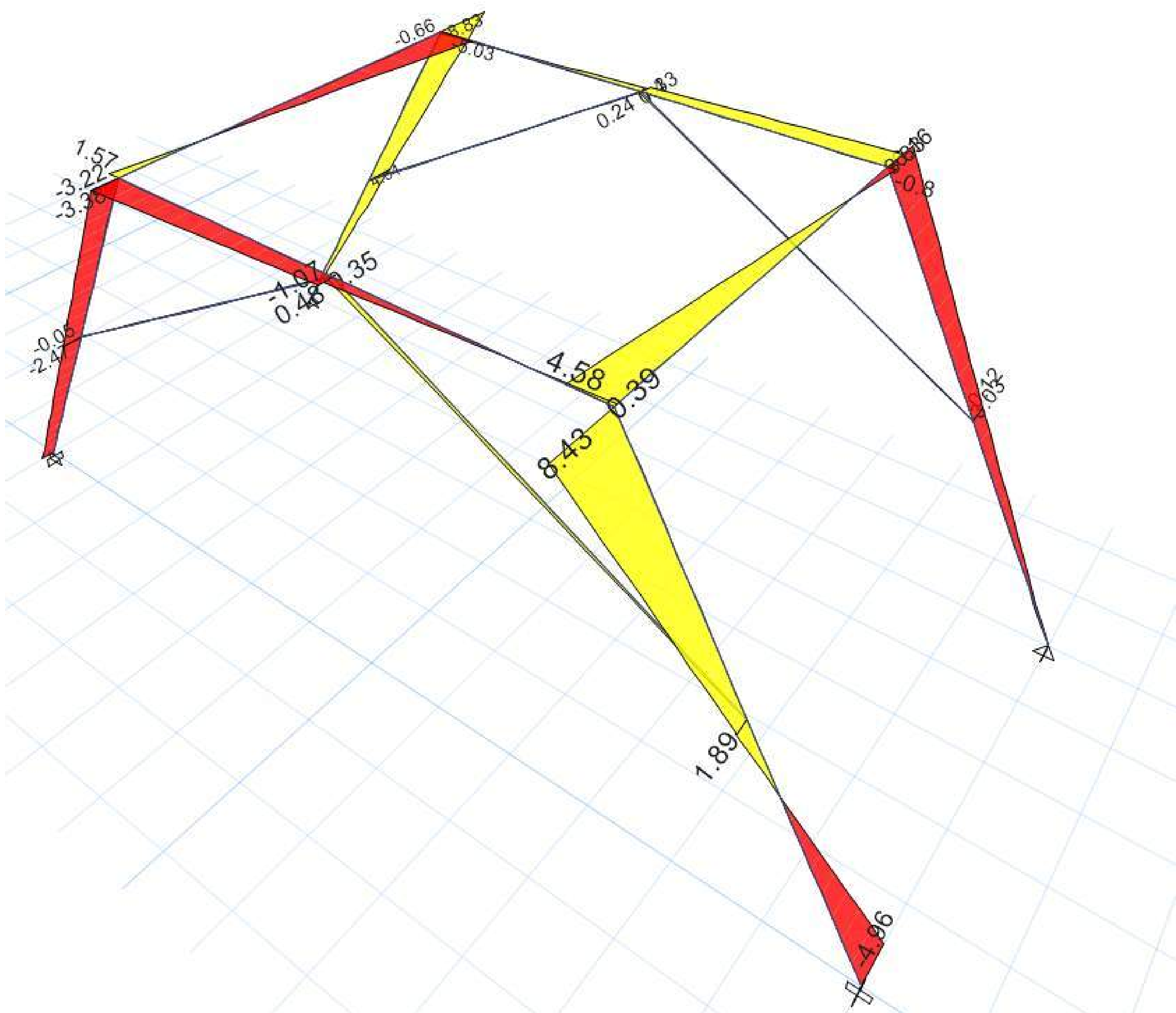


Bending Moment Diagram M33

Load Combo : 1.2DL + 1.5LL

LEARNING CENTRE	**Analysis Verification**	Concrete Frame	By	RK
		FEAKalc 3D Verifications	Sheet No. 4	Date 7/26

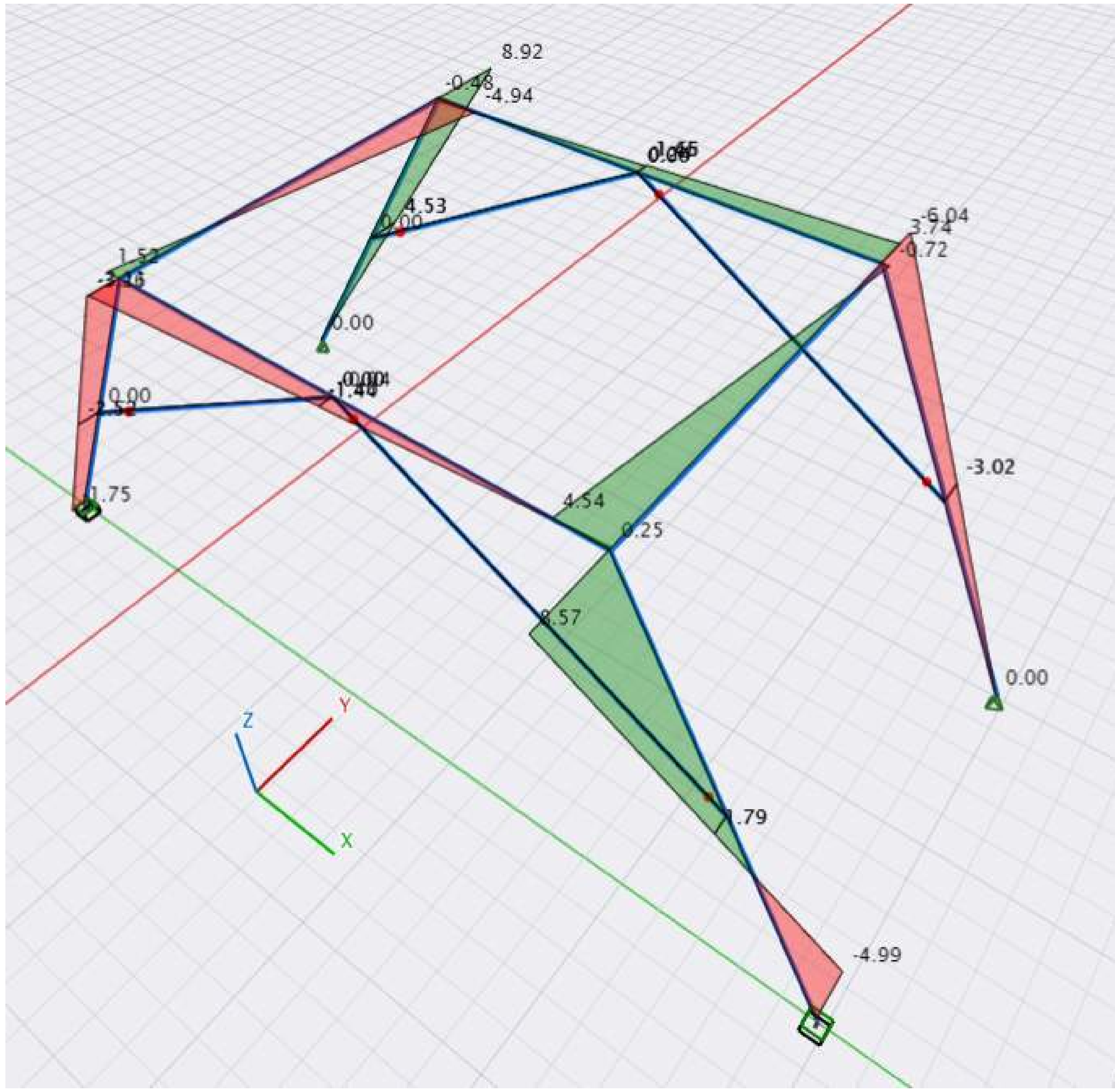
ETABS



Bending Moment Diagram M22

Load Combo : 1.2DL + 1.5LL

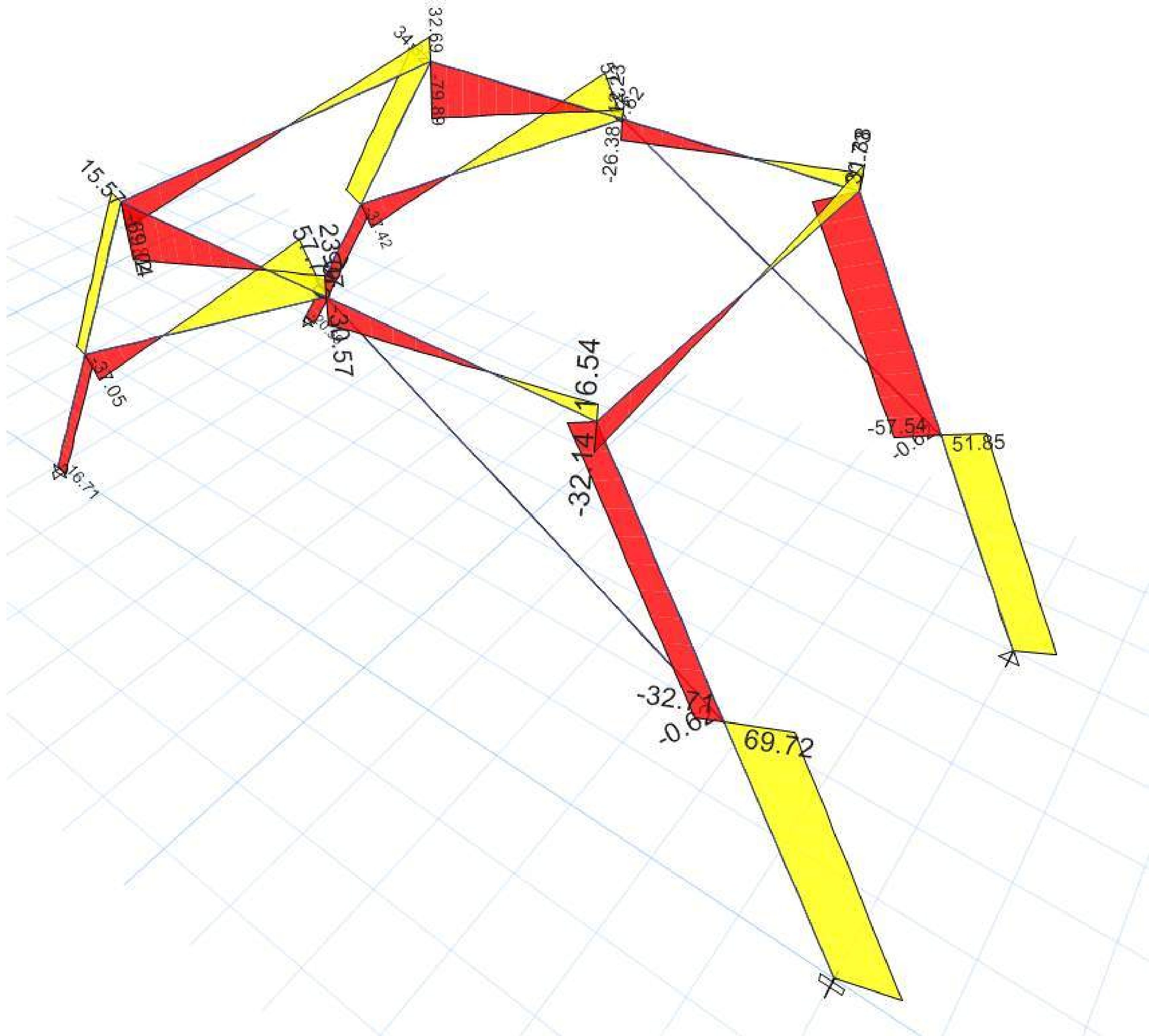
FEAKalc 3D



Bending Moment Diagram M22

Load Combo : 1.2DL + 1.5LL

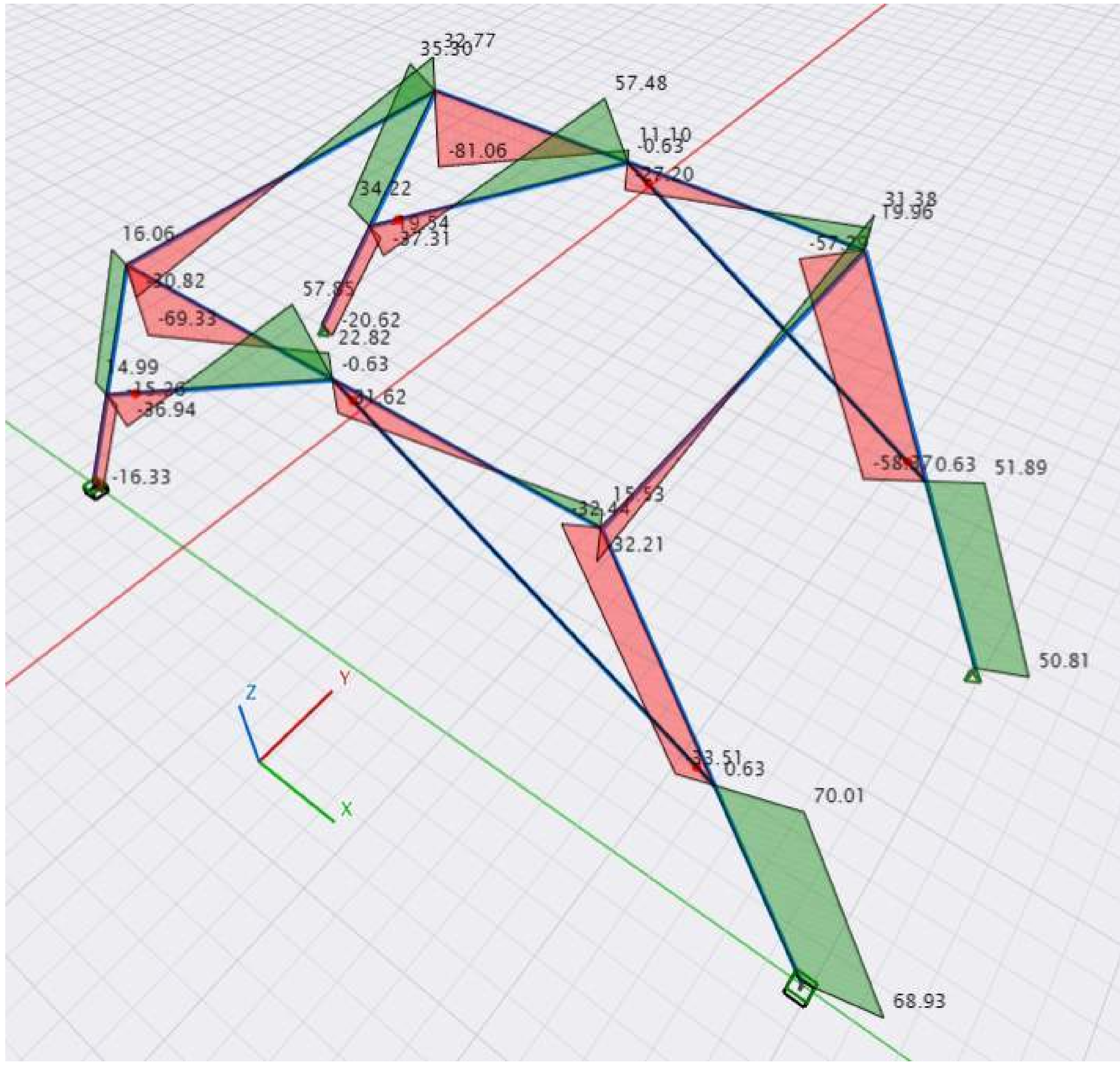
ETABS



Shear Diagram V22

Load Combo : 1.2DL + 1.5LL

FEAKalc 3D

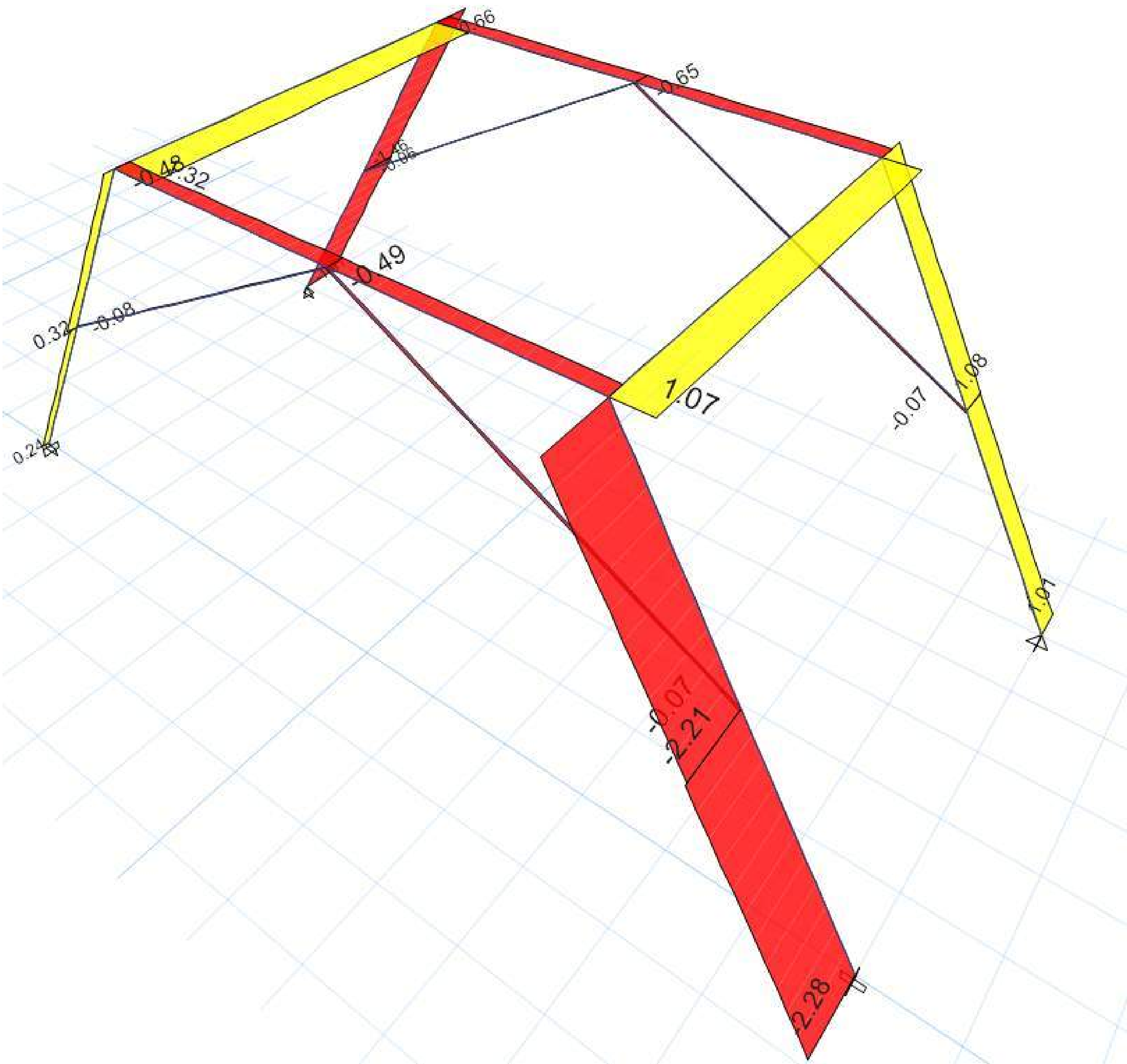


Shear Diagram V22

Load Combo : 1.2DL + 1.5LL

LEARNING CENTRE	Analysis Verification	Concrete Frame	By	RK
		FEAKalc 3D Verifications	Sheet No. 6	Date 7/26

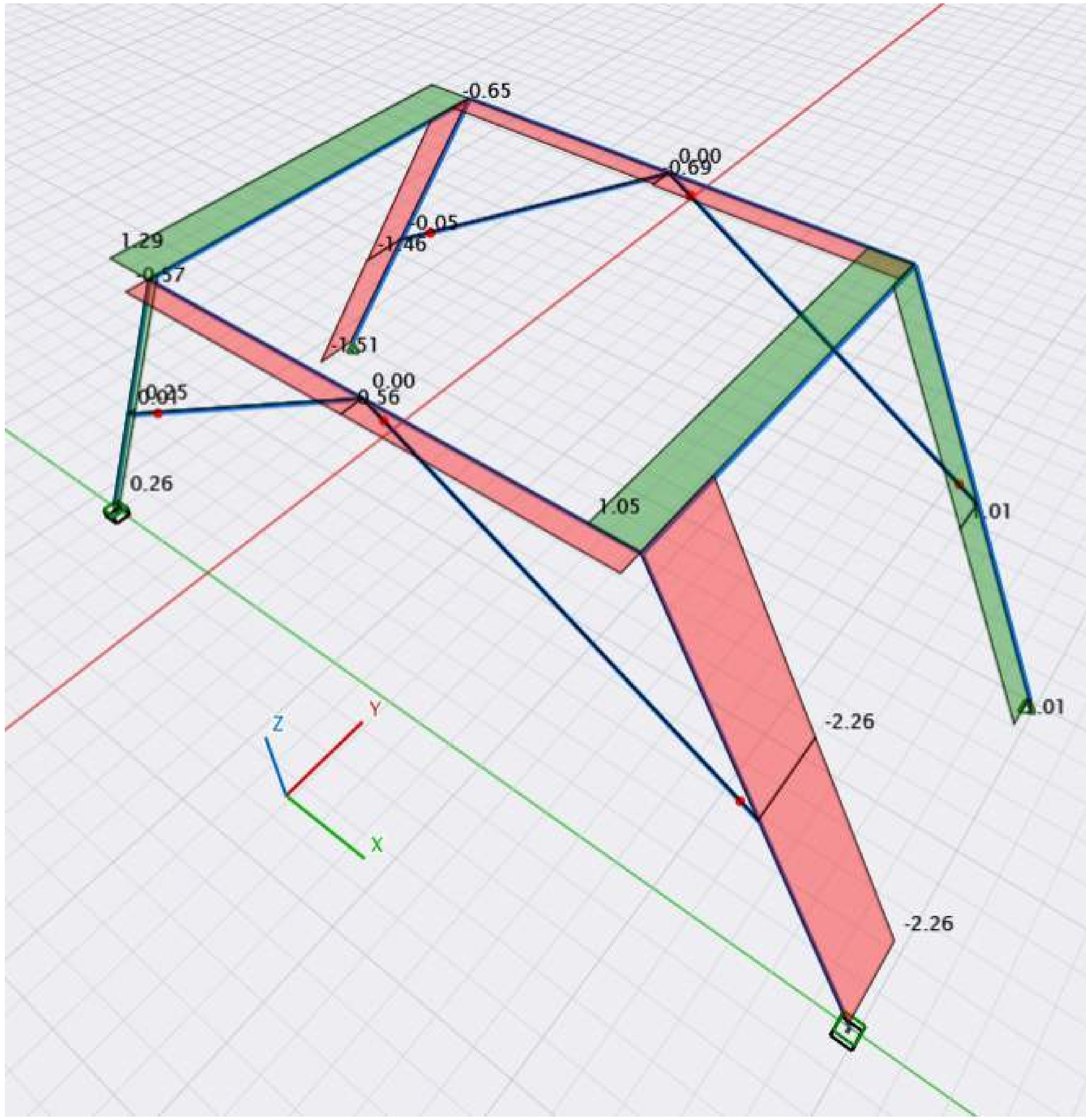
ETABS



Shear Diagram V33

Load Combo : 1.2DL + 1.5LL

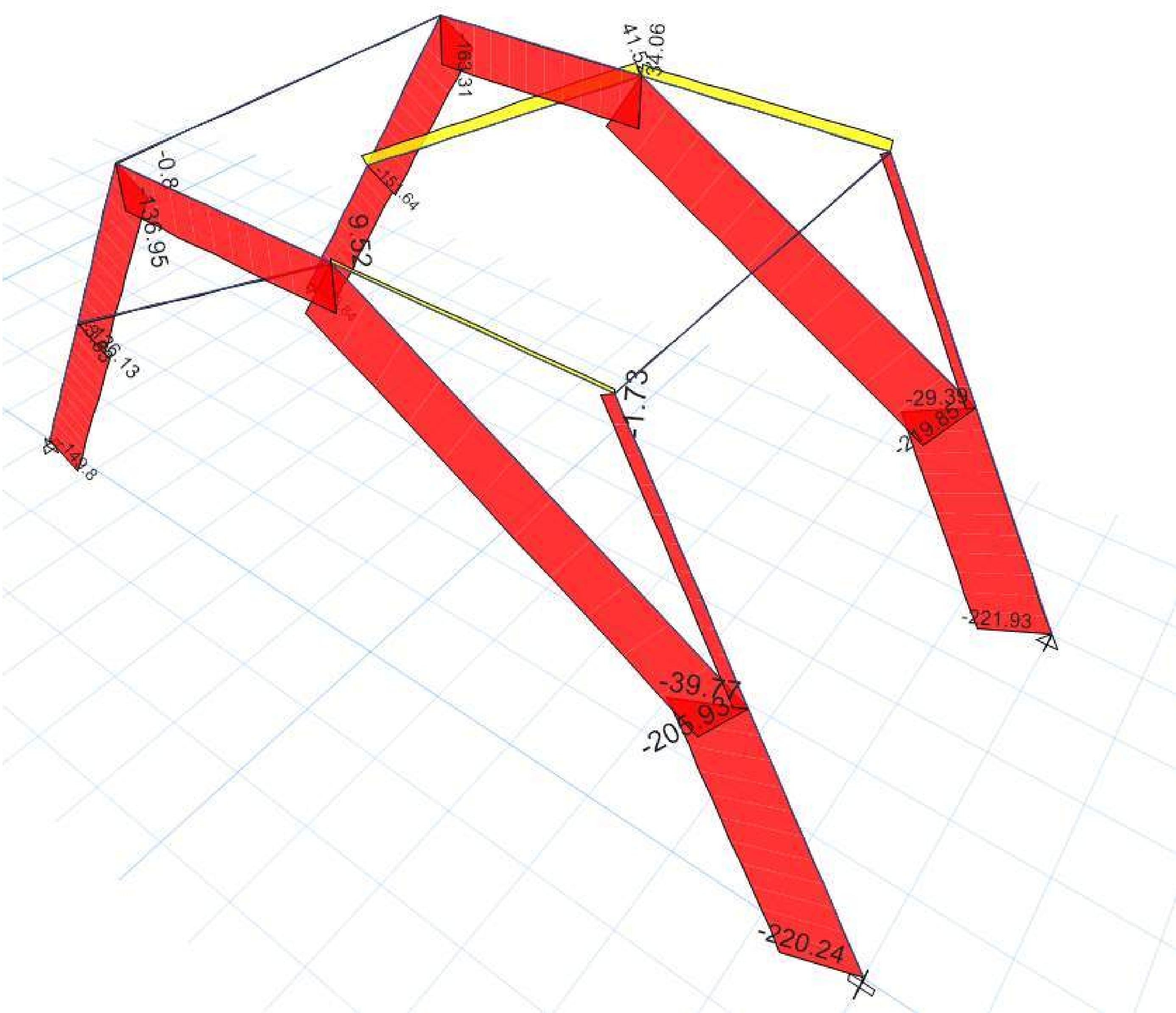
FEAKalc 3D



Shear Diagram V33

Load Combo : 1.2DL + 1.5LL

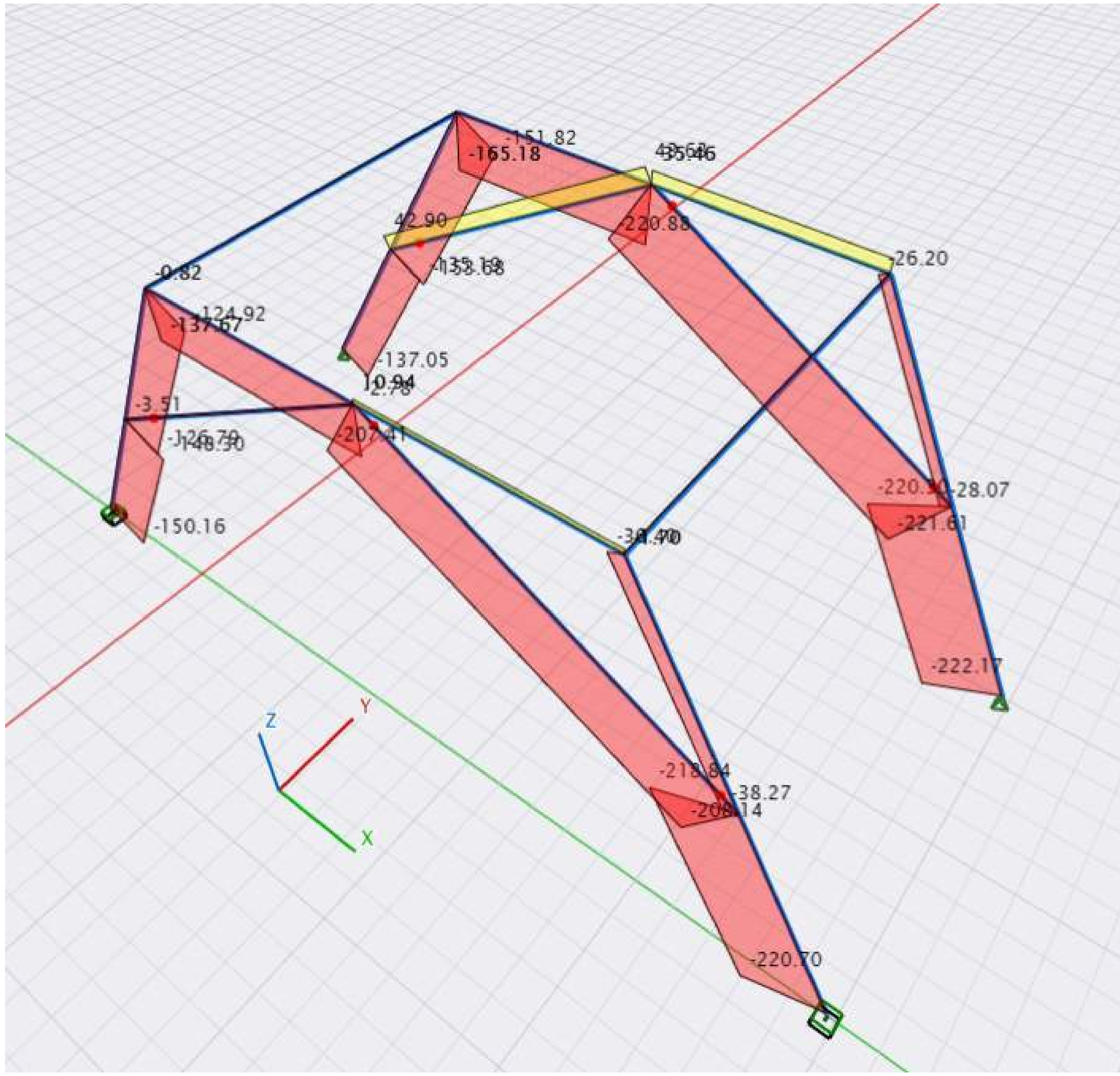
ETABS



Axial Force Diagram

Load Combo : 1.2DL + 1.5LL

FEAKalc 3D



Axial Force Diagram

Load Combo : 1.2DL + 1.5LL

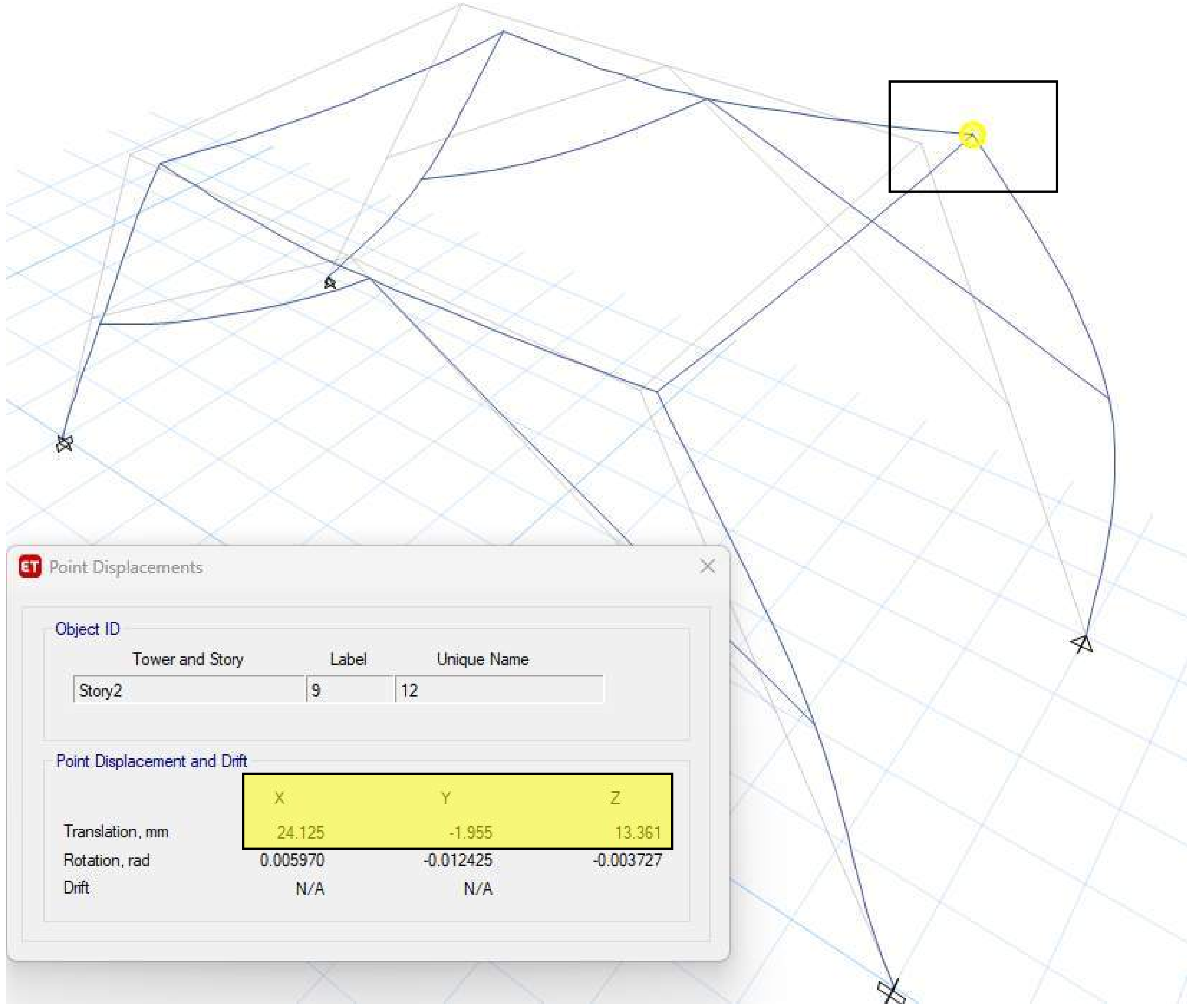
LEARNING CENTRE

RKALC

Analysis Verification

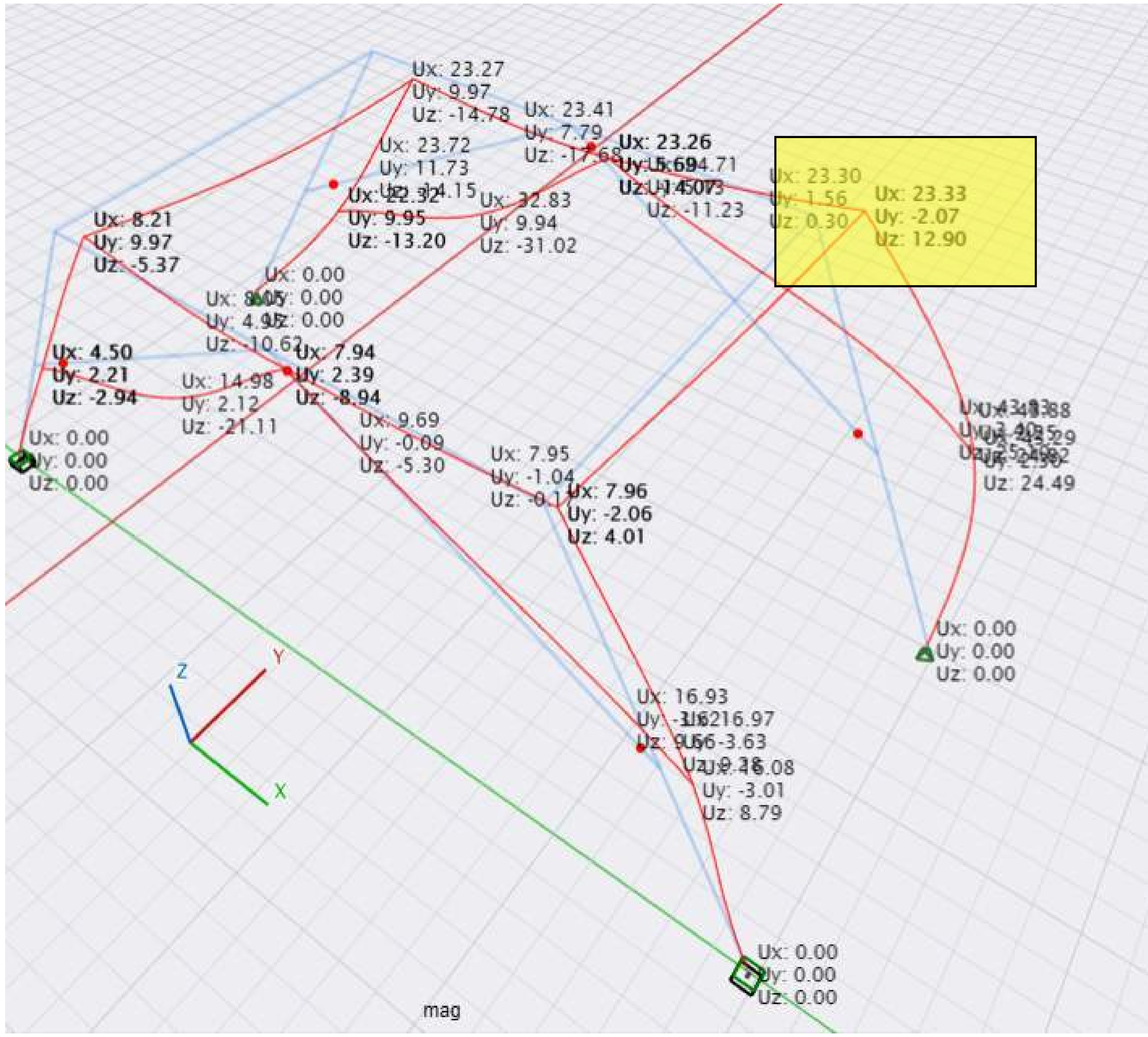
Concrete Frame	By	RK
FEAKalc 3D Verifications	Sheet No. 8	Date 7/26

ETABS



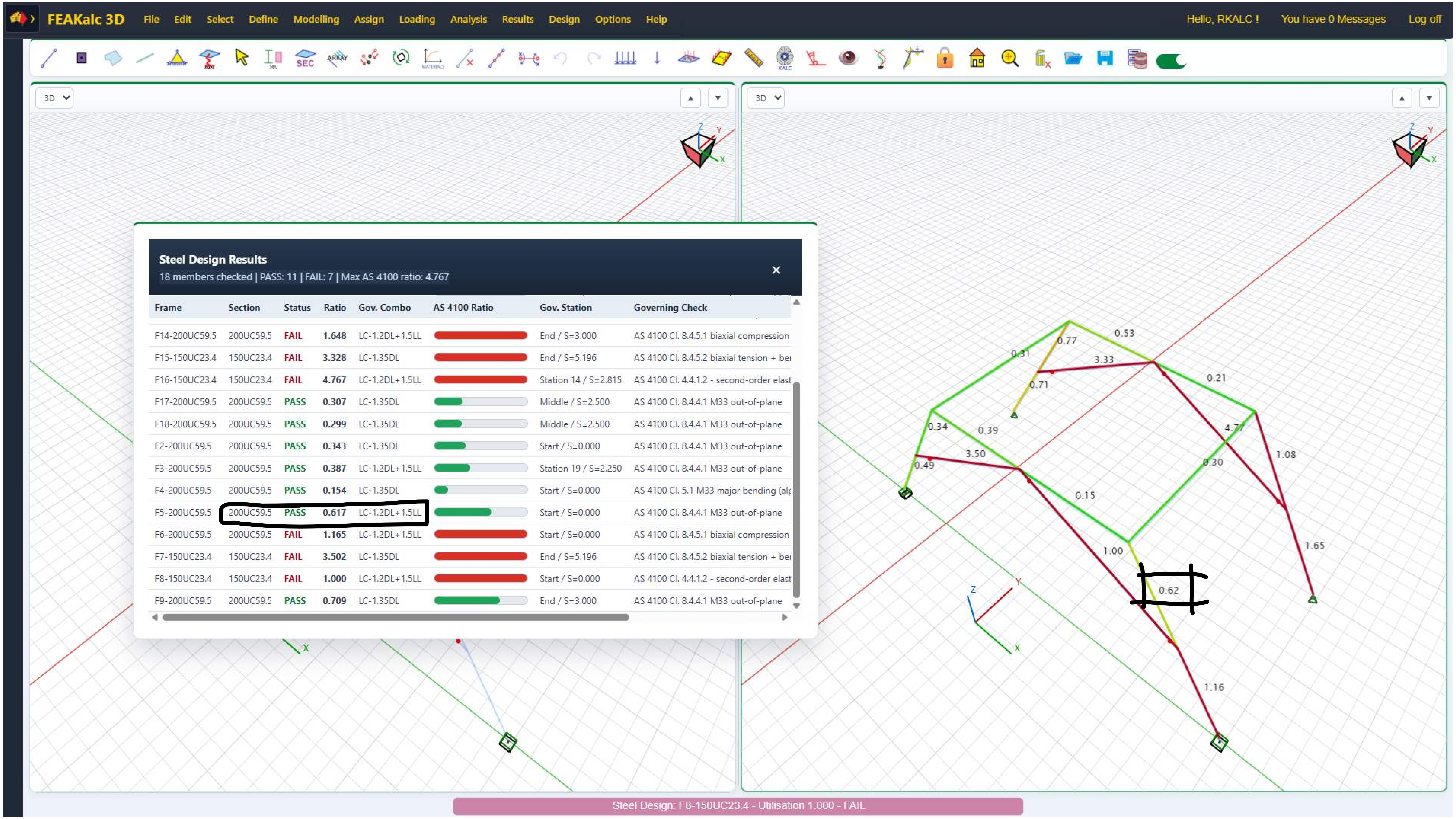
Load Combo : 1.2DL + 1.5LL

FEAKalc 3D



Load Combo : 1.2DL + 1.5LL

Following is user interface - design ratios shown below and deliberately left in case of over-stress, for example

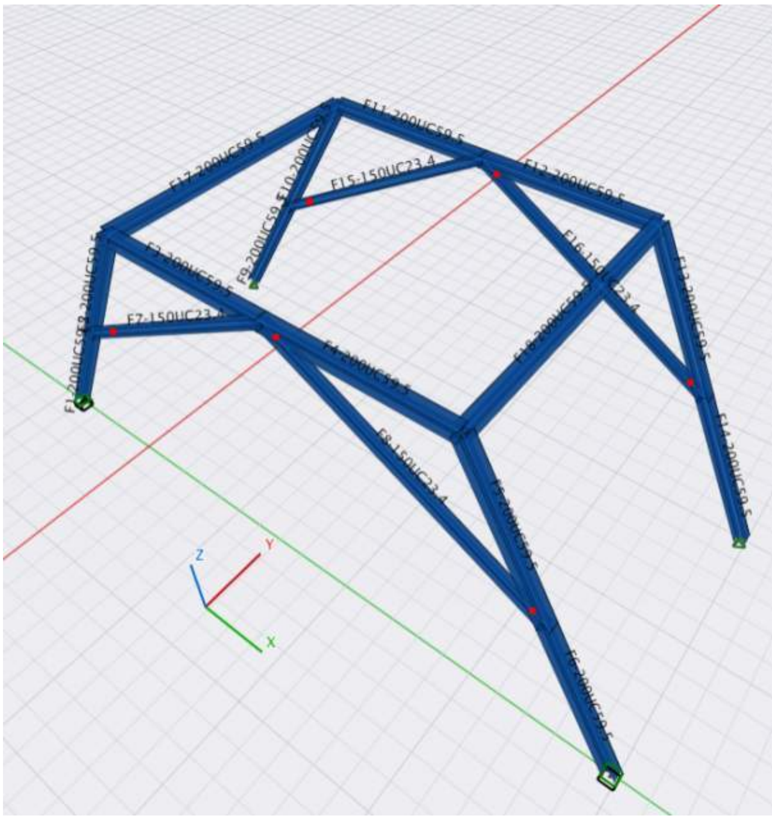


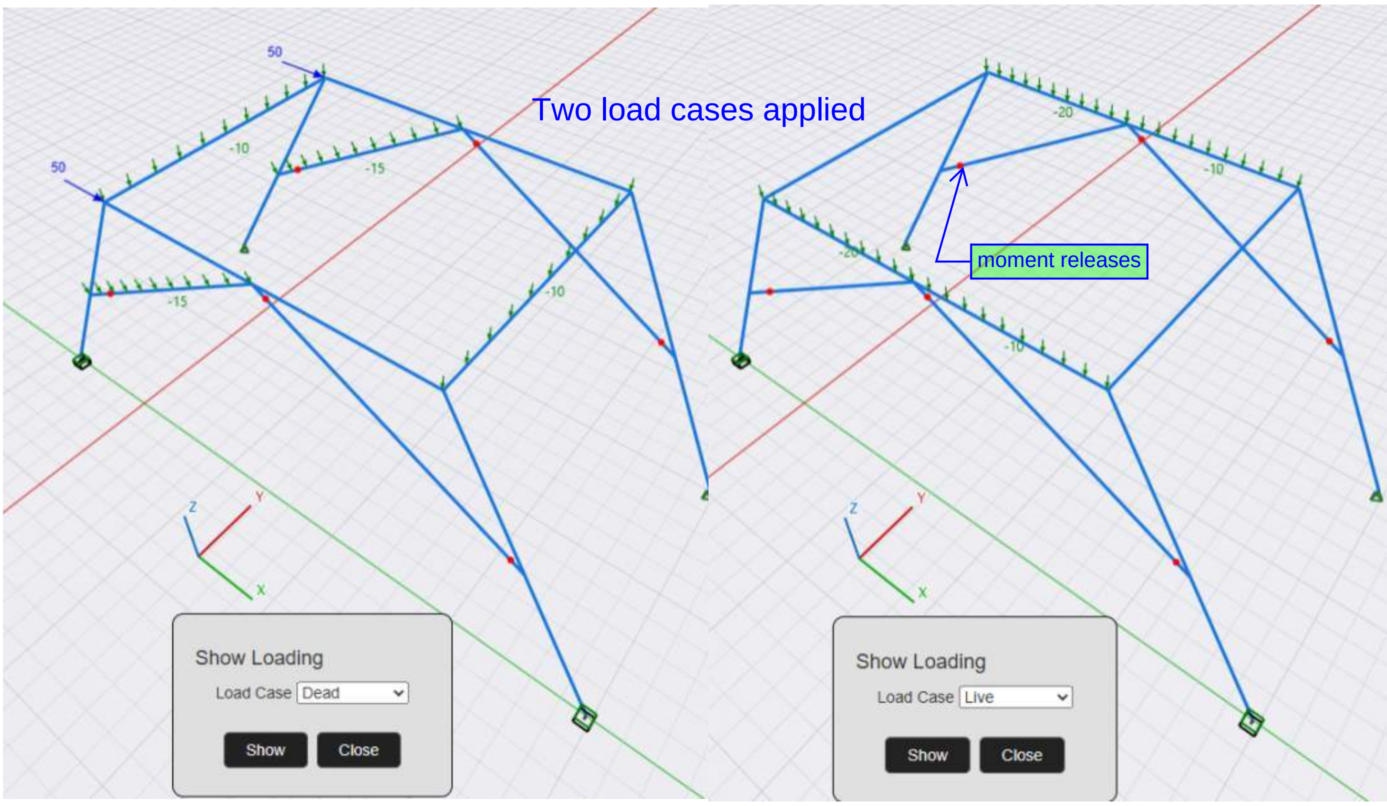
Frame	Section	Status	Ratio	Gov. Combo	AS 4100 Ratio	Gov. Station	Governing Check
F14-200UC59.5	200UC59.5	FAIL	1.648	LC-1.2DL+1.5LL		End / S=3.000	AS 4100 Cl. 8.4.5.1 biaxial compression
F15-150UC23.4	150UC23.4	FAIL	3.328	LC-1.35DL		End / S=5.196	AS 4100 Cl. 8.4.5.2 biaxial tension + bei
F16-150UC23.4	150UC23.4	FAIL	4.767	LC-1.2DL+1.5LL		Station 14 / S=2.815	AS 4100 Cl. 4.4.1.2 - second-order elast
F17-200UC59.5	200UC59.5	PASS	0.307	LC-1.35DL		Middle / S=2.500	AS 4100 Cl. 8.4.4.1 M33 out-of-plane
F18-200UC59.5	200UC59.5	PASS	0.299	LC-1.35DL		Middle / S=2.500	AS 4100 Cl. 8.4.4.1 M33 out-of-plane
F2-200UC59.5	200UC59.5	PASS	0.343	LC-1.35DL		Start / S=0.000	AS 4100 Cl. 8.4.4.1 M33 out-of-plane
F3-200UC59.5	200UC59.5	PASS	0.387	LC-1.2DL+1.5LL		Station 19 / S=2.250	AS 4100 Cl. 8.4.4.1 M33 out-of-plane
F4-200UC59.5	200UC59.5	PASS	0.154	LC-1.35DL		Start / S=0.000	AS 4100 Cl. 5.1 M33 major bending (alp
F5-200UC59.5	200UC59.5	PASS	0.617	LC-1.2DL+1.5LL		Start / S=0.000	AS 4100 Cl. 8.4.4.1 M33 out-of-plane
F6-200UC59.5	200UC59.5	FAIL	1.165	LC-1.2DL+1.5LL		Start / S=0.000	AS 4100 Cl. 8.4.5.1 biaxial compression
F7-150UC23.4	150UC23.4	FAIL	3.502	LC-1.35DL		End / S=5.196	AS 4100 Cl. 8.4.5.2 biaxial tension + bei
F8-150UC23.4	150UC23.4	FAIL	1.000	LC-1.2DL+1.5LL		Start / S=0.000	AS 4100 Cl. 4.4.1.2 - second-order elast
F9-200UC59.5	200UC59.5	PASS	0.709	LC-1.35DL		End / S=3.000	AS 4100 Cl. 8.4.4.1 M33 out-of-plane

Verification example - FEAKalc 3D vs. ETABS

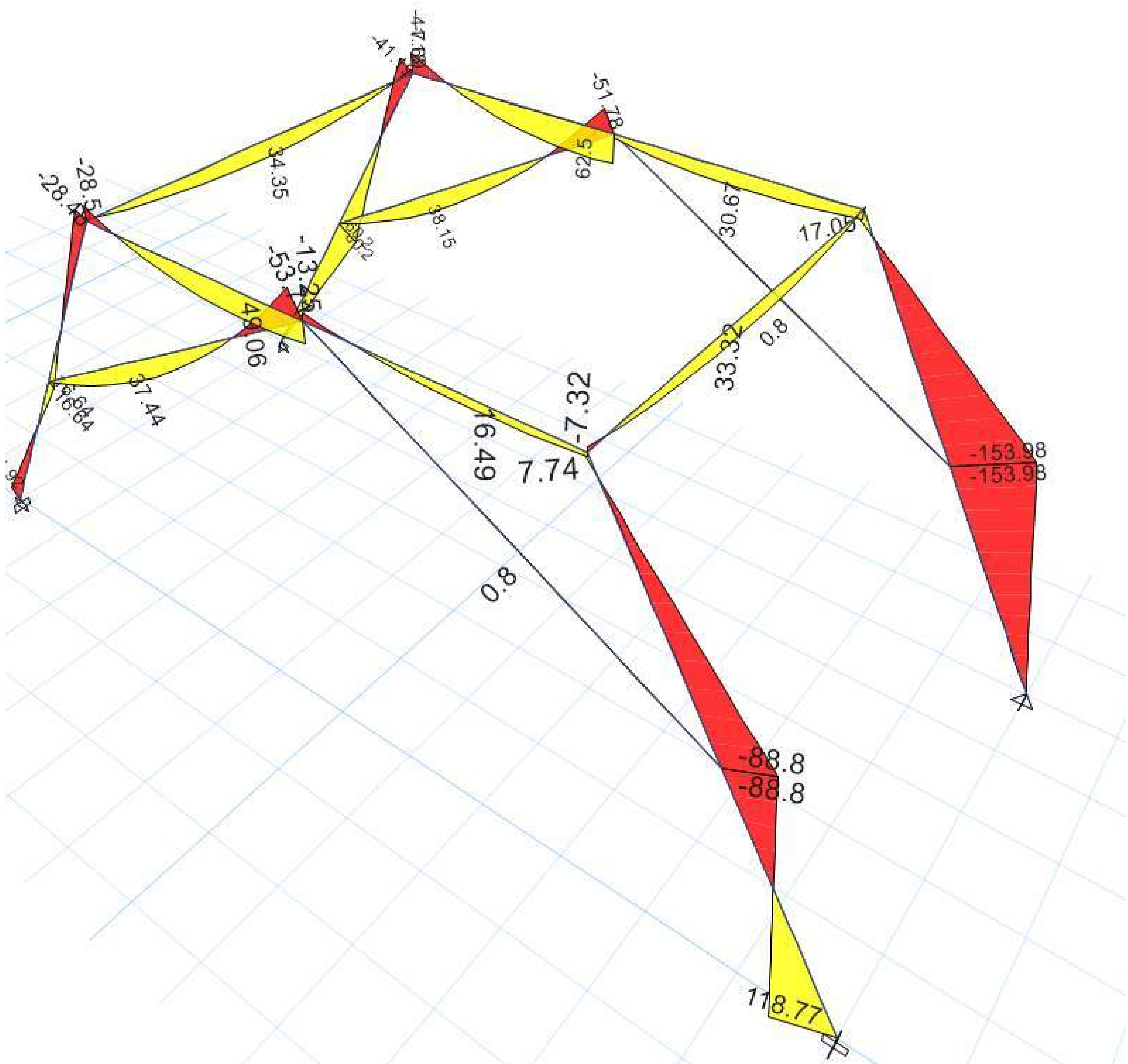
Verification Statement

This example compares FEAKalc 3D directly with ETABS for a representative steel space frame. Independent agreement is demonstrated for structural displacements, internal force distributions and support reactions, providing confidence that FEAKalc accurately reproduces established finite element solutions for three-dimensional frame analysis. The comparison validates the underlying finite element implementation rather than a single numerical result, showing consistent behaviour across the entire structural model





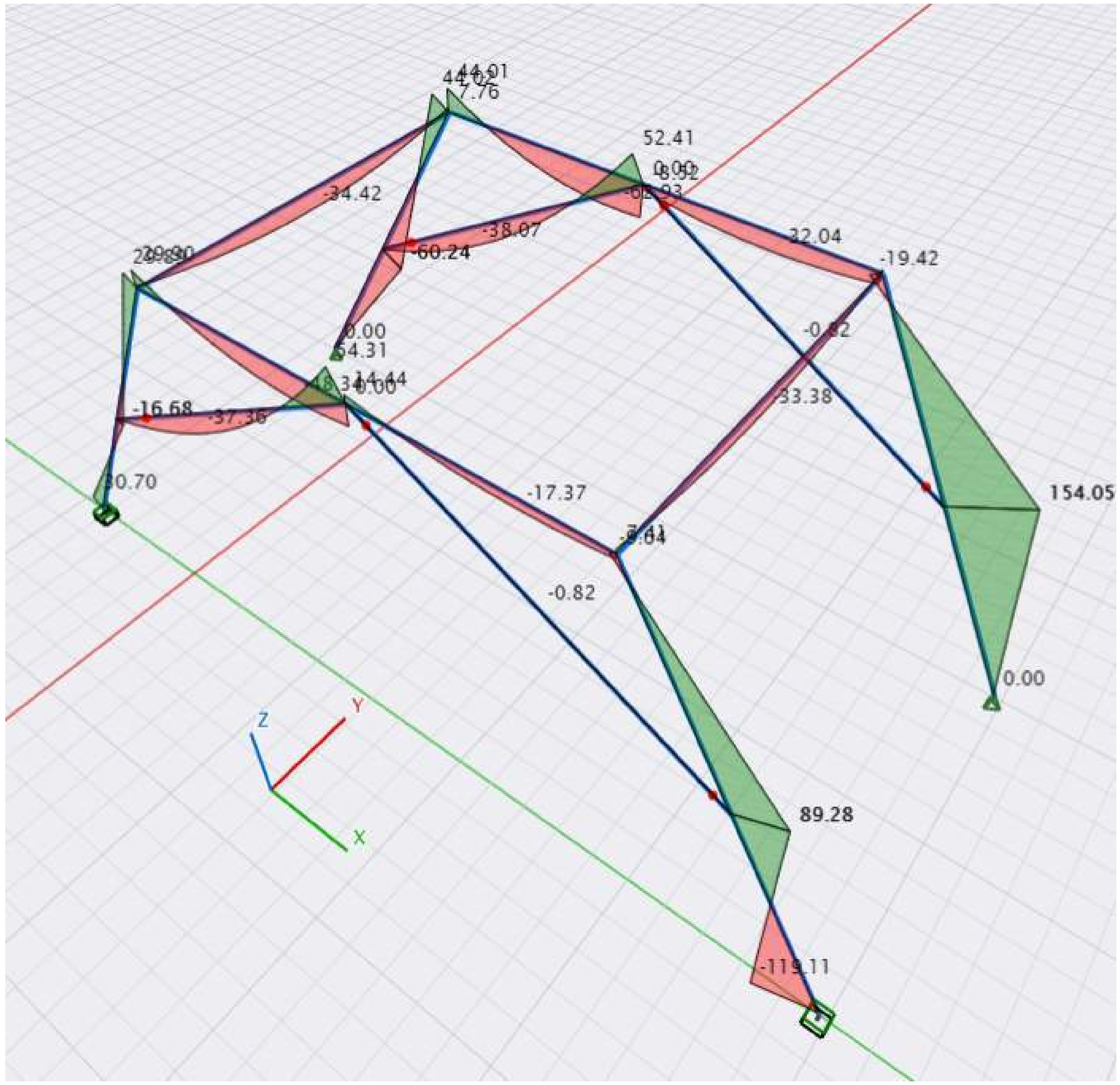
ETABS



Bending Moment Diagram M33

Load Combo : 1.2DL + 1.5LL

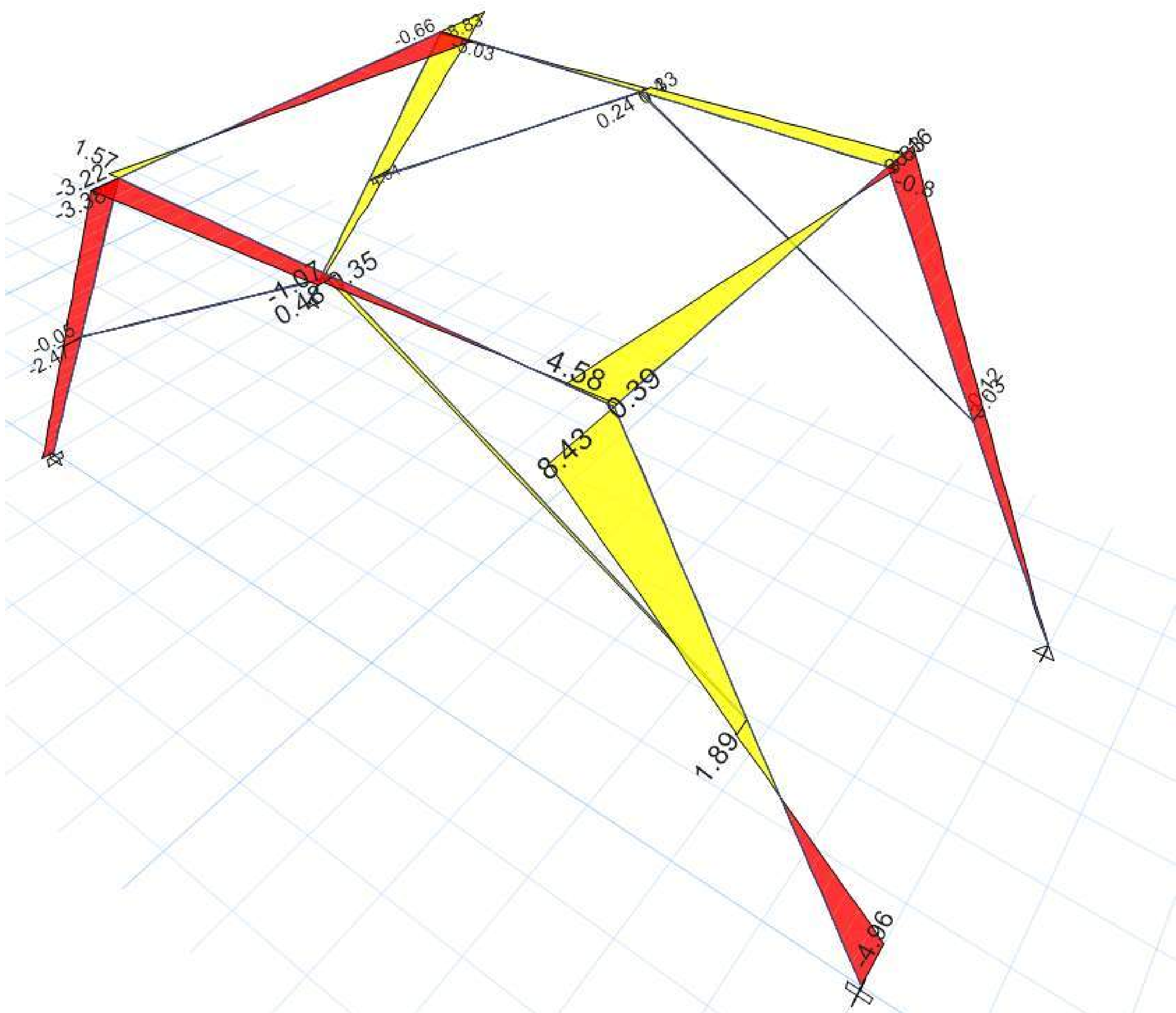
FEAKalc 3D



Bending Moment Diagram M33

Load Combo : 1.2DL + 1.5LL

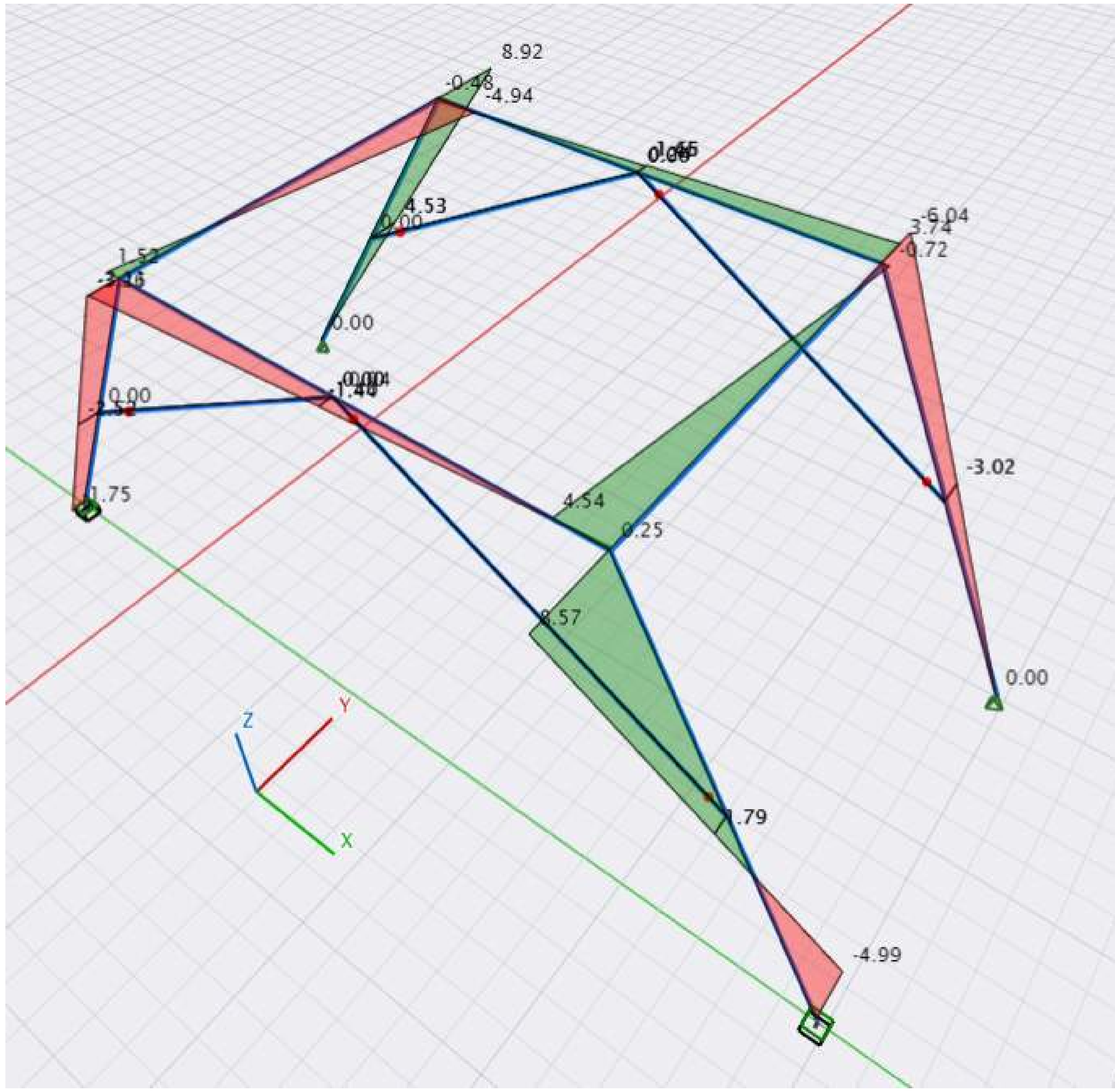
ETABS



Bending Moment Diagram M22

Load Combo : 1.2DL + 1.5LL

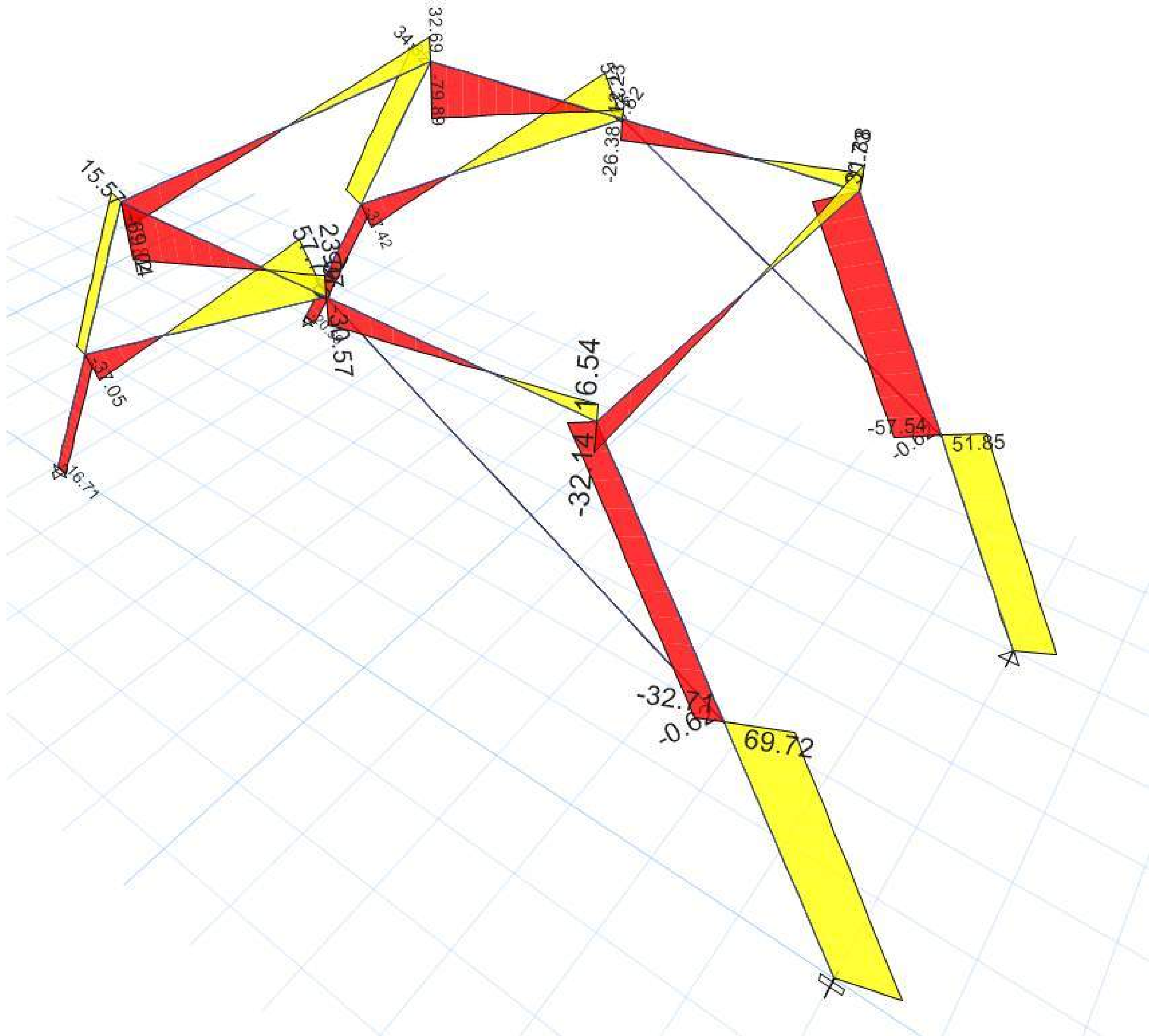
FEAKalc 3D



Bending Moment Diagram M22

Load Combo : 1.2DL + 1.5LL

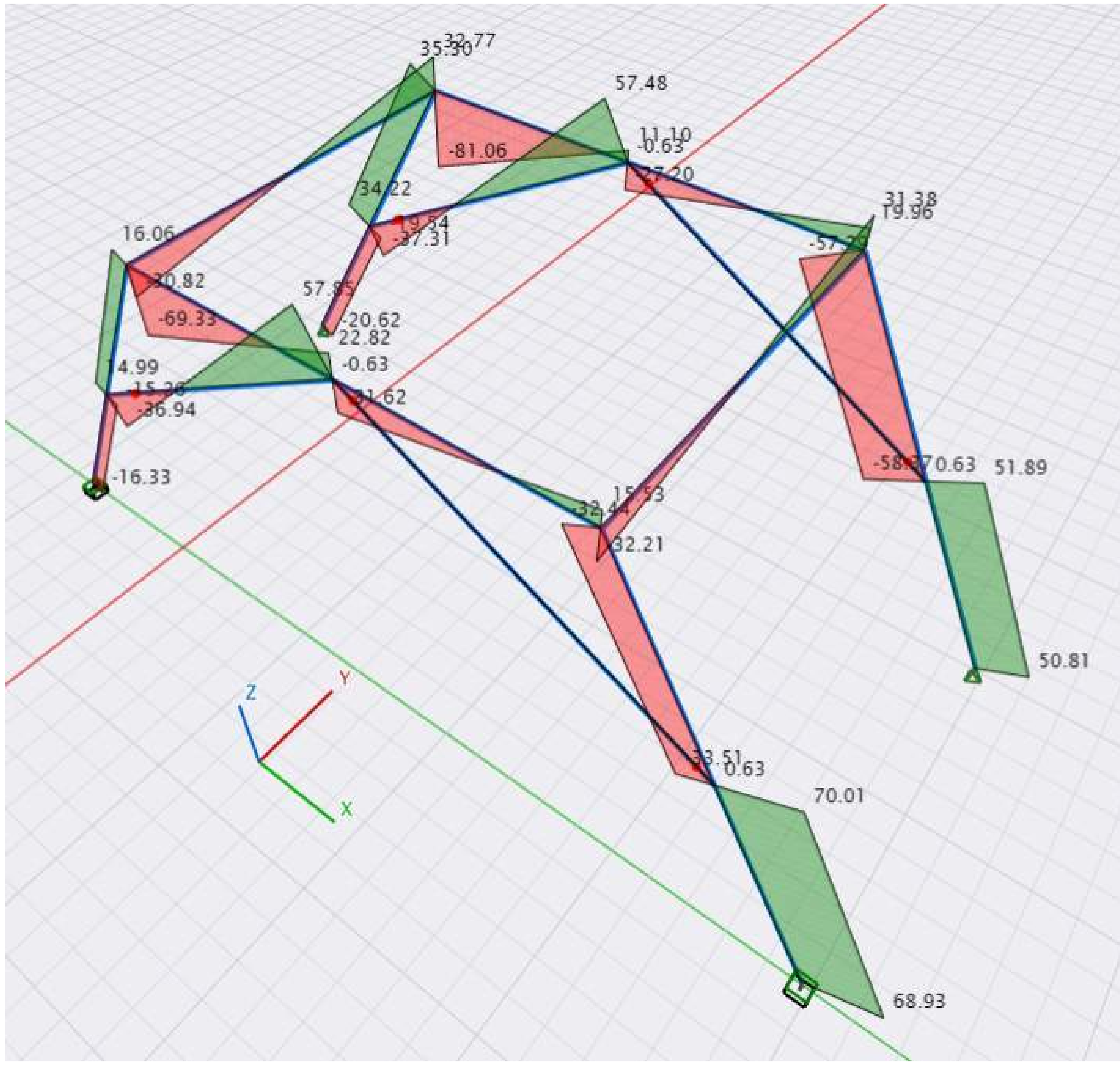
ETABS



Shear Diagram V22

Load Combo : 1.2DL + 1.5LL

FEAKalc 3D



Shear Diagram V22

Load Combo : 1.2DL + 1.5LL

LEARNING CENTRE

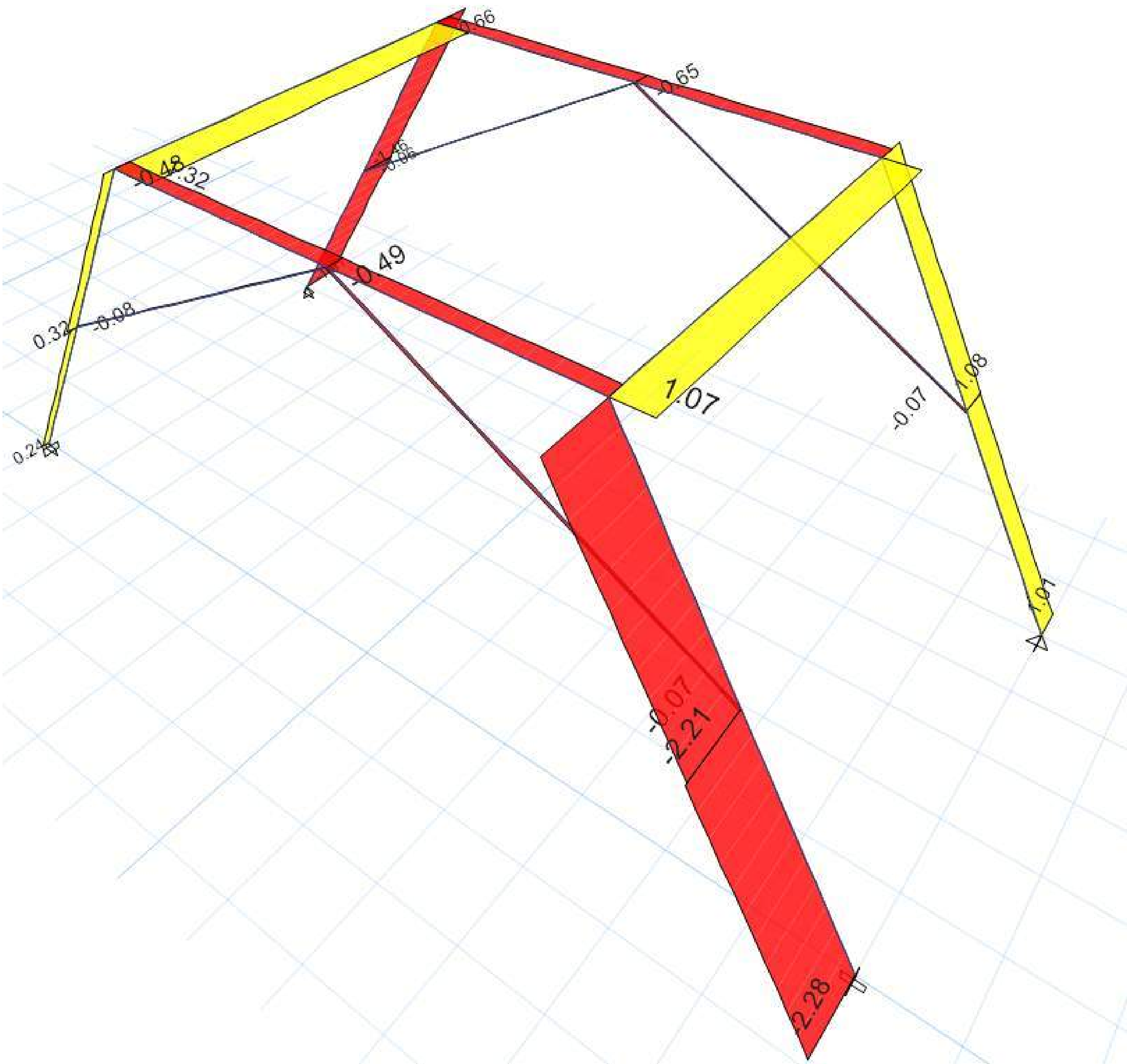
RKALC

STRUCTURAL ENGINEERING

Analysis Verification

Concrete Frame	By	RK
FEAKalc 3D Verifications	Sheet No. 6	Date 7/26

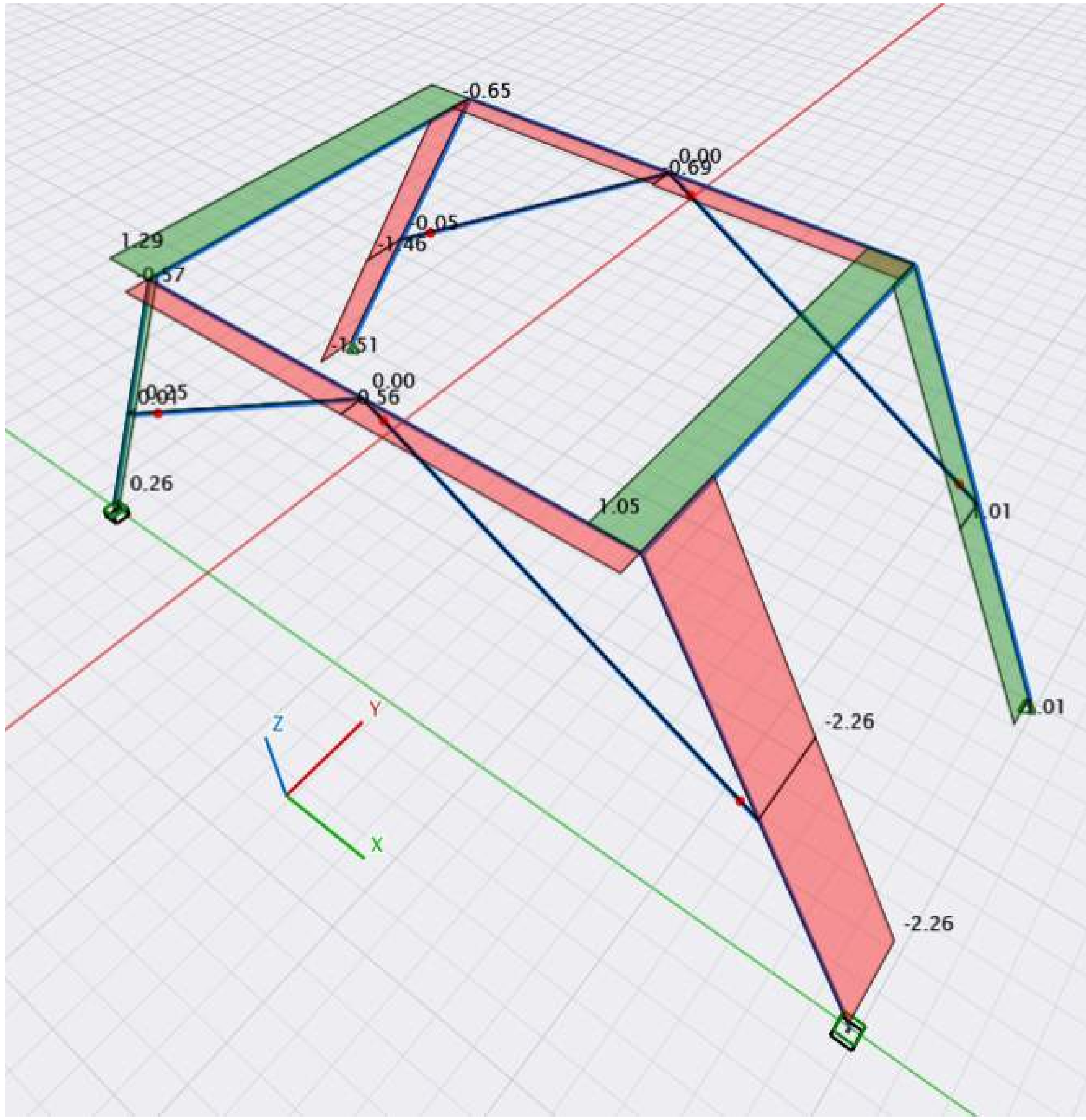
ETABS



Shear Diagram V33

Load Combo : 1.2DL + 1.5LL

FEAKalc 3D

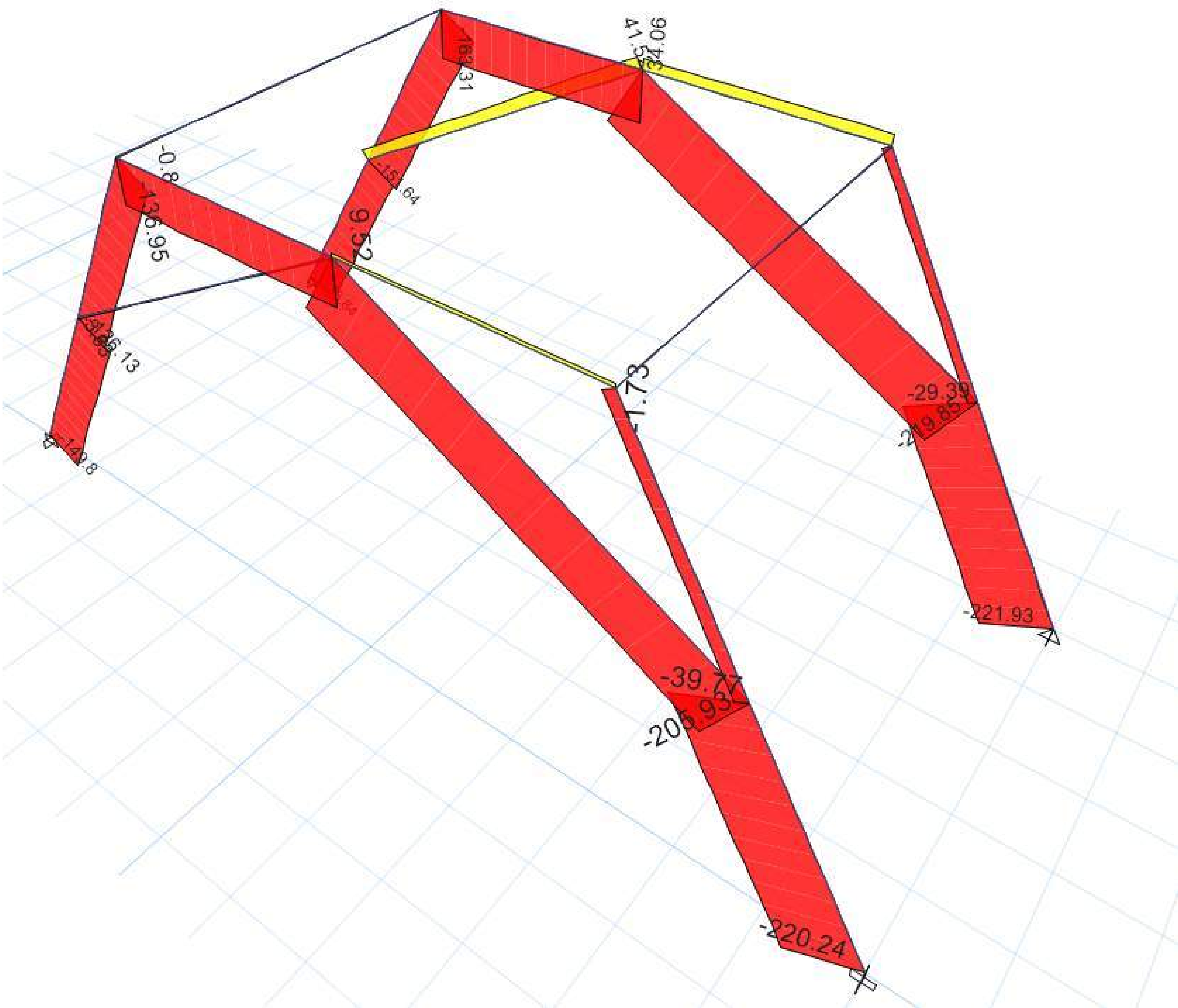


Shear Diagram V33

Load Combo : 1.2DL + 1.5LL

LEARNING CENTRE	Analysis Verification	Concrete Frame	By	RK
		FEAKalc 3D Verifications	Sheet No. 7	Date 7/26

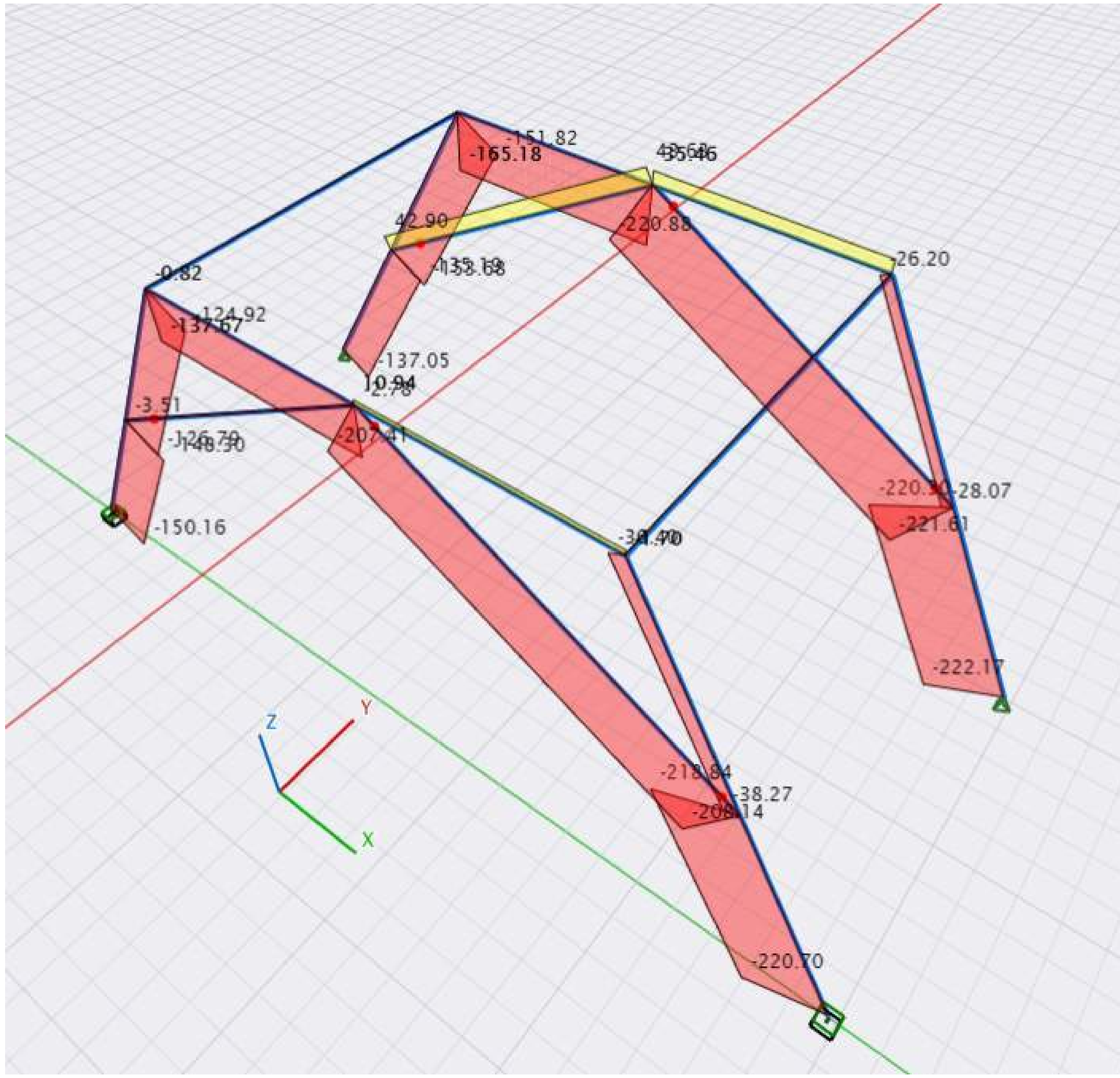
ETABS



Axial Force Diagram

Load Combo : 1.2DL + 1.5LL

FEAKalc 3D



Axial Force Diagram

Load Combo : 1.2DL + 1.5LL

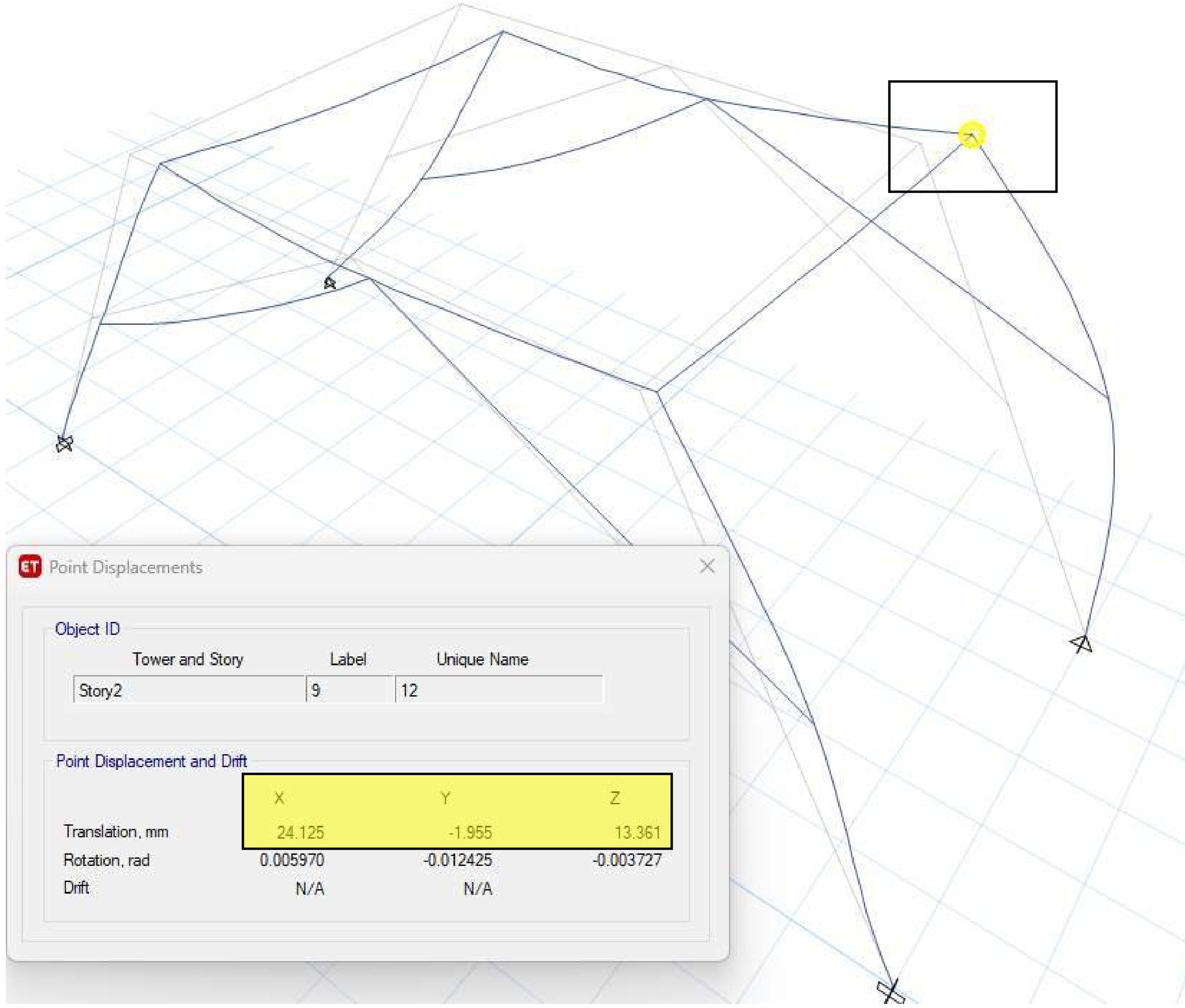
LEARNING CENTRE

RKALC STRUCTURAL ENGINEERING

Analysis Verification

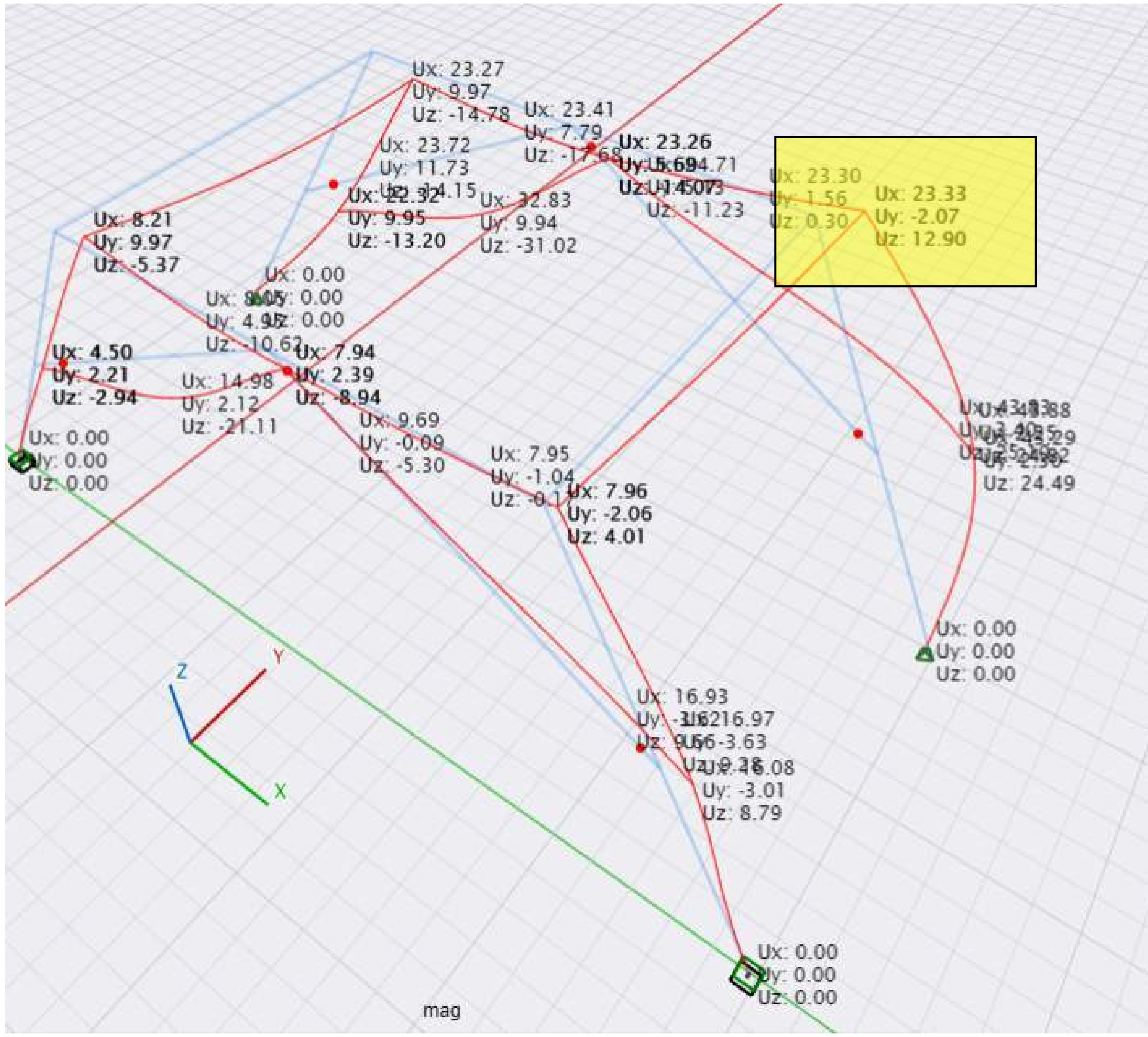
Concrete Frame	By	RK
FEAKalc 3D Verifications	Sheet No. 8	Date 7/26

ETABS



Load Combo : 1.2DL + 1.5LL

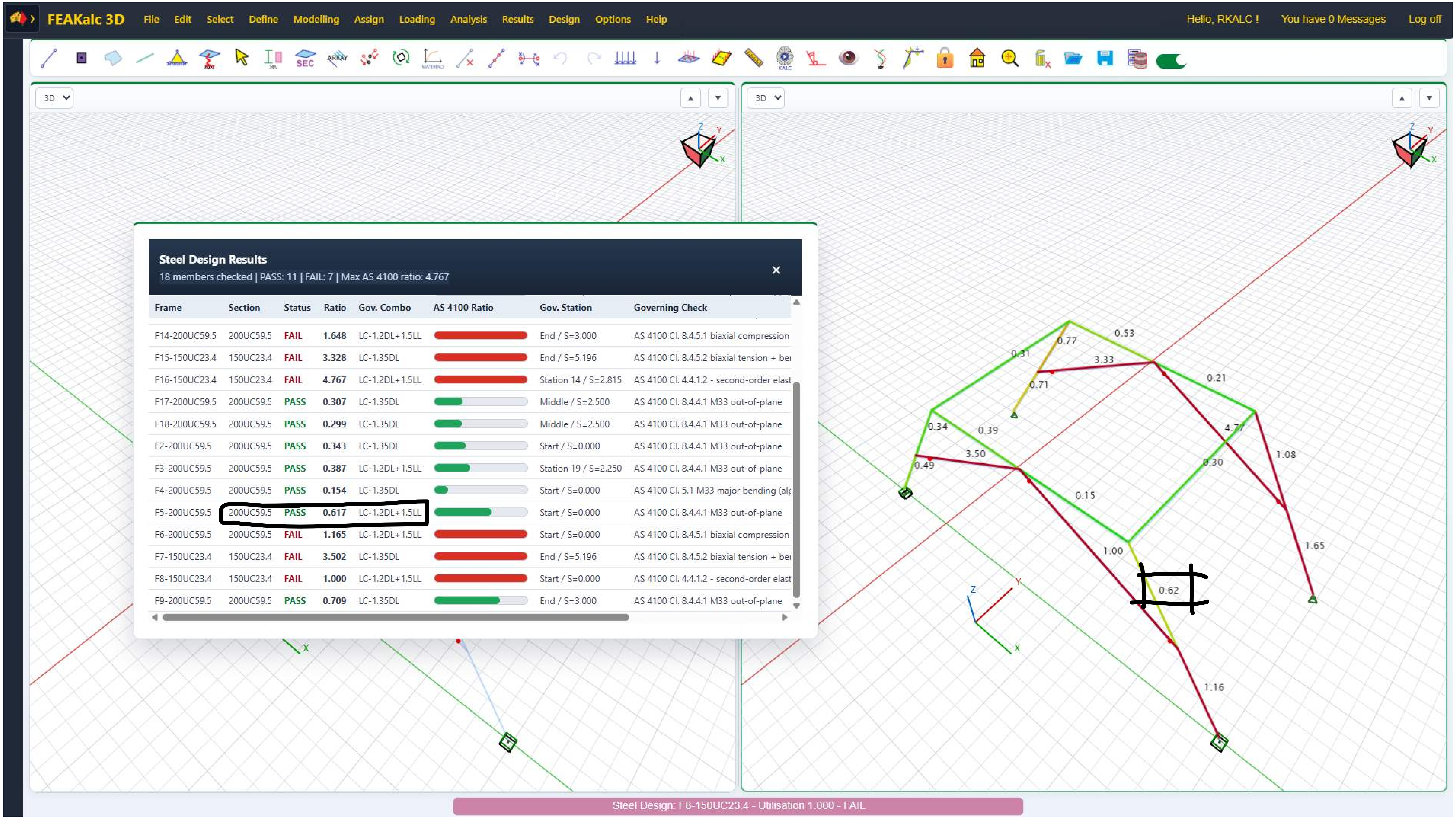
FEAKalc 3D



Load Combo : 1.2DL + 1.5LL

LEARNING CENTRE	Design to AS4100	Concrete Frame	By	RK
		FEAKalc 3D Verifications	Sheet No. 9	Date 7/26

Following is user interface - design ratios shown below and deliberately left in case of over-stress, for example



Steel Design Results

18 members checked | PASS: 11 | FAIL: 7 | Max AS 4100 ratio: 4.767

Frame	Section	Status	Ratio	Gov. Combo	AS 4100 Ratio	Gov. Station	Governing Check
F14-200UC59.5	200UC59.5	FAIL	1.648	LC-1.2DL+1.5LL		End / S=3.000	AS 4100 Cl. 8.4.5.1 biaxial compression
F15-150UC23.4	150UC23.4	FAIL	3.328	LC-1.35DL		End / S=5.196	AS 4100 Cl. 8.4.5.2 biaxial tension + be
F16-150UC23.4	150UC23.4	FAIL	4.767	LC-1.2DL+1.5LL		Station 14 / S=2.815	AS 4100 Cl. 4.4.1.2 - second-order elast
F17-200UC59.5	200UC59.5	PASS	0.307	LC-1.35DL		Middle / S=2.500	AS 4100 Cl. 8.4.4.1 M33 out-of-plane
F18-200UC59.5	200UC59.5	PASS	0.299	LC-1.35DL		Middle / S=2.500	AS 4100 Cl. 8.4.4.1 M33 out-of-plane
F2-200UC59.5	200UC59.5	PASS	0.343	LC-1.35DL		Start / S=0.000	AS 4100 Cl. 8.4.4.1 M33 out-of-plane
F3-200UC59.5	200UC59.5	PASS	0.387	LC-1.2DL+1.5LL		Station 19 / S=2.250	AS 4100 Cl. 8.4.4.1 M33 out-of-plane
F4-200UC59.5	200UC59.5	PASS	0.154	LC-1.35DL		Start / S=0.000	AS 4100 Cl. 5.1 M33 major bending (al
F5-200UC59.5	200UC59.5	PASS	0.617	LC-1.2DL+1.5LL		Start / S=0.000	AS 4100 Cl. 8.4.4.1 M33 out-of-plane
F6-200UC59.5	200UC59.5	FAIL	1.165	LC-1.2DL+1.5LL		Start / S=0.000	AS 4100 Cl. 8.4.5.1 biaxial compression
F7-150UC23.4	150UC23.4	FAIL	3.502	LC-1.35DL		End / S=5.196	AS 4100 Cl. 8.4.5.2 biaxial tension + be
F8-150UC23.4	150UC23.4	FAIL	1.000	LC-1.2DL+1.5LL		Start / S=0.000	AS 4100 Cl. 4.4.1.2 - second-order elast
F9-200UC59.5	200UC59.5	PASS	0.709	LC-1.35DL		End / S=3.000	AS 4100 Cl. 8.4.4.1 M33 out-of-plane

Member being checked is subject to N=38.27 / M22= 1.793/ M33=89.283 / V = 33.515

Member capacities shown below

Global Ratios (simplified checks by summing ratios)

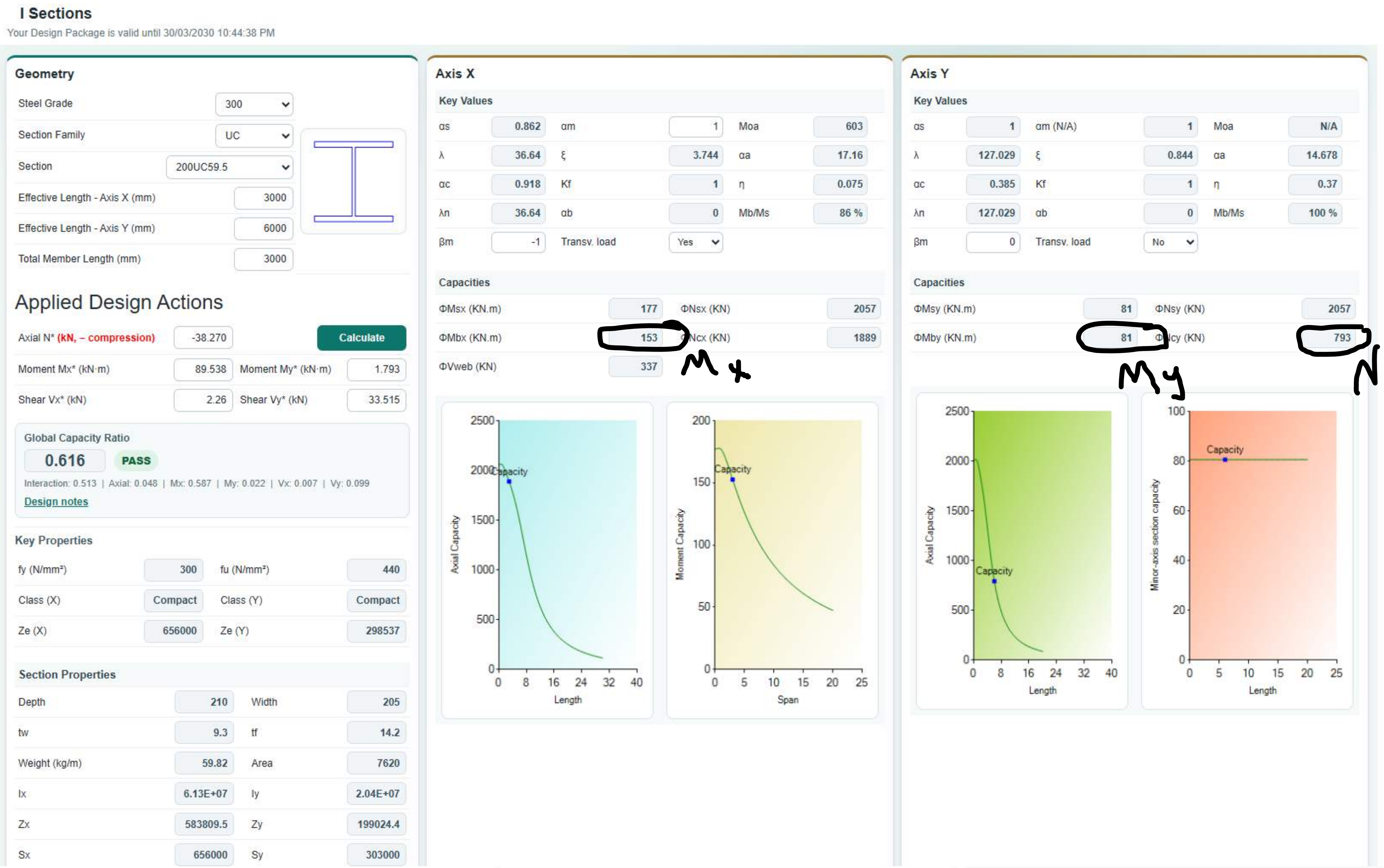
At M33 = 38.27 / 153 = 58.3%

At M22 = 1.793/81 = 2.2%

At N = 38.27 / 793 = 4.8%

≈ 66 %

Note FEAKalc uses articulated AS4100 clauses for combined actions (section 8) therefore 62% utilisation



FEAKalc 3D Steel Design Memo

AS 4100 Steel Member Check - Combined Actions

PASS

Member **F5-200UC59.5**	Section **200UC59.5**	Governing Load Case **LC-1.2DL+1.5LL**
Member Length **3.000 m**	Effective Length 22 **6.000 m**	Effective Length 33 **3.000 m**
LTB Length **Program determined**	β22 **2.000**	β33 **1.000**
βm M33 **-1.000**	βm M22 **-0.209**	cm M33 **1.000**
cm M22 **0.684**	δb M33 **1.003**	δb M22 **1.000**
δm M33 **1.003**	δm M22 **1.000**	Second-order analysis required **No**
Section 8 Method **Compact-section alternative where permitted**	Axial Action **Compression**	AS 4100 Governing Ratio **0.617**
Governing Station **Start**	Governing Check **AS 4100 Cl. 8.4.4.1 M33 out-of-plane**	

Governing Design Actions

Action	Value
Station	Start
S	0.000 m
N*	-38.270 kN
M33 first-order	89.283 kNm
M22 first-order	1.793 kNm
M33* amplified design moment	89.538 kNm
M22* amplified design moment	1.793 kNm
V2*	-2.260 kN
V3*	-33.515 kN
T*	-0.001 kNm

AS 4100 Clause 4.4 Moment Amplification

Item	M33 / x	M22 / y
βm	-1.000	-0.209
cm	1.000	0.684
Nomb	13445.186 kN	1118.604 kN
δb	1.003	1.000
δs	1.000	1.000
δm = max(δb, δs)	**1.003**	**1.000**
Transverse member load detected	Yes	No
Second-order elastic analysis required by Cl. 4.4.1.2	No	

AS 4100 Combined-Action Checks

Check	AS 4100 Ratio
Axial capacity	0.048
Clause 8.3 section capacity / interaction (compact alternative)	**0.384**
Clause 8.4.2 M33 in-plane (compact alternative where eligible)	0.516
Clause 8.4.2 M22 in-plane (compact alternative where eligible)	0.023
Clause 8.4.4 M33 out-of-plane	0.617
Clause 8.4.5 combined member	**0.513**
Clause 5.12.3 M33 + V3 shear/bending	**0.099**
Clause 5.11 V2 shear	0.007
Clause 5.11 V3 shear	0.099
Governing Section 8 interaction	**0.513**

Clause 8.4.5 equation: (M33*/φMcx)^1.4 + (M22*/φMiy)^1.4 ≤ 1

AS 4100 ratio convention: Powered Clause 8.3.4 and 8.4.5 equations are reported as their actual left-hand-side value with a unity limit. No exponent-root normalisation is applied.

Section 8 method: Compact-section alternative where permitted.

Clause 5.12.3 shear/bending: $\varphi V_{vm} = \varphi V_v$ for $M^* \le 0.75\varphi M_s$; otherwise $\varphi V_{vm} = \varphi V_v[2.2 - 1.6M^*/(\varphi M_s)]$ up to $M^* = \varphi M_s$. FEAKalc pairs M33 with local V3.

Second-order action effect: Clause 4.4 amplification is applied to the first-order moments before the Section 5 and Section 8 checks. $\delta_m = \max(\delta_b, \delta_s)$.

LTB moment modification: Clause 5.6 α_m = 1.000. This is a capacity factor and is separate from Clause 4.4 moment amplification.

Sway amplification: δ_s defaults to 1.0 unless a frame/storey sway factor is supplied. A sway frame still requires Clause 4.4.2.3 or a second-order elastic analysis where applicable.

For Clause 8.4.2.2, the in-plane compression capacities use k_e = 1.0 unless the supplied braced effective length is lower than the actual member length.

Design Capacities (φ already applied)

Capacity	Value
φNs - compression section capacity	2057.400 kN
φNt - gross tension yielding	2057.400 kN
φNcx - compression member, x	1889.297 kN
φNcy - compression member, y	793.045 kN
φNc - governing compression member	793.045 kN
φNcx - Clause 8.4.2 in-plane	1889.300 kN
φNcy - Clause 8.4.2 in-plane	1622.003 kN
φMsx	177.120 kNm
φMsy	80.605 kNm
φMbx - major-axis member bending	152.586 kNm
φMrx - Clause 8.3.2	177.120 kNm
φMry - Clause 8.3.3	80.605 kNm
φMix - Clause 8.4.2.2	173.532 kNm
φMiy - Clause 8.4.2.2	79.648 kNm
φMox - Clause 8.4.4	145.222 kNm
φNoz - torsional buckling capacity	0.000 kN
αbc - Clause 8.4.4.1 compact I-section	0.000
φMcx = min(φMix, φMox)	145.222 kNm
φMtx - tension major-axis combined capacity	152.586 kNm
φVv - web shear alone (Cl. 5.11)	337.478 kN
Cl. 5.12.3 shear reduction factor	1.000
φVvm - M33 + V3 shear/bending	337.478 kN
M33 exceeds φMs range of Cl. 5.12.3	No

Section Classification

Major axis class	Compact
Minor axis class	Compact
λ web	22.092
λ flange	7.549
Kf	1.000
Compact Section 8 concession eligible	Yes
Compact Section 8 concession used	Yes
M33 transverse load detected	Yes
M22 transverse load detected	No

Applied Actions at Stations

Station	S m	N* kN	M33* kNm	M22* kNm	V3* kN	V2* kN	T* kNm
Start	0.000	-38.270	89.538	1.793	-33.515	-2.260	-0.001
Station 2	0.125	-38.193	85.340	2.075	-33.470	-2.260	-0.001
Station 3	0.250	-38.115	81.147	2.358	-33.425	-2.260	-0.001
Station 4	0.375	-38.037	76.960	2.641	-33.380	-2.260	-0.001
Station 5	0.500	-37.959	72.778	2.923	-33.335	-2.260	-0.001
Station 6	0.625	-37.882	68.602	3.206	-33.291	-2.260	-0.001
Station 7	0.750	-37.804	64.432	3.488	-33.246	-2.260	-0.001
Station 8	0.875	-37.726	60.267	3.771	-33.201	-2.260	-0.001
Station 9	1.000	-37.649	56.109	4.053	-33.156	-2.260	-0.001
Station 10	1.125	-37.571	51.955	4.336	-33.111	-2.260	-0.001
Station 11	1.250	-37.493	47.807	4.618	-33.066	-2.260	-0.001
Station 12	1.375	-37.415	43.665	4.901	-33.021	-2.260	-0.001
Middle	1.500	-37.337	39.528	5.184	-32.976	-2.260	-0.001
Station 14	1.625	-37.260	35.398	5.466	-32.931	-2.260	-0.001
Station 15	1.750	-37.182	31.272	5.749	-32.886	-2.260	-0.001
Station 16	1.875	-37.104	27.153	6.031	-32.842	-2.260	-0.001
Station 17	2.000	-37.027	23.039	6.314	-32.797	-2.260	-0.001
Station 18	2.125	-36.949	18.930	6.596	-32.752	-2.260	-0.001
Station 19	2.250	-36.871	14.828	6.879	-32.707	-2.260	-0.001
Station 20	2.375	-36.793	10.730	7.161	-32.662	-2.260	-0.001
Station 21	2.500	-36.716	6.639	7.444	-32.617	-2.260	-0.001
Station 22	2.625	-36.638	2.553	7.726	-32.572	-2.260	-0.001
Station 23	2.750	-36.560	-1.527	8.009	-32.527	-2.260	-0.001
Station 24	2.875	-36.482	-5.602	8.292	-32.483	-2.260	-0.001
End	3.000	-36.405	-9.671	8.574	-32.438	-2.260	-0.001

Station-by-Station AS 4100 Check

Station	S	Status	Ratio	Axial	Cl. 8.3	Cl. 8.4.2 M33	Cl. 8.4.2 M22	Cl. 8.4.4	Cl. 8.4.5	Cl. 5.12.3 M33/V3	Governing Check
Start	0.000	PASS	**0.617**	0.048	0.384	0.516	0.023	0.617	0.513	0.099	AS 4100 Cl. 8.4.4.1 M33 out-of-plane
Station 2	0.125	PASS	**0.588**	0.048	0.361	0.492	0.026	0.588	0.481	0.099	AS 4100 Cl. 8.4.4.1 M33 out-of-plane
Station 3	0.250	PASS	**0.559**	0.048	0.337	0.468	0.030	0.559	0.450	0.099	AS 4100 Cl. 8.4.4.1 M33 out-of-plane
Station 4	0.375	PASS	**0.530**	0.048	0.314	0.443	0.033	0.530	0.419	0.099	AS 4100 Cl. 8.4.4.1 M33 out-of-plane
Station 5	0.500	PASS	**0.501**	0.048	0.292	0.419	0.037	0.501	0.390	0.099	AS 4100 Cl. 8.4.4.1 M33 out-of-plane
Station 6	0.625	PASS	**0.472**	0.048	0.271	0.395	0.040	0.472	0.361	0.099	AS 4100 Cl. 8.4.4.1 M33 out-of-plane
Station 7	0.750	PASS	**0.443**	0.048	0.250	0.371	0.044	0.443	0.333	0.099	AS 4100 Cl. 8.4.4.1 M33 out-of-plane
Station 8	0.875	PASS	**0.415**	0.048	0.230	0.347	0.047	0.415	0.306	0.098	AS 4100 Cl. 8.4.4.1 M33 out-of-plane
Station 9	1.000	PASS	**0.386**	0.047	0.210	0.323	0.051	0.386	0.279	0.098	AS 4100 Cl. 8.4.4.1 M33 out-of-plane
Station 10	1.125	PASS	**0.357**	0.047	0.191	0.299	0.054	0.357	0.254	0.098	AS 4100 Cl. 8.4.4.1 M33 out-of-plane
Station 11	1.250	PASS	**0.329**	0.047	0.173	0.275	0.058	0.329	0.229	0.098	AS 4100 Cl. 8.4.4.1 M33 out-of-plane
Station 12	1.375	PASS	**0.300**	0.047	0.156	0.252	0.062	0.300	0.206	0.098	AS 4100 Cl. 8.4.4.1 M33 out-of-plane
Middle	1.500	PASS	**0.272**	0.047	0.140	0.228	0.065	0.272	0.183	0.098	AS 4100 Cl. 8.4.4.1 M33 out-of-plane
Station 14	1.625	PASS	**0.243**	0.047	0.124	0.204	0.069	0.243	0.162	0.098	AS 4100 Cl. 8.4.4.1 M33 out-of-plane
Station 15	1.750	PASS	**0.215**	0.047	0.109	0.180	0.072	0.215	0.141	0.097	AS 4100 Cl. 8.4.4.1 M33 out-of-plane

Station	S	Status	Ratio	Axial	Cl. 8.3	Cl. 8.4.2 M33	Cl. 8.4.2 M22	Cl. 8.4.4	Cl. 8.4.5	Cl. 5.12.3 M33/V3	Governing Check
Station 16	1.875	PASS	**0.187**	0.047	0.095	0.156	0.076	0.187	0.122	0.097	AS 4100 Cl. 8.4.4.1 M33 out-of-plane
Station 17	2.000	PASS	**0.158**	0.047	0.082	0.133	0.079	0.158	0.105	0.097	AS 4100 Cl. 8.4.4.1 M33 out-of-plane
Station 18	2.125	PASS	**0.130**	0.047	0.071	0.109	0.083	0.130	0.088	0.097	AS 4100 Cl. 8.4.4.1 M33 out-of-plane
Station 19	2.250	PASS	**0.102**	0.046	0.060	0.085	0.086	0.102	0.073	0.097	AS 4100 Cl. 8.4.4.1 M33 out-of-plane
Station 20	2.375	PASS	**0.097**	0.046	0.051	0.062	0.090	0.074	0.060	0.097	AS 4100 Cl. 5.11 V3 shear
Station 21	2.500	PASS	**0.097**	0.046	0.044	0.038	0.093	0.046	0.049	0.097	AS 4100 Cl. 5.11 V3 shear
Station 22	2.625	PASS	**0.097**	0.046	0.038	0.015	0.097	0.018	0.042	0.097	AS 4100 Cl. 8.4.2.2 M22 compact in-plane
Station 23	2.750	PASS	**0.100**	0.046	0.039	0.009	0.100	0.010	0.042	0.096	AS 4100 Cl. 8.4.2.2 M22 compact in-plane
Station 24	2.875	PASS	**0.104**	0.046	0.047	0.032	0.104	0.038	0.053	0.096	AS 4100 Cl. 8.4.2.2 M22 compact in-plane
End	3.000	PASS	**0.108**	0.046	0.058	0.056	0.108	0.066	0.067	0.096	AS 4100 Cl. 8.4.2.2 M22 compact in-plane

Design Notes

AS 4100 Cl. 4.4.2 moment amplification: beta_x = -1, c_mx = 1, Nomb,x = 13445.186 kN, delta_bx = 1.003, delta_sx = 1, delta_mx = 1.003; beta_y = -0.209, c_my = 0.684, Nomb,y = 1118.604 kN, delta_by = 1, delta_sy = 1, delta_my = 1. No frame/storey sway amplification was supplied to the steel request, so delta_s = 1.0 is used. For a sway frame, a non-unity delta_s from Clause 4.4.2.3 or a second-order elastic analysis must be supplied/used where required.
GLOBAL CAPACITY RATIO BREAKDOWN
Actions: N* = -38.27 kN; M33* (Mx) = 89.538 kNm; M22* (My) = 1.793 kNm; V3* (Vx) = -33.515 kN; V2* (Vy) = -2.26 kN.
Standalone ratios: axial = 38.27/793.045 = 0.048; M33 = 89.538/152.586 = 0.587; M22 = 1.793/80.605 = 0.022; V3 = 33.515/337.478 = 0.099; V2 = 2.26/337.478 = 0.007.
Relevant design capacities: phiNc = 793.045 kN; phiNt = 2057.4 kN; phiMbx = 152.586 kNm; phiMsy = 80.605 kNm; phiMrx = 177.12 kNm; phiMry = 80.605 kNm; phiVv = 337.478 kN.
Clause 8.3 section interaction = 0.384. Calculation: (89.538/177.12)^1.419 + (1.793/80.605)^1.419 = 0.384.
Section 8 member interaction = 0.513. Calculation: (89.538/145.222)^1.4 + (1.793/79.648)^1.4 = 0.513.
Other interaction components: M33 in-plane = 0.516; M22 in-plane = 0.023; M33 out-of-plane = 0.617; M33 + V3 shear/bending = 0.099.
Global capacity ratio = max of all applicable checks:
AS 4100 Cl. 8.4.4.1 M33 out-of-plane = 0.617
AS 4100 Cl. 5.1 M33 major bending (alpha_m = 1) = 0.587
AS 4100 Cl. 8.4.2.2 M33 compact in-plane = 0.516
AS 4100 Cl. 8.4.5.1 biaxial compression + bending = 0.513
AS 4100 Cl. 8.3 compact section interaction = 0.384
AS 4100 Cl. 5.11 V3 shear = 0.099
AS 4100 Cl. 5.12.3 M33 + V3 shear/bending = 0.099
AS 4100 Cl. 6.1/6.3 axial compression = 0.048
AS 4100 Cl. 8.4.2.2 M22 compact in-plane = 0.023
AS 4100 Cl. 5.1 M22 minor bending = 0.022
AS 4100 Cl. 5.11 V2 shear = 0.007
Governing global capacity ratio = 0.617 from AS 4100 Cl. 8.4.4.1 M33 out-of-plane.
AS 4100 powered biaxial interaction equations are reported exactly as the left-hand side of the Standard equation; no exponent-root normalisation is applied. Clause 8.3 powered value = 0.384, exponent = 1.419. Clause 8.4.5 powered value = 0.513, exponent = 1.4.
I-section steel design to AS 4100. M33 uses EffectiveLengthLTB for lateral-torsional buckling; M22 uses section capacity.
AS 4100 Section 8 compact-section alternative provisions are applied where the section type, compactness and clause-specific conditions permit.
M33 transverse loading detected: beta_m = -1.0 is adopted conservatively for the Clause 8.4.2.2 compact in-plane alternative; the Clause 8.4.4.1 compact out-of-plane alternative is not used.
AS 4100 Cl. 5.12.3 shear/bending interaction is checked for M33 with its associated local V3 web shear, using the whole-cross-section method.
The Clause 5.6 moment modification factor alpha_m used for the major-axis member capacity is 1.
The M33*/M22* values used in the strength checks are the AS 4100 Clause 4.4.2 amplified design moments. FirstOrderM33Star/FirstOrderM22Star retain the unamplified frame-analysis actions for audit.
Powered Clause 8.3.4 and Clause 8.4.5 interaction checks are reported as the actual AS 4100 equation value with a unity limit; no exponent-root normalisation is applied.
Capacities returned by the steel API are design capacities with phi = 0.9 already applied.
Section 8 compact alternatives are reported separately from the standalone axial, bending and shear checks.
Clause 5.12.3 is checked without extrapolating its shear-reduction equation beyond M* = φMs; if that limit is exceeded, the Clause 5.1 bending failure remains explicit.
Governing result is the maximum utilisation from all checked stations for the governing LC-* combination.

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