CADS A3D MAX White Paper

Directional member analysis with tension and compression-only members and lift-off supports

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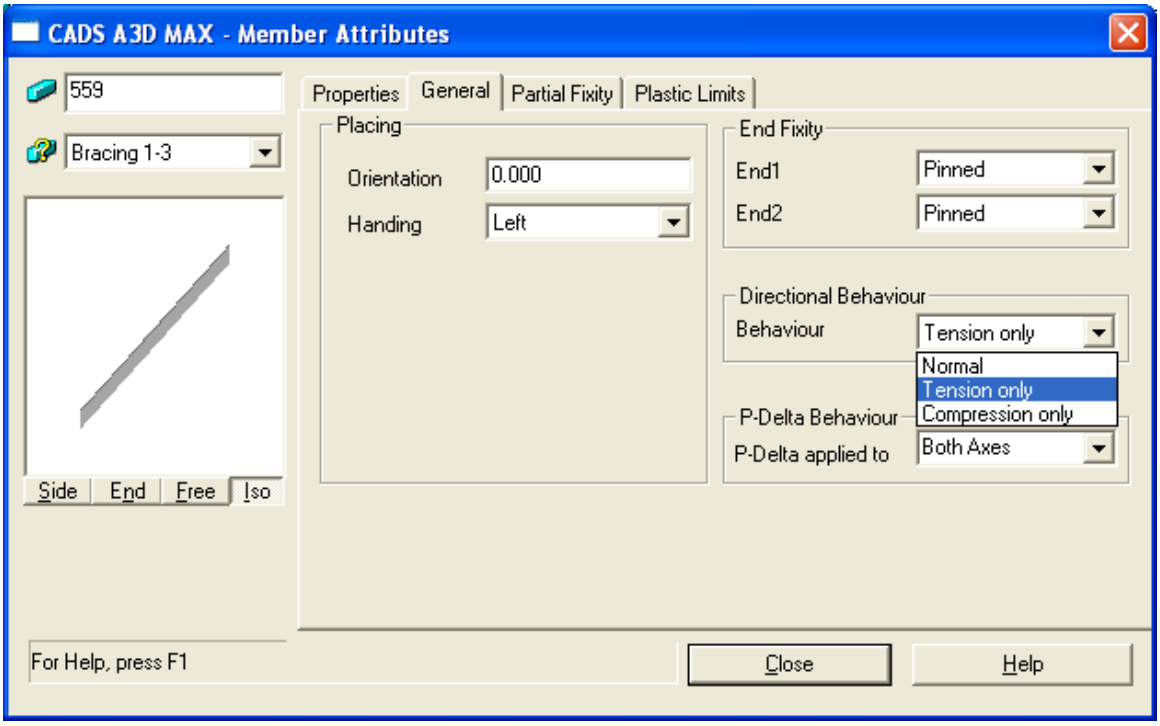
Directional member functionality

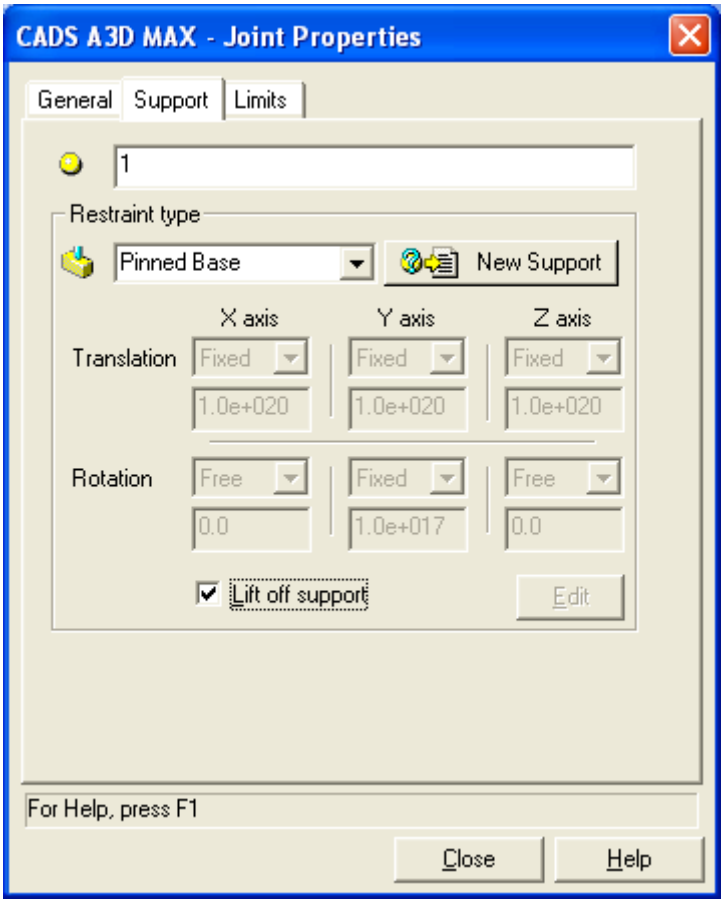
Directional members are assumed to be effective only in one direction of axial loading and they include both tension-only and compression-only members.
Compression-only members are commonly used to model structural elements which have negligible tension resistance such as masonry walls and piers.
Tension-only members are commonly used to model structural elements which are so slender that they will buckle elastically and harmlessly under very small compressive forces. Tension-only cross bracing is the commonest example whereby steel flats or angles are provided in pairs so that one member acting in tension under wind loads is active whilst the other which would normally be in compression is ineffective and ignored.
Lift-off supports are another instance of directionality and are treated in similar fashion but more simply. Lift-off supports are common in scaffolding structures and other demountable and mobile structures.

Operation

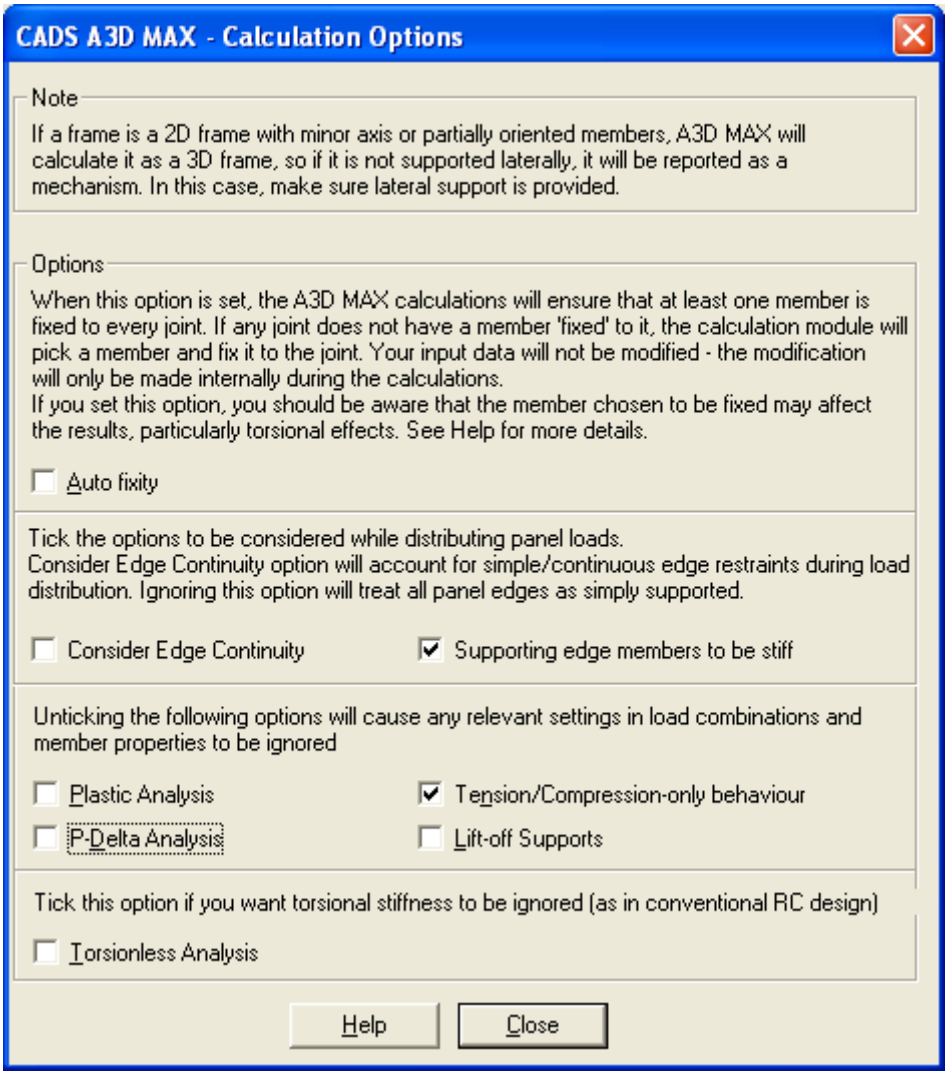
In A3D MAX, members may be given directional properties using the Member Attributes dialog. First select the relevant members, right mouse click on one of them and select Properties to open the dialog. Directional properties are selected in the General page.



Supports may be defined as `lift-off' using the Joint properties dialog. First select the relevant supports, right mouse click on one of them and select Properties to open the dialog. Tick the Lift-off support box in the Support page.



In order to invoke the directional properties of any members or supports, the relevant option must be selected in the Analysis options dialog, otherwise they are treated as normal reversible members. If directional members or supports are present in the structural model *and* the relevant analysis options are selected, the program will carry out a special directional member analysis for all the active load combinations (those not marked `ignore'). The analysis options step is inserted so that you can easily try the effect of alternative options with and without directionality without having to edit the properties of individual members and supports.



Note that Tension/compression-only behaviour and Lift-off supports may be selected simultaneously for the same analysis session as the other options: Plastic analysis, P-Delta analysis and Torsionless analysis, if this is required. Plastic analysis and P-delta analysis are load combination dependent and set up in the Load categories and combinations dialog, but the other options are applied to all active load combinations. The more analysis options that are applied to a load combination, the more stages/iterations that are required to complete and therefore the longer the execution time. This can be significant for large structures with many load combinations.

Directional member analysis method

The simplest method of analysis with directional members consists of two stages:-

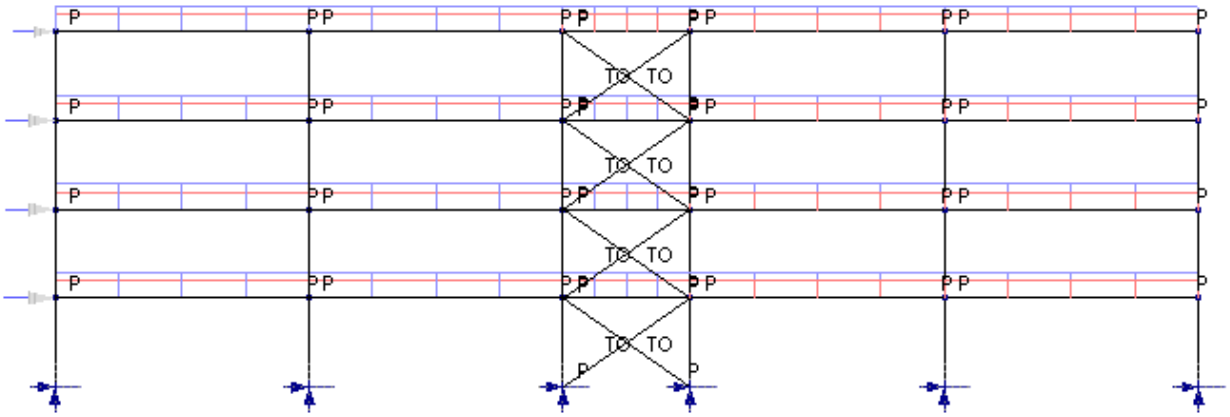
a: An initial linear elastic analysis is carried out ignoring any directionality to identify members and supports with axial forces/reactions acting opposite to their proposed directionality.

b: A second linear elastic analysis is carried out with the identified ineffective members and supports `removed'. The components are not actually removed. Instead they are assigned very low stiffness so that they attract negligible load.

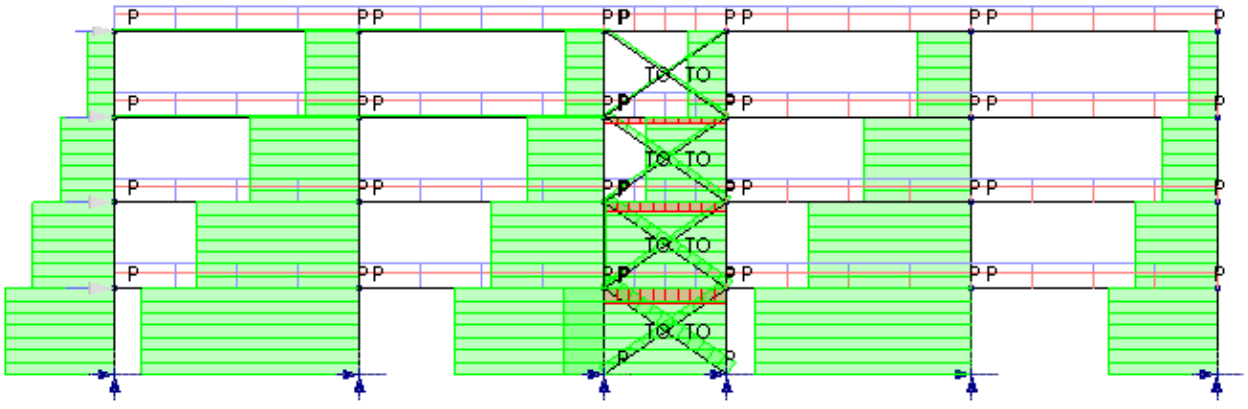
The above sequence is repeated if necessary if the second analysis generates more ineffective members or supports.

Obviously the effective removal of directional members or supports may cause a mechanism condition and this will be reported in the Error log and will prevent any numerical results being reported for the relevant load combination. This is a valuable function of the analysis especially for lift-off supports.

However, the simple procedure described above is not an adequate model for the behaviour of an important category of structural members:- tension-only bracings. Consider the simplified 2D example shown below of a four storey five span frame with tension-only cross bracing in one bay.
The beams are pin-ended so that lateral stability relies entirely on the cross bracing.



Under horizontal loads acting alone, the bracing pairs are alternately in compression and tension and application of the simple directional analysis procedure causes the `windward diagonals' to be removed and the `leeward diagonals' to transmit the all the wind loads to the foundation supports – no problem. However in a typical load combination the gravity loadings may be dominant causing all the diagonals to be in compression under normal linear analysis as shown below:



The diagonals, columns and beams of the braced bay form a closed system in which vertical loads are shared between the columns and diagonals according to their stiffness.
The second stage of the simple analysis removes all the diagonals leaving the frame as a sway mechanism – and a (spurious) failure is reported.

Obviously the real structure does not behave like this, it sways slightly until one diagonal in each pair goes into tension to produce a stable condition. With user intervention the problem can be avoided because the behaviour can be predicted - at least for simple structures.

The user can choose to model only the `leeward' diagonals. The single diagonal system does not divert vertical loads from the columns and transmits only forces due to horizontal loads.

Expert user intervention has its place but is inconvenient and time consuming so it was necessary to refine the analysis to provide an automatic solution.

The solution is based on the observations that for a frame of `simple construction' ie: pin-ended beams supported by continuous columns with diagonal bracing:-

a: The bracing system resisting horizontal loads is *statically determinate*. ie the member forces are independent of their stiffnesses.

b: The loads in the bracing members due to vertical loads are *statically indeterminate* ie they are dependent on the relative stiffnesses of the bracings and columns.

It therefore follows that if we carry out a trial linear analysis in which the bracing members are assigned very small section properties, they will attract only a very small component of the vertical loading but will still carry the same horizontal load component. Vertical loads will no longer be the dominant effect in the bracings so that the diagonal pairs will be alternately in tension and compression. The `true' tension and compression diagonals are thereby identified ready for a final analysis stage in which the tension diagonals are restored to their original sections and the compression diagonals are assigned a minimal section area of $1e10^{-12}$ mm^2.

The above description is a simplification because the section adopted for the trial analysis has to be sufficiently small to generate tension in the `leeward' diagonals but not so small as to cause instability. Some iteration is involved. The solution works best for frames of simple construction and not so well for frames in which the beams have fixed ends (rigid joints) because they have inherent sway stiffness without the bracing. The solution will not work if the horizontal loads are so extremely small that their effects do not dominate even when the diagonals are assigned extremely small trial properties. However, this will not happen if code recommendations are followed for notional horizontal loads and minimum wind loads. In 3D structures each load combination should include at least code notional horizontal loading in *both* X and Z directions. (ie in the absence of greater wind or seismic loads). In 2D structures only the X –direction minimum loading is required.

When directional members are included in an analysis with P-Delta effects, the directional member analysis is done first in order to correctly determine the axial loads in the frame members so that the stability factors can be calculated for the second order P-delta analysis.

When either or both of these effects are included in a plastic analysis or in an elastic critical load analysis, the procedures described above are carried out at each increment of loading in the iterations to determine either plastic hinge formation or the elastic critical load.

Recommendations

It is important to note that if tension-only members are present in the structure their effects should be selected in Analysis options for any analysis which includes P-Delta effects. This is because the members normally adopted for tension-only members (flats, angles, cables) will buckle at very low compression loads. If the tension-only procedure is not followed to establish a tension-only bracing system as described above, both members of each bracing pair will be removed by Pdelta analysis. At worst this may cause a spurious instability report and at best overestimate deflections and second order effects.

The above applies also to elastic critical load analysis.

It is recommended that tension-only and compression-only members should be specified with pinned end fixity.

It is recommended to use the Tension only.smd template when checking tension-only steel members in CADS SWMD or in the A3D MAX Design dialog.

Results of directional member analysis

The inclusion of directional members or supports in analysis may affect the stability and deflection results as discussed above. You can use the Analysis options dialog to make ready comparisons of numerical values with and without. Other effects will show as follows:-

1: In member Effects results, numerical results will not be available for members which have been `removed' by tension/compression-only analysis and a message is displayed instead of the usual table.

2: In Support reactions, a numerical value will not be shown for any support that has `lifted off' and a statement is shown instead of the usual figures.

3: If directional effects are included, the Error log report for any unstable load combination will record the fact.

4: In graphical results there will be no effects displayed along any member `removed' by the analysis.