

A3D MAX FAQ

How to model column base % fixity.





1.0 Introduction

BS 5950-1:2000 Section 5.1.3 gives recommendations for modelling base stiffness and capacity. The recommendations are given in terms of proportions or percentages of the stiffness and moment capacity of the supported column. There is no comparable guidance in Eurocode 3 (BS EN 1993-1-1) so BS 5950-1 could be considered non-conflicting complementary information (NCCI) in this respect. **CADS A3D MAX** provides tools for specifying partial elastic fixity in these terms as well as other options. **CADS A3D MAX** additionally provides for partial plastic moment capacity limits to be applied at member ends including the column to base connection. This is described in section 3 below.

Four categories of base fixity are defined in BS 5950-1 section 5.1.3. These are discussed in 1.1 to 1.4 below because the code recommendations are not clear. Instructions for modelling are given in section 2 below. If you do not require to read the discussion but only want guidance on using the software go straight to section 2.

This guide has been prepared with appropriate professional engineering logic and care but it has no official status and its interpretation and application is the responsibility of the user.

1.1 Fully pinned bases

Clause 5.1.3.1 states that the stiffness of a base with a true pin or rocker connection should be taken as zero. Such connections are only rarely adopted for columns in practice because they can be hazardous during temporary erection conditions. However the 'pinned base' support is commonly adopted as a safe default for frame analysis and design purposes even though the connection is actually detailed with four anchor bolts providing at least some rotational restraint.

When applying a support to a frame joint at the foot of a column it is recommended to use the 'pinned base' support type rather than the 'pinned' type. The former has rotational restraint about the vertical axis which avoids 'spinning column' type mechanisms when pins or plastic hinges are inserted at higher level. Fully pinned bases require no further discussion.

1.2 Nominally pinned base

Clause 5.1.3.3 implicitly authorises an inconsistent design model (a 'fudge') whereby the steel frame design may include some allowance for base fixity whilst the base itself is designed for zero moments applied by the frame. This is used mainly to 'massage' portal frame deflection calculations but sometimes also used in stability calculations. This means that two or three frame models have to be maintained to take advantage of this clause:-

- 1: For calculating moments and forces in the frame under ultimate limit state (ULS) load combinations, and for the design of the bases the column base supports are assumed pinned.
- 2: For calculating deflections under serviceability limit state (SLS) load combinations, the column base supports may be assumed to have partial fixity up to 20% of the column stiffness.
- 3: For checking frame stability or determining in-plane effective lengths under ULS load combinations, the column base supports may be assumed to have partial fixity up to 10% of the column stiffness.

In many cases the third condition is not worth pursuing and so the above simplifies to ULS and base design– pinned, SLS deflections up to 20% fixity.

The justification for this widely used option is that the beneficial details of construction (eg effects of floor slabs, cladding) are more complex and uncertain than can be readily included in normal analysis models and limited partial fixity is a reasonable indirect allowance for this.

1.3 Nominally rigid base

Clause 5.1.3.2 (a) states that “in global elastic analysis the stiffness of the base [ie column support] should be taken as equal to the stiffness of the column for all ultimate limit state calculations. However, in determining deflections under serviceability loads, the base may be treated as rigid [ie a fully fixed or encastré support]

Clause 5.1.3.2 (b) states that “in plastic global analysis any base moment capacity between zero and the plastic moment capacity of the column may be assumed, provided that the foundation is designed to resist a moment equal to this assumed moment capacity, together with the forces obtained from the analysis. In elastic-plastic global analysis the assumed base stiffness should be consistent with the assumed base moment capacity, but should not exceed the stiffness of the column.”

Careful reading of 5.1.3.2(b) reveals that it actually permits the full range of partial fixity from zero to 100% to be assumed. This subclause is therefore incorrectly placed under the heading “Nominally rigid base” and should really be either under 5.1.3.4 “Nominally semi-rigid base” or preferably a new category “Semi-rigid bases” since they are not nominal but must be consistently designed.

It will also be noted that no recommendations are given for the design of the base / foundation itself.

In order to make some sense of the above confusion, the following categories are suggested to achieve consistent design:

1.3.1 Nominally rigid bases

- 1: For calculating moments and forces in the frame under ultimate limit state (ULS) load combinations, the column base supports should be assumed to have partial fixity equal to 100% of the stiffness of the supported column. If plastic analysis is applied (as available in A3D MAX), the plastic resistance moment at the foot of the column should be 100% of the plastic resistance moment of the column itself.
- 2: For calculating deflections under serviceability limit state (SLS) load combinations, the column base supports may be assumed to be rigid [ie a fully fixed or encastré support]. However if deflections are not critical it may be simpler to use the same model as for the ULS with partial fixity equal to 100% of the stiffness of the supported column.
- 3: The base connection should be designed for the same ULS conditions as the frame.
- 4: The base/foundation should be designed for the same ULS and SLS conditions as the frame.

1.3.2 Semi-rigid bases

The column base supports may be assumed to have any value of partial fixity between zero and 100% of the stiffness of the supported column. If plastic analysis is applied (as available in A3D MAX), the plastic resistance moment at the foot of the column should be the same percentage of the plastic resistance moment of the column itself as the % elastic fixity. The same fixity should be assumed for ULS and SLS load combinations and for base/foundation design.

1.4 Nominally semi-rigid base

BS 5950-1 Clause 5.1.3.4 states: “ nominal base stiffness of up to 20% of the stiffness of the column may be assumed in elastic global analysis, provided that the foundation is designed for the moments and forces obtained from this analysis.”

It is difficult to see the point of this clause when clause 5.1.3.2(b) allows *any* percentage stiffness to be adopted with consistent design and clause 5.1.3.3 allows 20% fixity to be assumed for deflection calculations for nominally pinned bases. Pending possible clarification, this clause will be ignored for the remainder of this note and instead reference will be made to consistent semi-rigid design as described in 1.3.2 above in accordance with clause 5.1.3.2(b).

2 Modelling base fixity – examples and inputs

The principles discussed in the above interpretation of BS 5950-1 section 5.1.3 will be applied to the modest example frame shown below in fig1 as a 'stick model'.

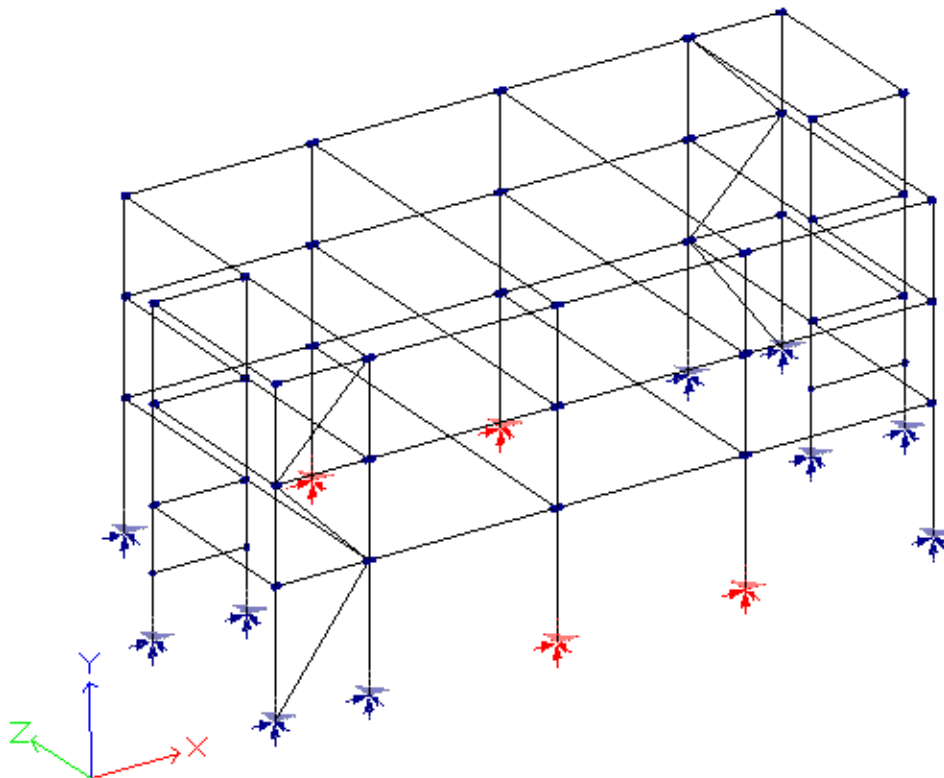


Fig 1: Example frame stick model with pinned base supports of which four are selected for editing.

2.1 Fully fixed (encastré) bases

Under BS 5950-1, strictly speaking, this option is only applicable to serviceability (SLS) deflection load combinations. Select the relevant supports or joints as shown in red in fig 1. Use the *Quick support* tool to select the fixed base option from the *Quick support* selection palette. The support symbols will change accordingly as shown in fig 3.



Fig 2: Quick support selection palette.

Alternatively right click on one of the selected joints and select *Properties* to open the *Joint properties* dialog. Open the *Support* tab and select *Fixed* from the *Restraint type* drop menu. The support symbols will change accordingly as shown in fig 3

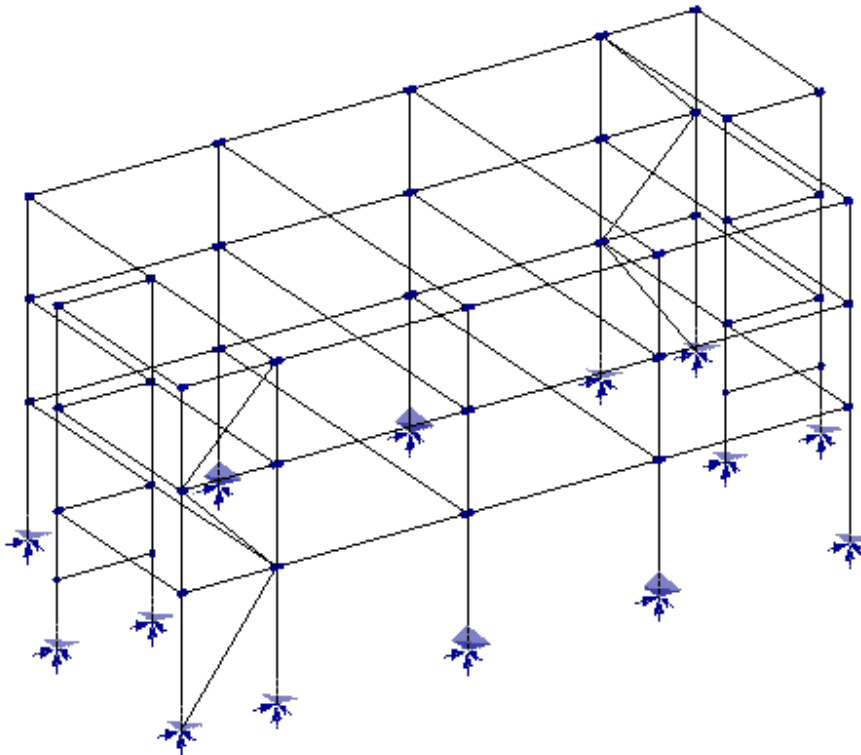


Fig 3: Example frame with four supports changed to 'fixed'

2.2 Fully pinned bases.

Reselect the four support joints. Use either *Quick support* or *Properties* to select the *Pinned base* option. The support symbols will change accordingly as shown in fig 1. Note that when applying a support to a frame joint at the foot of a column it is recommended to use the *Pinned base* support type rather than the *Pinned* type. The former has rotational restraint about the vertical axis which avoids 'spinning column' type mechanisms when pins or plastic hinges are inserted at higher level. The simple *Pinned* type should be used only when the base connection (or other support) definitely provides no restraint to rotation about the Y axis.

2.3 Partially fixed bases – linear analysis

The following applies to any partial fixity in the normal range 0.10 to 1.00 x member stiffness [ie 10% to 100% of member stiffness] as long as second-order P-delta effects are not required in the columns in analysis. For P-delta analysis see below (2.4).

First ensure that the relevant support joints are set to 'fixed' as shown in fig 3. If not, edit as noted in 2.1 above. Then select the relevant column members as shown in fig 4 and select the member direction symbols. Note that the column members in this instance all have end 1 at their bases so they can be treated together. If the directions are not consistent the members must be considered separately or they should be made consistent by using the *Swap* function in the *Member editor*.

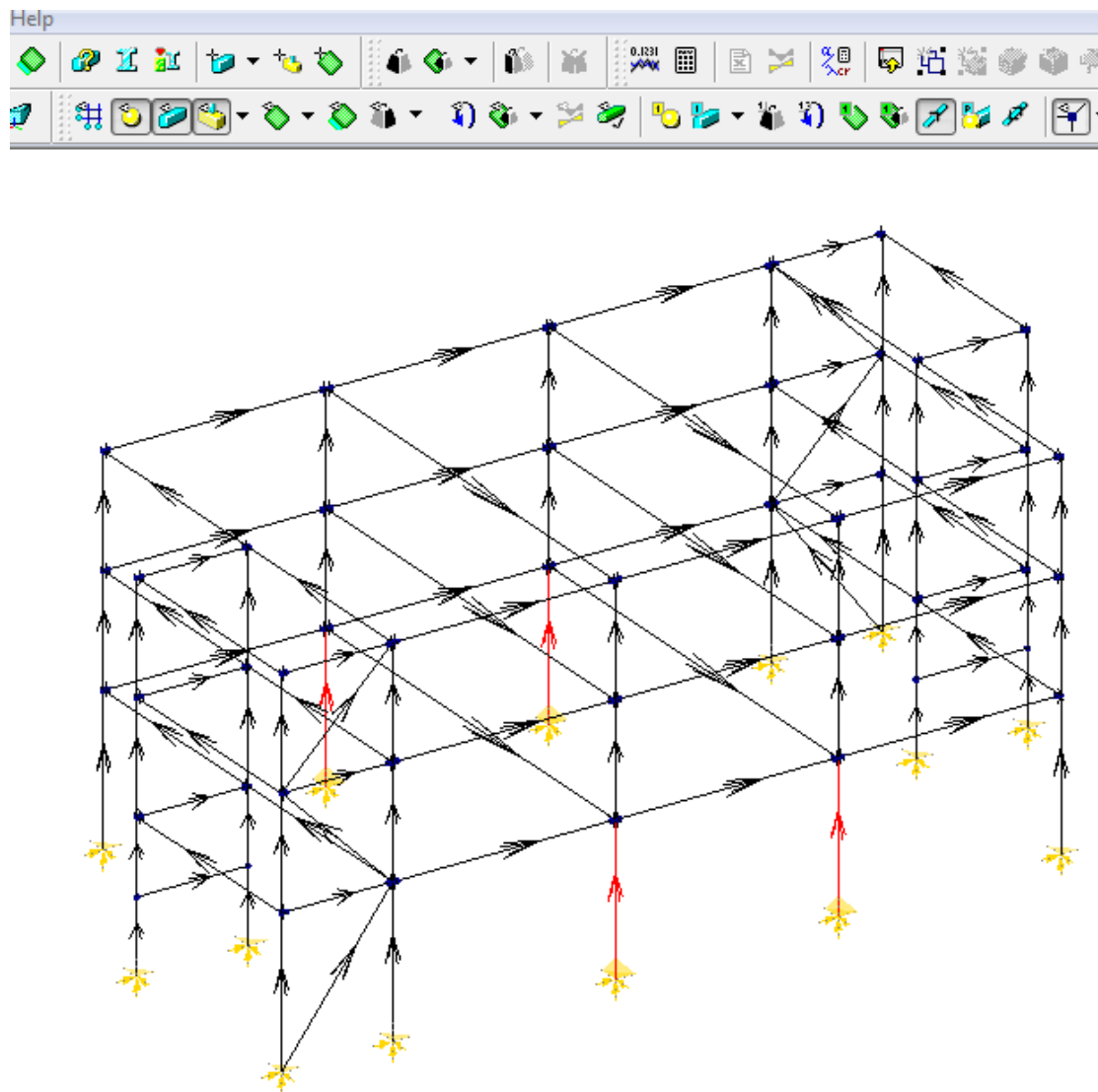


Fig 4: Example frame with four columns selected having fixed supports. Member direction symbols selected.

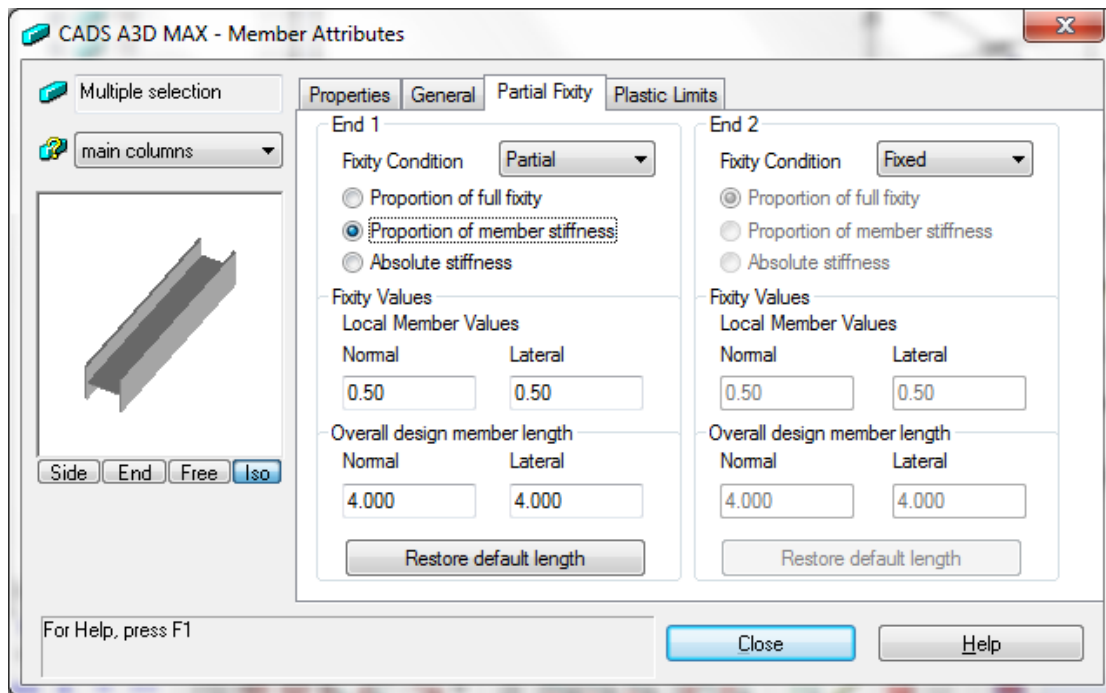


Fig 5: Partial fixity page for the four selected column members showing default values.

Right click on one of the selected members and select *Properties* to open the *Member attributes* dialog. Select the *Partial fixity* tab as shown in fig 5.

In the *Partial fixity* tab use the drop menu for end 1 (or the relevant end) to select the fixity condition *Partial*. There are three options for entering and displaying partial fixity (fixity of the end connection):-

- Proportion of full fixity
- Proportion of member stiffness
- Absolute stiffness

The definitions of these are given in *A3D MAX>Help>Analysing the structure>Partial fixity*. The derivation of the relationships between the above is given in the CADS website technical note *A3D MAX Derivation of proportional partial fixity factors*. The selection defaults to *Proportion of member stiffness* with value 0.50 corresponding to connection partial fixity 50% of member stiffness $4EI/L$. By selecting the other options you can see the equivalent values.

Note that the absolute or actual value of fixity (as used in the analysis) depends on the length of the member. If for any reason the member is split into sub-members as exemplified in fig 6, the selection of the sub-member immediately above the base may cause the absolute value of partial fixity to be calculated on its length rather than the relevant overall length resulting in an overestimate of connection stiffness. For this reason the software allows the overall design length of the member to be entered as shown in fig 5. If necessary different values may be entered for each principal axis and the default value based on the selected member length may be restored.

For 20% member fixity edit 0.50 to 0.20. Selection of *Absolute stiffness* causes 27167 kNm/radian and 9712 kNm/radian to be displayed for the normal and lateral values for the column section 356x368 UKB 202 kg as shown in fig 7.

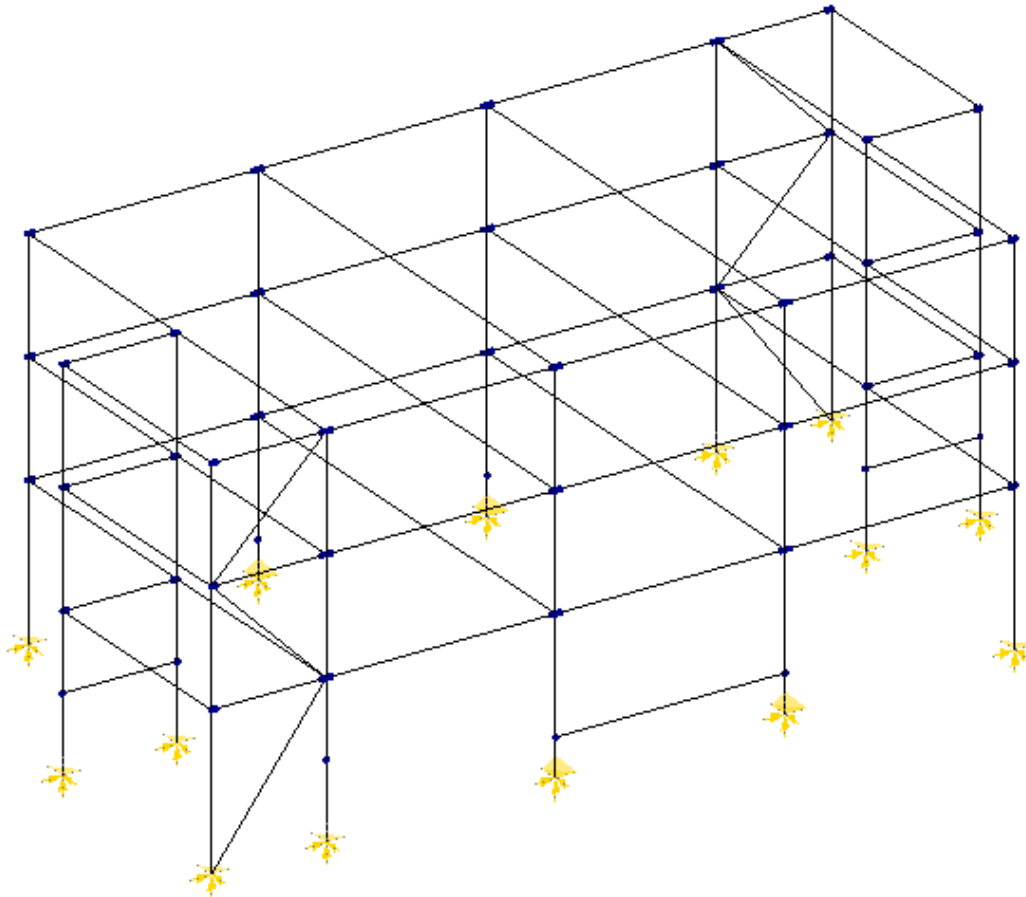


Fig 6: Example frame with some columns split into sub-members.

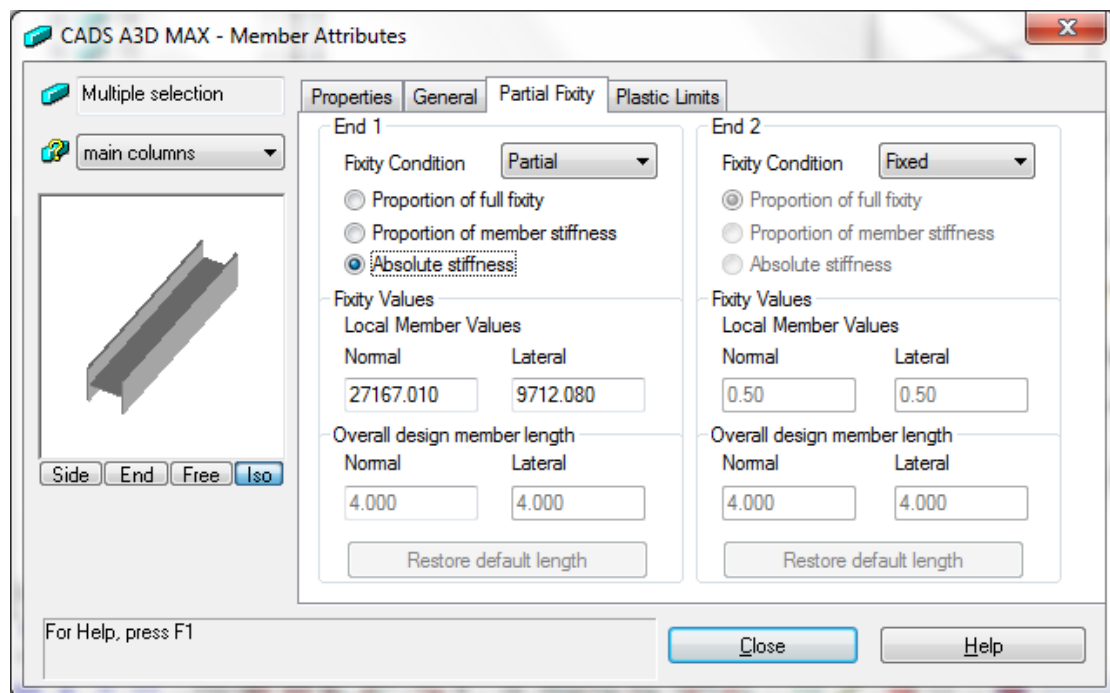


Fig 7: Partial fixity page for the four selected column members showing absolute stiffness values corresponding to member proportional stiffness 0.20 with 356x368 UKB 202 kg column 4.0 m long.

Check calculation: $K_{normal} = 0.20 \times 4 \times E \times I / L$
 $= 0.20 \times 4 \times 205 \times 66261 \times 10^4 / (4000 \times 10^3)$
 $= 27167 \quad \text{kNm/radian}$

When the relevant end fixities have been entered for the columns the frame may be subjected to linear elastic analysis. If an analysis with Pdelta effects (second order geometric) is required the following section should be followed.

2.4 Partially fixed bases – non linear analysis

It will be noted that if analysis with Pdelta effects is requested and there are members with partial end fixity included in the model, the following message will be displayed in the Error log:-

Analysis limitations: Pdelta effects are not considered for partially fixed members.

This means that the stiffness of all the partially fixed members in the model will be calculated assuming linear elastic behaviour. For the majority of conventional building frames, the members sustaining significant compression forces are columns and bracings and it is important for these to be calculated taking into account Pdelta effects. Generally it does not matter that partially fixed beams should be calculated as linear because they normally sustain only insignificant axial forces. However in cases where beams are also part of a bracing system and so carrying significant axial compression, the neglect of Pdelta effects can be significant.

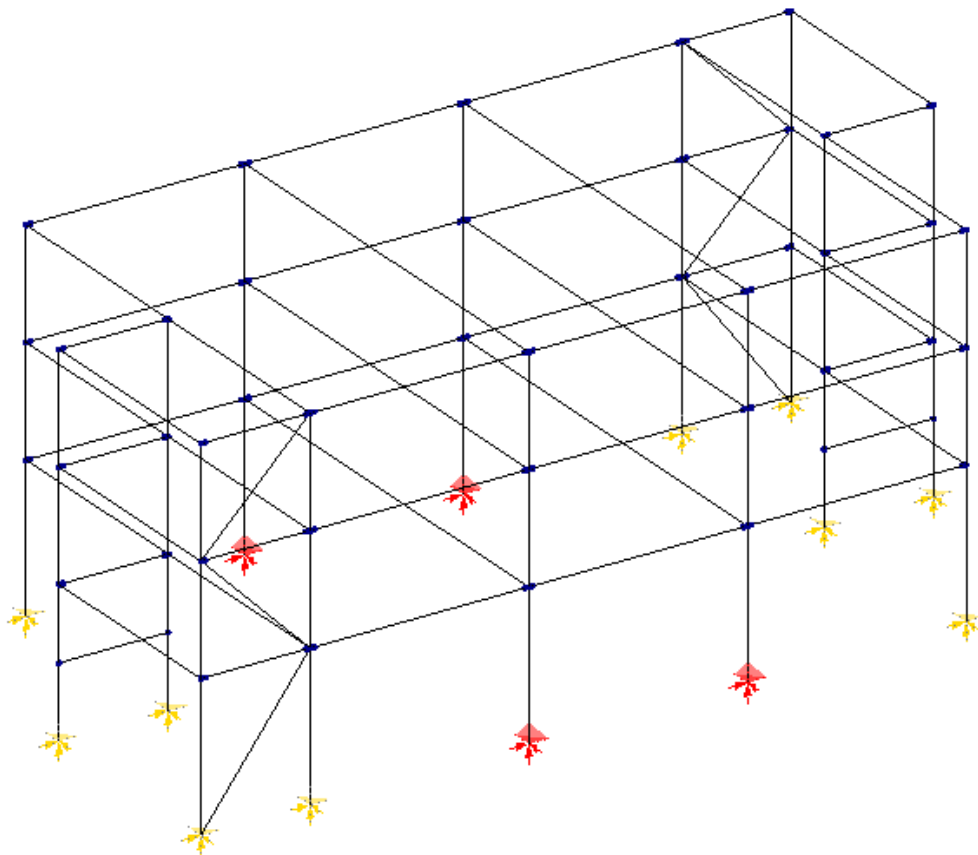


Fig 8: Example frame with four column supports selected.

Although A3D MAX cannot calculate the stability functions for partially fixed members, this limitation can be avoided for columns connected to base supports by applying the partial fixity to the support instead of to the column member. In such cases follow the procedure given in 2.3 above and make a note of the absolute values of fixity (eg as in fig 7). Then change the end condition to *fixed* (ie rigidly connected). Next select the support(s) to which the column member(s) are attached as shown in fig 8:

Right click on any of the selected supports and select *Properties* to open the *Joint properties* dialog in which select the *Support* tab. Select *New support* to enable the support rotational stiffnesses to be edited. From the drop menus select *Spring* stiffness input for rotation about the X and Z axes and enter the required values. Fig 9 shows the inputs for this example.

Note that the previously calculated value has been entered for rotation about the X axis but for rotation about the Z axis the support is assumed to rotate freely about the Z axis to avoid designing the connection and base for partial fixity in the XY plane. This is a user decision. Obviously any appropriate and valid value can be input providing that the subsequent design checks are satisfied.

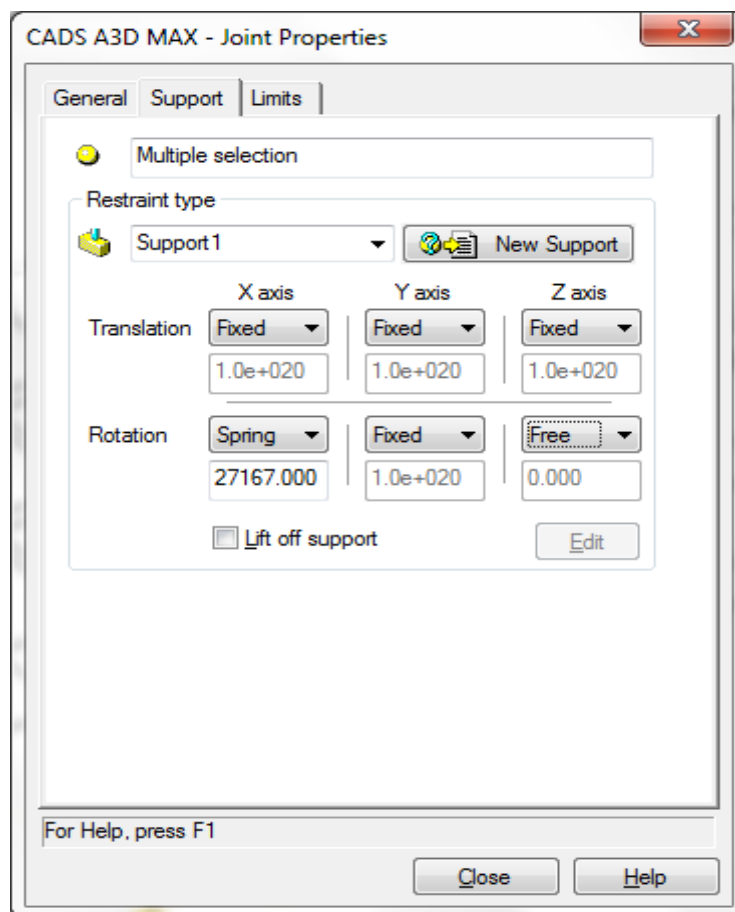


Fig 9: Support properties input page for the column supports selected in fig 8 after applying partial fixity to rotation about the X axis.

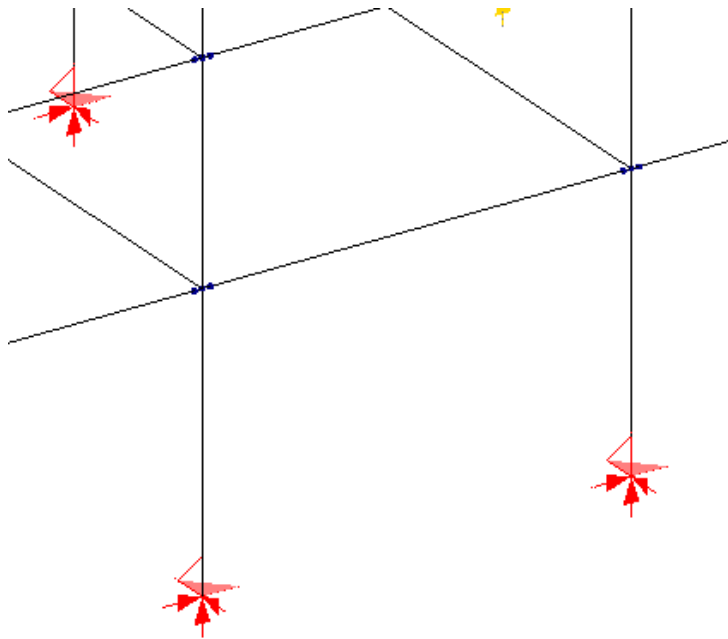


Fig 10: Portion of example frame after applying partial fixity to selected supports.

Note that support properties are specified relative to the global axes so care must be taken when relating to the member axes and orientation. For columns with skew orientations it will be necessary to resolve member stiffnesses to the global axes.

3.0 Plastic analysis

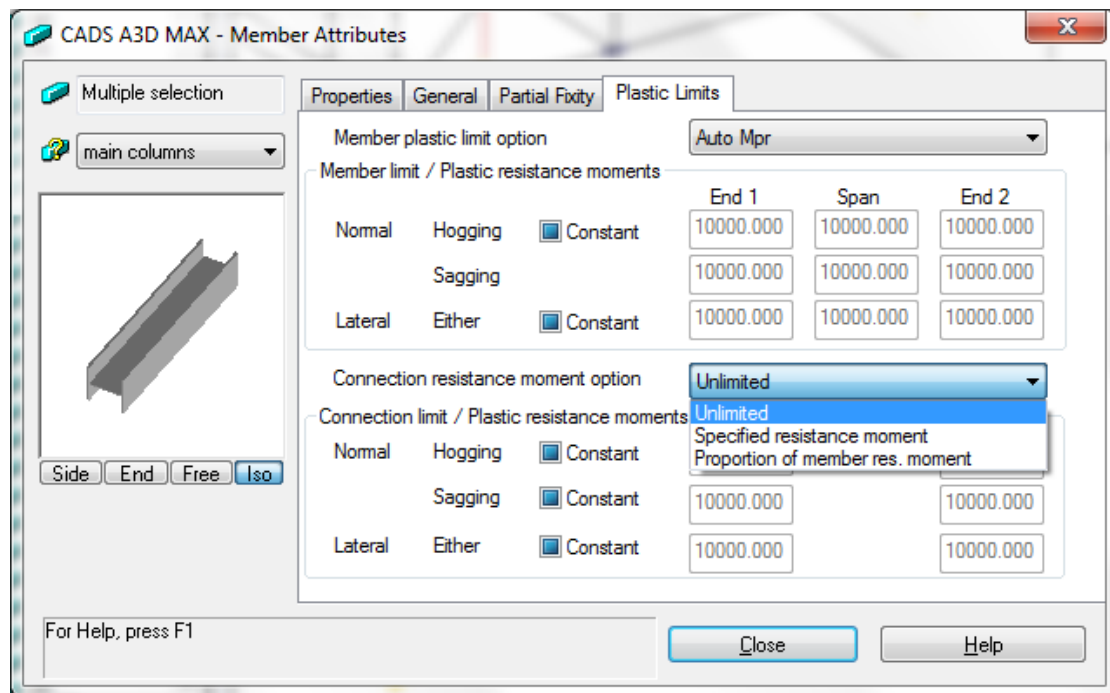


Fig 11: Plastic limits input page with default settings and drop menu selection.

In addition to elastic partial fixity A3D MAX allows the input of limiting moments using the *Member attributes* dialog. Select the relevant members eg: the columns in fig 4. Right click on

any of the selected members and select *Properties* to open the *Member attributes* dialog then select the *Plastic limits* page. Fig 11 shows the default settings in this page for which refer to *A3D MAX>Help>Creating and adding members>Member attributes>Plastic limits* for general guidance. For the purposes of the current example it is sufficient to say that the lower part of the page may be used to define or imposed limits on the resistance moment of the connection at either end of the member. The options are:

- Unlimited.
- Specified resistance moment. This can be used if the connection resistance is known.
- Proportion of resistance moment.

In this case we will specify proportional resistance moments consistent with the proportional elastic stiffness values adopted in 2.4 and fig 9 above as shown in fig 12.

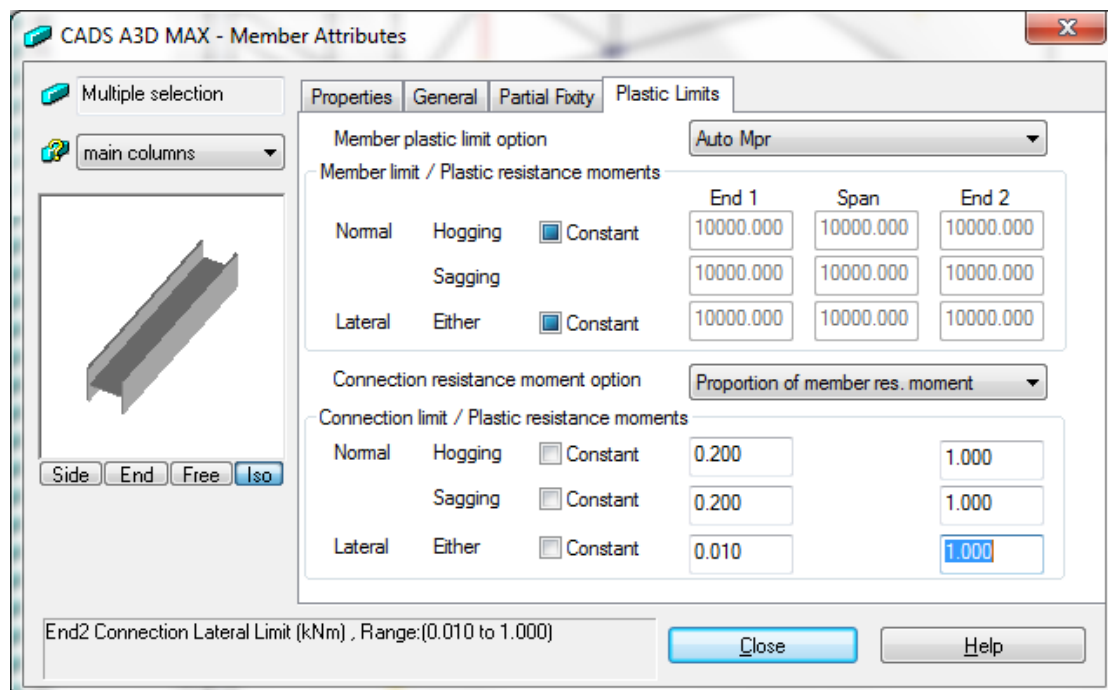


Fig 12: Plastic limits page after editing.

Note that:

- 'Constant' is not selected because we are limiting moments at end 1 only.
- At end 2 the full resistance moment of the member section is assumed.
- At end 1, 20% of the resistance moment of the section is to be assumed as the connection resistance in the normal/major direction.
- The resistance moments are here assumed symmetrical.
- The minimum value is entered for proportional moment resistance in the lateral/minor direction but in fact any value could be entered because in 2.4 we specified free rotation in this direction so no moment is generated by the stiffness analysis.

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