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Chapter 1. INTRODUCTION

ADAPTIC is an adaptive static and dynamic structural analysis program which has been developed to provide an efficient tool for the nonlinear analysis of steel and composite frames, slabs, shells and integrated structures. The program features are described briefly hereafter.

The initial development of ADAPTIC was driven by the needs of the offshore industry for an accurate yet efficient nonlinear analysis of offshore jackets subject to extreme static and dynamic loading. This motivated the development of pioneering adaptive nonlinear dynamic analysis techniques for framed structures, accounting for geometric and material nonlinearity, which formed the basis of Prof. Izzuddin’s PhD thesis, and which were extensively applied in nonlinear structural analysis under earthquake loading. Since then the program has been extensively developed to deal with other extreme loading, such as fire and blast, as well as numerous additional structural forms, such as R/C and steel-decked composite slabs, cable and membrane structures, and curved shells. Most of these novel developments have been published in leading international scientific and professional journals as well as in international conferences (see http://imperial.ac.uk/people/b.izzuddin/publications.html).

This version of the manual (V1.5e) covers some of the main capabilities of ADAPTIC related to plane/space frames, slabs/shells and 3D continuum solid analysis. The more recent developments related to partitioned modelling for HPC will be covered in future versions. The following discussions focus on the nonlinear analysis of plane and space frames as examples of the more general nonlinear analysis capability.

Inelastic analysis of steel frames may be performed by either of two methodologies. The first is an approximate solution using ideal plastic hinge elements, while the second is a more accurate solution employing elements which account for the spread of plasticity across the section depth and along the member length. For reinforced concrete and composite frames, inelastic analysis is performed using the second approach only.

The loading can be either applied forces or prescribed displacements/accelerations at nodal points. The loads can vary proportionally under static conditions, or can vary independently in the time or pseudo-time domains. The latter variation can be utilised for static or dynamic analysis.
1.1 Types of Analysis

Loads can be applied at the nodal positions for the translational and rotational freedoms in the three global directions (X, Y, Z). A load can be an applied force or a prescribed displacement/acceleration. The only restriction on the application of loads is that a load corresponding to a structural freedom should only be specified once, and that the loaded freedom should not be restrained. This requires that ground excitation, for example, should be specified as an applied acceleration at the ground nodal freedoms, and that these freedoms should not be restrained.

Static loads applied only once to the structure at the start of analysis. Any further loads applied during proportional or time-history loading are applied incrementally on top of these loads.

The initial loads are useful for modelling the structure dead weight. Also, they can model initial support settlement through using a displacement load at a support nodal freedom.

1.1.1 Static analysis – proportional loading

These are loads which vary proportionally according to one load factor. The behaviour of a structure under proportional loading can be studied in the post-ultimate range using the displacement control strategy. These loads cannot be applied with time-history loads within the same analysis.

1.1.2 Static analysis – time-history loading

These are loads which can vary independently in the time or pseudo-time domain. As such, if the structure has reached a stage where the loads cannot be incremented as specified by the user, the analysis is terminated since the program cannot establish how the user would want to continue the analysis.

Time-history loads are useful for modelling cyclic loading under various force or displacement regimes.

1.1.3 Dynamic analysis

Dynamic loads can be specified in a similar way to time-history loads and can be applied forces or prescribed accelerations. Note that the latter allow the modelling of ground excitation, which is different from the case of static analysis where support motion is indicated by means of prescribed displacements. The ability to model loads varying independently in the time domain allows asynchronous excitation to be represented with relative ease.

1.1.4 Eigenvalue analysis

Eigenvalue analysis is performed using the efficient Lanczos algorithm, which requires as input the number of modes within the range of frequencies of interest as well as the number of iterative steps. This algorithm can also be used with dynamic analysis, where the frequencies and modes are obtained during analysis using the tangent stiffness.
1.2 Structural Modelling

The following sections describe how various analysis assumptions can be modelled using the ADAPTIC elements, which are discussed in detail in Chapter 6. Note that different assumptions can be utilised in the same analysis for different members of the structure. Note also that similar element types usually exist for 2D and 3D analysis, distinguished by the last number in the element type identifier (e.g. qph2 & qph3).

1.2.1 Elastic Modelling

Quartic elastic elements (qel2, qel3) can be used to model the beam-column effect and large displacements for selected structural members. One quartic element is capable of representing the beam-column action and large displacements for a whole member.

1.2.2 Plastic Hinge Modelling

Quartic plastic hinge element (qph2, qph3) have the same elastic representation power of elements (qel2, qel3) but can represent material inelasticity through the utilisation of zero-length plastic hinges at the element end nodes. The introduction of these plastic hinges depends on the interaction between the bending moments at the element ends and the axial force, established from the specification of the element cross-section.

1.2.3 Elasto-Plastic Modelling

Detailed elasto-plastic modelling, based on the inelastic uniaxial material response, can be performed using cubic elasto-plastic elements (cbp2, cbp3), which accurately model the spread of plasticity across the cross-section through the utilisation of material monitoring point. To represent the spread of inelasticity along the member length, a number of cubic elements, usually over 5, are required per member.

1.2.4 Adaptive Elasto-Plastic Modelling

Adaptive analysis can be applied in the elasto-plastic analysis of steel frames to reduce the modelling task, which previously required a fine mesh of cubic elements all over the structure, and to enable the analysis to be performed quite efficiently. The concept of adaptive analysis entails the utilisation of elastic quartic element (gdp2, gdps) which would sub-divide into inelastic cubic elements (cbp2, cbp3) when inelasticity is detected during analysis. The analysis is started using only one quartic element per member, with element refinement performed automatically when necessary in zones along the element which are pre-defined by the user.

1.2.5 Joints and Boundary Conditions

Joint behaviour can be modelled by means of joint elements (jet2, jet3) with de-coupled axial, shear and moment actions. These joint elements can have any orientation, and may utilise a number of force-displacement relationships described in Chapter 4.

The joint elements may also be used to model special boundary conditions, such as inclined supports, soil-structure interaction and structural gaps, through choosing appropriate terms for the force-displacement relationships.
1.2.6 Dynamic Characteristics Modelling

The dynamic characteristics of the structure, namely mass and damping, are modelled by means of non-structural elements which must be included for dynamic analysis to be performed. The dynamic element types are:

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>cnm2, cnm3</td>
<td>Lumped mass elements</td>
</tr>
<tr>
<td>lnm2, lnm3</td>
<td>Linear distributed mass elements</td>
</tr>
<tr>
<td>cbm2, cbm3</td>
<td>Cubic distributed mass elements</td>
</tr>
<tr>
<td>cnd2, cnd3</td>
<td>Dashpot damping elements</td>
</tr>
<tr>
<td>rld2, rld3</td>
<td>Rayleigh damping elements</td>
</tr>
</tbody>
</table>
Chapter 2. USING ADAPTIC

2.1 ADAPTIC Data File

In order to perform nonlinear structural analysis using ADAPTIC, the problem data is stored in a data file which the program reads and processes. Such data specifies the structural configuration and the loading applied to structure, and must follow the syntax described in the Data Syntax chapter.

All ADAPTIC data files must have a ".dat" extension (e.g. one_storey.dat, SW_2.1.dat). A new data file may be created through modifying an existing data file or through typing the data from scratch. The former approach is usually more convenient, especially for parametric studies when only some data entries require modification.

2.2 Starting ADAPTIC

ADAPTIC currently runs on Linux workstations, where it is started using the following command:

```
{prompt} adaptic filename
```

Note that the `filename` does not include the ".dat" extension (e.g. adaptic one_storey).

ADAPTIC can also be run in the background using the following command:

```
{prompt} adaptic filename > filename.log &
```

where `filename.log` is a file which stores the job progress.

The execution of ADAPTIC invokes two successive stages. The first is a data reading stage, where the problem details are read from the data file, and several temporary files are created which incorporate problem and plotting information. The second is the analysis stage, where the information is retrieved from the temporary files and the nonlinear analysis is undertaken as specified. If the program seems to hang up before entering the reading stage, make sure that the two files `param.inc` and `stat.x` are removed from the working directory.

2.3 ADAPTIC Output Files

Upon successful completion of an ADAPTIC run, three additional files corresponding to `filename` should exist (`filename.out`, `filename.num` & `filename.plt`). The first file echoes the data file and contains the solution progress log. The second file contains the numerical results at all requested load/time steps. The third file is a plot file used by the post-processing programs.

Numerical results may be obtained through direct extraction from `filename.num`. Graphical visualisation of the results is also available through a number of post-processing programs described in the Post-Processing chapter.
Chapter 3. MATERIAL MODELS

The ADAPTIC library includes a number of uniaxial material models which can be used to model steel, concrete and other materials with similar behavioural characteristics. The models and their applicability are briefly described below, with full details given in next pages:

<table>
<thead>
<tr>
<th>Model</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>stl1</td>
<td>Bilinear steel model with kinematic strain-hardening</td>
</tr>
<tr>
<td>stl2</td>
<td>Multisurface steel model</td>
</tr>
<tr>
<td>con1</td>
<td>Simple trilinear concrete model</td>
</tr>
<tr>
<td>con2</td>
<td>Constant confinement concrete model</td>
</tr>
<tr>
<td>con3</td>
<td>Variable confinement concrete model</td>
</tr>
</tbody>
</table>

Cubic elasto-plastic formulations (cbp2, cbp3) utilise the full inelastic characteristics of the above models.

Quartic plastic hinge formulations (qph2, qph3) utilise only the yield characteristics of the models.

The elastic formulations utilise only the elastic characteristics of the models.

This section describes the material models available in ADAPTIC. Each model is referred to by a unique name, displayed at the top of the following pages, and requires the specification of a number of properties in the order indicated.
**stl1**

<table>
<thead>
<tr>
<th>Description</th>
<th>Bilinear elasto-plastic model with kinematic strain hardening.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>No. of properties</strong></td>
<td>3</td>
</tr>
<tr>
<td><strong>Properties</strong></td>
<td>Young's modulus (( E ))</td>
</tr>
<tr>
<td></td>
<td>Yield strength (( \sigma_y ))</td>
</tr>
<tr>
<td></td>
<td>[ Strain-hardening factor (( \mu )) ]</td>
</tr>
<tr>
<td><strong>Application</strong></td>
<td>Uniaxial modelling of mild steel</td>
</tr>
</tbody>
</table>

![Stress-Strain Diagram](image)

*Material model stl1*
<table>
<thead>
<tr>
<th><strong>Description</strong></th>
<th>Multi-surface model for cyclic plasticity.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>No. of properties</strong></td>
<td>42</td>
</tr>
<tr>
<td><strong>Properties</strong></td>
<td>Young's modulus (E)</td>
</tr>
<tr>
<td></td>
<td>Plastic strains used for curves description</td>
</tr>
<tr>
<td></td>
<td>($\varepsilon_{p1}, \varepsilon_{p2}, \ldots, \varepsilon_{p5}$)</td>
</tr>
<tr>
<td></td>
<td>Virgin stress-plastic strain properties</td>
</tr>
<tr>
<td></td>
<td>($\kappa_{a0}, \kappa'<em>{a0}, \kappa</em>{a1}, \kappa'<em>{a1}, \ldots, \kappa</em>{a5}, \kappa'_{a5}$)</td>
</tr>
<tr>
<td></td>
<td>Cyclic stress-plastic strain properties</td>
</tr>
<tr>
<td></td>
<td>($\kappa_{b0}, \kappa'<em>{b0}, \kappa</em>{b1}, \kappa'<em>{b1}, \ldots, \kappa</em>{b5}, \kappa'_{b5}$)</td>
</tr>
<tr>
<td></td>
<td>Weighting function properties</td>
</tr>
<tr>
<td></td>
<td>($W_0, W'_0, W_1, W'_1, \ldots, W_5, W'_5$)</td>
</tr>
<tr>
<td><strong>Application</strong></td>
<td>Cyclic behaviour of steel modelling hardening, softening and mean stress relaxation.</td>
</tr>
<tr>
<td><strong>Restrictions</strong></td>
<td>No descending branch beyond ultimate point</td>
</tr>
<tr>
<td></td>
<td>(i.e $\kappa_{a5} &gt; 0$, $\kappa'_{b5} &gt; 0$).</td>
</tr>
</tbody>
</table>
Material model $stl2$
**Description**
Rate-sensitive bilinear elasto-plastic model with kinematic strain hardening.

**No. of properties**
5

**Properties**
- Young's modulus (E)
- Yield strength (\(\sigma_y\))
- Strain-hardening factor (\(\mu\))
- Rate-sensitive parameter (S)
- Rate-sensitive parameter (\(\dot{\varepsilon}_s\))

**Application**
Uniaxial modelling of mild steel

---

**Material model \textit{stl3}**

\[
\text{Overstress} = S \log \left( 1 + \frac{\dot{\varepsilon}_p}{\dot{\varepsilon}_s} \right)
\]
<table>
<thead>
<tr>
<th><strong>Description</strong></th>
<th>Bilinear material model</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>No. of properties</strong></td>
<td>20</td>
</tr>
</tbody>
</table>
| **Properties** | Young's modulus and temperatures used for trilinear description:  
\[
(E_1, E_2, T_1, T_2, T_3)
\]
Yield strength and temperatures for trilinear description  
\[
(\sigma_{y1}, \sigma_{y2}, T_{\sigma1}, T_{\sigma2}, T_{\sigma3})
\]
Strain-hardening factor and temperatures for trilinear description:  
\[
(\mu_1, \mu_2, T_{\mu1}, T_{\mu2}, T_{\mu3})
\]
Thermal strain and temperatures  
\[
(\alpha_1, \alpha_3, T_{\alpha1}, T_{\alpha2}, T_{\alpha3})
\]
| **Application** | Requires the specification of Young’s modulus, the yield strength, the strain-hardening factor, the thermal strain and their variations with temperature. |
| **Restrictions** |
Material model \textit{stl4}
### stl5

<table>
<thead>
<tr>
<th><strong>Description</strong></th>
<th>Creep model</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>No. of properties</strong></td>
<td>28</td>
</tr>
</tbody>
</table>
| **Properties** | The first 20 properties are the same as those of the bilinear model. Material constants for modelling creep  
 \((A, B, C, D, F, G, \Delta H, R, \sigma^*)\) |
| **Application** | In addition to the 20 parameters for the bilinear material model, 8 more parameters are required to specify the creep response of the material |
| **Restrictions** | |
**Description**  Elliptical model

**No. of properties**  37

**Properties**
- Young’s modulus and corresponding temperatures
  \( (E_1, E_2, E_3, E_4, T_1, T_2, T_3, T_4, T_5) \)
- Proportional limit and corresponding temperatures
  \( (f_{p1}, f_{p2}, f_{p3}, f_{p4}, T_{p1}, T_{p2}, T_{p3}, T_{p4}, T_{p5}) \)
- Yield strength and corresponding temperatures
  \( (f_{y1}, f_{y2}, f_{y3}, f_{y4}, T_{y1}, T_{y2}, T_{y3}, T_{y4}, T_{y5}) \)
- Thermal strain and corresponding temperatures
  \( (\alpha_1, \alpha_2, \alpha_3, \alpha_4, T_{\alpha1}, T_{\alpha2}, T_{\alpha3}, T_{\alpha4}, T_{\alpha5}) \)

[Ultimate strain \( (\varepsilon_u) \)]

**Application**
Requirements 37 parameters in total to describe Young’s modulus, the proportional limit, the yield strength, the thermal strain and their variations with temperature. The nine parameters used to define the proportional limit and its variation with temperature is illustrated in figure. The other parameters are defined in the same sequence. The ultimate strain should be \( (\varepsilon_u > 0.15) \) and defaults to 0.20.

**Restrictions**

---

*Material model st10*
### Description
Trilinear concrete model, with optional tensile response and piecewise quadratic/cubic compressive and tensile responses.

### No. of properties
8

### Properties
- Secant compressive stiffness \( (E_{c1}) \)
- Compressive strength \( (f_{c1}) \)
- Compressive softening stiffness \( (E_{c2}) \)
- Residual compressive strength \( (f_{c2}) \)
- Initial tensile stiffness \( (E_{t1}) \)
- Tensile strength \( (f_t) \)
- Tensile softening stiffness \( (E_{t2}) \)
- Curvilinear compressive parameter \( (\alpha_c) \)
- Curvilinear tensile parameter \( (\alpha_t) \)

### Application
Simplified uniaxial modelling of concrete material.

### Notes
\( \alpha_c = [-1,+1] \) and \( \alpha_t = [-1,+1] \).

\( |\alpha_c| \neq 0 \) corresponds to a quadratic initial compressive branch, with \( \alpha_c = \pm 1 \) corresponding to a zero slope at \( f_{c1} \).

\( \alpha_c < 0 \) corresponds to a cubic post-peak softening branch, with \( \alpha_c = -1 \) corresponding to zero slopes at \( f_{c1} \) and \( f_{c2} \).

\( \alpha_t > 0 \) corresponds to a quadratic initial tensile branch and a cubic post-peak softening branch, with \( \alpha_t = 1 \) corresponding to zero slopes at \( f_t \) and the end of the softening branch.

\( \alpha_t < 0 \) corresponds to a quadratic post-peak softening branch, with \( \alpha_t = -1 \) corresponding to a zero slopes at the end of this branch.
Material model $con1$
**Description**
Uniaxial constant confinement concrete model.

**No. of properties**
4

**Properties**
- Concrete compressive strength \( (f_c) \)
- Concrete tensile strength \( (f_t) \)
- Crushing strain \( (\varepsilon_{co}) \)
- Confinement factor \( (k) \)

**Application**
Uniaxial modelling of concrete assuming constant confinement.

**Restrictions**
Parameter units must be in Newtons and Millimetres.
The confinement factor must be greater or equal to 1.

---

**Material model con2**
Uniaxial variable confinement concrete model.

No. of properties

10

Properties

Concrete compressive strength \( (f_c) \)
Concrete tensile strength \( (f_t) \)
Crushing strain \( (e_{co}) \)
Poisson's ratio of concrete \( (\nu) \)
Yield stress of stirrups \( (\sigma_y) \)
Young's modulus of stirrups \( (E) \)
Strain hardening of stirrups \( (\mu) \)
Diameter of stirrups \( (\phi) \)
Stirrups spacing \( (s) \)
Diameter of concrete core \( (\Phi_c) \)

Application

Uniaxial modelling of concrete accounting for variable confinement effects, which are influenced by the core area within the stirrups, stirrups size and material, and stirrups spacing.

Restrictions

Parameter units must be in Newtons and Millimetres.

Material model con3
### Description
Trilinear compressive concrete model for elevated temperature, with zero tensile response.

### No. of properties
28

### Properties
Compressive strength and its reduction factors
\[ r_i = \frac{f_{c1(T)}}{f_{c1(0)}} \]

\[ (f_{c1}, T_{r,1,1}, r_{i,1}, T_{r,2,1}, r_{2,1}, T_{r,3,1}, r_{3,1}) \]

Peak compressive strain and temperature factors
\[ r_2 = \frac{\varepsilon_{c1(T)}}{\varepsilon_{c1(0)}} \]

\[ (\varepsilon_{c1}, T_{r,1,2}, r_{i,2}, T_{r,2,2}, r_{2,2}, T_{r,3,2}, r_{3,2}) \]

Limit compressive strain and temperature factors
\[ r_3 = \frac{\varepsilon_{c2(T)}}{\varepsilon_{c2(0)}} \]

\[ (\varepsilon_{c2}, T_{r,1,3}, r_{i,3}, T_{r,2,3}, r_{2,3}, T_{r,3,3}, r_{3,3}) \]

Thermal strain and temperatures
\[ (0, T_{\alpha_1}, \alpha_1, T_{\alpha_2}, \alpha_2, T_{\alpha_3}, \alpha_3) \]

### Application
Requires the specification of the compressive strength, the peak compressive strain, the limit compressive strain at zero stress, the thermal strain and their variations with temperature. Note that \( r_2 \) and \( r_3 \) can be greater than 1.

### Restrictions
Material model $con6$
### Description
Rotating-crack elevated-temperature model for concrete with linear compressive response.

### No. of properties
25

### Properties
- Young's modulus and temperatures: 
  \[(E_0, r_2, T_1, T_2, T_3)\]
- Possion’s ratio and temperatures: 
  \[(\nu_0, r_2, T_1, T_2, T_3)\]
- Tensile strength and temperatures: 
  \[(f_0, r_2, T_1, T_2, T_3)\]
- Softening slope and temperatures: 
  \[(a_0, r_2, T_1, T_2, T_3)\]
- Thermal strain and temperatures
  \[(\varepsilon_{th1}, r_2, T_1, T_2, T_3)\]

### Application
Plasticity-based model of concrete taking account of tensile cracking and elevated temperature.

### Restrictions
Material model `con9`
Description
Uniaxial concrete model for long term analysis.

No. of properties
7

Properties
Type of analysis
1 (linear viscoelastic)
2 (brittle viscoelastic)

Time of casting [days]

Compressive strength [N/mm²]

Tensile strength [N/mm²]

Relative humidity of environment [%]

Notional size of member * [mm]

Shrinkage ratio

Application
The long-term concrete model can be employed for long-term analysis. Two different options are allowed:
- Linear viscoelastic concrete
- Brittle viscoelastic concrete

In the linear viscoelastic analysis both creep and shrinkage phenomena are evaluated according to the CEB-FIP Model Code 90[1]. The Volterra’s integral equation is solved by developing the relaxation function in series of exponential functions and applying the trapezoidal rule[2,3].

In the brittle viscoelastic analysis, the concrete is considered linear viscoelastic in compression and in tension before cracking. In cracked phase a brittle law is assumed and both creep and shrinkage are not taken into account.

References


(*) Given by the ratio $2A_c/u$, where $A_c$ is the cross section and $u$ is the perimeter of the member in contact with the atmosphere.
**Description**
Fixed-crack elevated-temperature model for concrete.

**No. of properties**
37

**Properties**
- Young’s modulus and temperatures:
  \( (E_0, r_2, T_1, T_2, T_3) \)
- Possion’s ratio and temperatures:
  \( (\nu_0, r_2, T_1, T_2, T_3) \)
- Tensile strength and temperatures:
  \( (f_{t0}, r_2, T_1, T_2, T_3) \)
- Tensile softening slope and temperatures:
  \( (a_{t0}, r_2, T_1, T_2, T_3) \)
- Thermal strain and temperatures:
  \( (\varepsilon_{th1}, r_2, T_1, T_2, T_3) \)
- Compressive strength and temperatures:
  \( (f_{c0}, r_2, T_1, T_2, T_3) \)
- Normalised initial compressive strength: \( (s_c) \)
- Normalised residual compressive strength: \( (r_c) \)
- Normalised strain increment beyond \( \varepsilon_c \): \( (m_c) \)
- Factor for biaxial compressive interaction: \( (b_c) \)
- Elastic shear retention factor: \( (\beta_s) \)
- Factor scaling direct tensile stresses for shear interaction: \( (\Phi_s) \)
- Normalised shear softening relative to direct tensile softening: \( (\gamma_s) \)

**Application**
- Representation of tensile cracking and compressive nonlinearity, including softening effects.
- Modelling of crack opening and closure, the latter being an important requirement under dynamic loading and fire conditions.
- Consideration of the effects of elevated temperature, both in terms of the resulting thermal strains and the change of material properties.

**Restrictions**
Material model con11 (Cont’d...)
Material model con11
**Description**  
Biaxial concrete model for long term analysis, including creep, shrinkage and thermal strains.

**No. of properties**  
12

**Properties**

- Compressive strength  \( (f_c) \) [N/mm²]
- Poisson’s ratio  \( (\nu) \)
- Tensile strength  \( (f_t) \) [N/mm²]
- Tensile softening slope  \( (a_t) \) [N/mm²]
- Elastic shear retention factor  \( (\beta_s) \)
- Factor scaling direct tensile stresses for shear interaction  \( (\Phi_s) \)
- Normalised shear softening relative to direct tensile softening  \( (\gamma_s) \)
- Time of casting  \( (t_c) \) [days]
- Relative humidity of environment  \( (R_h) \) [%]
- Notional size of member  \( (H_o) \) [mm]
- Shrinkage ratio  \( (D_{sh}) \)

\[ \text{[ Coefficient of thermal expansion (\(\alpha\))]} \]

**Application**

Combines creep and shrinkage model (as for con10) with fixed crack biaxial concrete model (instance of con11), considering the following:

- Linear elastic compressive response (\(f_c\) used only to determine elastic modulus)
- If optional \(\alpha\) is specified: \(\varepsilon_{sh} = \alpha T\)

**References**

con10 and con11.
**Description**

Material properties for connection components/connected member at elevated temperature.

**No. of properties**

45

**Properties**

Ultimate strength, temperatures and reduction factors for quadlinear description:

\[(\sigma_u, T_{r1,1}, r_{1,1}, T_{r2,1}, r_{2,1}, T_{r3,1}, r_{3,1}, T_{r4,1}, r_{4,1})\]

Young’s modulus, temperatures and reduction factors:

\[(E, T_{r1,2}, r_{1,2}, T_{r2,2}, r_{2,2}, T_{r3,2}, r_{3,2}, T_{r4,2}, r_{4,2})\]

Reduced strain hardening coefficient, temperatures and reduction factors:

\[(\mu_r, T_{r1,3}, r_{1,3}, T_{r2,3}, r_{2,3}, T_{r3,3}, r_{3,3}, T_{r4,3}, r_{4,3})\]

Yield strength, temperatures and reduction factors:

\[(\sigma_y, T_{r1,4}, r_{1,4}, T_{r2,4}, r_{2,4}, T_{r3,4}, r_{3,4}, T_{r4,4}, r_{4,4})\]

Strain hardening coefficient, temperatures and reduction factors:

\[(\mu, T_{r1,5}, r_{1,5}, T_{r2,5}, r_{2,5}, T_{r3,5}, r_{3,5}, T_{r4,5}, r_{4,5})\]

**Application**

Requires the specification of the compressive strength, the peak compressive strain, the limit compressive strain at zero stress, the thermal strain and their variations with temperature. Note that \(r_2\) and \(r_3\) can be greater than 1.

**Restrictions**

Can be used to define material properties for joint element jbc2.
<table>
<thead>
<tr>
<th><strong>Description</strong></th>
<th>Elastic isotropic material model with thermal strains.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>No. of properties</strong></td>
<td>3</td>
</tr>
<tr>
<td><strong>Properties</strong></td>
<td>Young's modulus ( (E) )</td>
</tr>
<tr>
<td></td>
<td>Possion’s ratio ( (\nu) )</td>
</tr>
<tr>
<td></td>
<td>[ Coefficient of thermal expansion ( (\alpha) ) ]</td>
</tr>
<tr>
<td><strong>Application</strong></td>
<td>Can be used for 1D, 2D and 3D elements.</td>
</tr>
</tbody>
</table>
**Description**
Biaxial/triaxial elasto-plastic material model with *isotropic* strain-hardening and material rate sensitivity.

**No. of properties**
9

**Properties**
- Young's modulus \(( E )\)
- Possion’s ratio \(( \nu )\)
- Yield strength \(( \sigma_y )\)
- Strain-hardening parameter \(( \mu )\)
- Plastic strain at onset of hardening \(( \varepsilon_h )\)
- Features flag \(( m )\)
- Plastic strain at ultimate strength \(( \varepsilon_m )\)
- Rate-sensitivity parameter (1) \(( S, q )\)
- Rate-sensitivity parameter (2) \(( \dot{\varepsilon}_*, D )\)

**Application**
Can be used for 1D, 2D and 3D elements

Features flag takes the following values:
- \( m = 0 \): linear hardening without rate sensitivity (Default)
- \( m = 1 \): quadratic hardening with an ultimate strength limit
- \( m = 2 \): same as \(( m = 1 )\) with Malvern rate sensitivity
- \( m = 3 \): same as \(( m = 1 )\) with Cowper-Symonds rate sensitivity.

Ultimate strength is defined for models \( m=1,2,3 \) by:
\[
\sigma_u = \sigma_y + \frac{\mu E}{1-\mu} \left( \varepsilon_m - \varepsilon_h \right)
\]

Only default model \(( m = 0 )\) is applicable to 1D.

Malvern rate sensitivity is defined by:
\[
\text{Overstress} = S \log \left( 1 + \frac{\dot{\varepsilon}_p}{\dot{\varepsilon}_*} \right)
\]

Cowper-Symonds rate sensitivity is defined by:
\[
\text{Overstress} = \sigma_y \left( \frac{\dot{\varepsilon}_p}{D} \right)^{1/q}
\]
Material model \textit{bnsi} (m=0)

Material model \textit{bnsi} (m=1,2,3)
Description
Biaxial/triaxial elasto-plastic material model with *kinematic* strain-hardening and material rate sensitivity.

No. of properties
9

Properties
- Young's modulus $(E)$
- Possion’s ratio $(\nu)$
- Yield strength $(\sigma_y)$
- Strain-hardening parameter $(\mu)$
- Plastic strain at onset of hardening $(\varepsilon_h)$
- [ Features flag $(\text{m})$:
  - Plastic strain at ultimate strength $(\varepsilon_m)$
  - Rate-sensitivity parameter (1) $(\text{S, q })$
  - Rate-sensitivity parameter (2) $(\dot{\varepsilon}_*, D )$ ]

Application
Can be used for 1D, 2D and 3D elements.

Features flag takes the following values:
- $m = 0$: linear hardening without rate sensitivity (Default)
- $m = 1$: quadratic hardening with an ultimate strength limit
- $m = 2$: same as $(m = 1)$ with Malvern rate sensitivity
- $m = 3$: same as $(m = 1)$ with Cowper-Symonds rate sensitivity.

Ultimate strength is defined for models $m=1,2,3$ by:
\[
\sigma_u = \sigma_y + \frac{\mu E (\varepsilon_m - \varepsilon_h)}{1 - \mu} \frac{2}{2}
\]

Only default model $(m = 0)$ is applicable to 1D.

Malvern rate sensitivity is defined by:
\[
\text{Overstress} = S \log \left( 1 + \frac{\dot{\varepsilon}_p}{\dot{\varepsilon}_*} \right)
\]

Cowper-Symonds rate sensitivity is defined by:
\[
\text{Overstress} = \sigma_y \left( \frac{\dot{\varepsilon}_p}{D} \right)^{1/q}
\]
Material model bnsk \((m=0)\)

Material model bnsk \((m=1,2,3)\)
Description
Triaxial elasto-plastic material model with *kinematic* strain-hardening and elevated temperature effects.

No. of properties
30

Properties
Young's modulus and temperatures:
\((E_0, E_2, T_1, T_2, T_3)\)

Yield strength and temperatures
\((\sigma_{y0}, \sigma_{y2}, T_1, T_2, T_3)\)

Plastic strain at onset of hardening
\((\varepsilon_{h0}, \varepsilon_{h2}, T_1, T_2, T_3)\)

Strain-hardening parameter
\((\mu_0, \mu_2, T_1, T_2, T_3)\)

Poisson’s ratio and temperatures:
\((\nu_0, \nu_1, \nu_2, T_1, T_2)\)

Thermal strain and temperatures
\((\varepsilon_{th1}, \varepsilon_{th3}, T_1, T_2, T_3)\)

Application
3D brick elements
Material model $tpth$ (Cont’d...)
Material model *tpth*
**Description**  
Advanced material model for coated fabrics.

**No. of properties**  
19

**Properties**

<table>
<thead>
<tr>
<th>Property</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Half the wavelength of the warp yarn</td>
<td>$d_{01}$</td>
</tr>
<tr>
<td>Half the wavelength of the weft yarn</td>
<td>$d_{02}$</td>
</tr>
<tr>
<td>Half the thickness of the warp yarn</td>
<td>$T_{01}$</td>
</tr>
<tr>
<td>Half the thickness of the weft yarn</td>
<td>$T_{02}$</td>
</tr>
<tr>
<td>Crimp height</td>
<td>$Z_{01}$</td>
</tr>
<tr>
<td>Half the width of the warp yarn</td>
<td>$b_{01}$</td>
</tr>
<tr>
<td>Half the width of the weft yarn</td>
<td>$b_{02}$</td>
</tr>
<tr>
<td>Linear term material property for yarn elements</td>
<td>$E_{A1}$</td>
</tr>
<tr>
<td>Cubic term material property for yarn elements</td>
<td>$h_{1}$</td>
</tr>
<tr>
<td>Linear term material property for crushing elements</td>
<td>$E_{A2}$</td>
</tr>
<tr>
<td>Cubic term material property for crushing elements</td>
<td>$h_{2}$</td>
</tr>
<tr>
<td>Material property for unloading response of crushing elements</td>
<td>$E_{AC}$</td>
</tr>
<tr>
<td>Stiffness term for coating material</td>
<td>$K_{C}$</td>
</tr>
<tr>
<td>Poisson’s ratio for coating material</td>
<td>$\mu$</td>
</tr>
<tr>
<td>Shear stiffness of coated fabric</td>
<td>$G$</td>
</tr>
<tr>
<td>$E_{11}$ and $E_{22}$ material properties for simple material model</td>
<td>$E_{11} , E_{22}$</td>
</tr>
<tr>
<td>$E_{12}$ and $E_{21}$ material properties for simple material model</td>
<td>$E_{11} , E_{22}$</td>
</tr>
<tr>
<td>Number of step reductions used in material models</td>
<td>$N$</td>
</tr>
<tr>
<td>Key allowing friction to be included or not</td>
<td>$k$</td>
</tr>
</tbody>
</table>

**Application**

Tensioned fabric structures modelled with membrane elements

The yarn elements axial force is given by:

$$F_A = E_{A1} \varepsilon_A + E_{A1} h_1 \varepsilon_A^3$$

The yarn crushing elements force is given by:

$$F_C = E_{A2} \varepsilon_C + E_{A2} h_2 \varepsilon_C^3$$
Material model \textit{tfsI} (Cont’d...)
Unstrained cross section of warp yarn

Unstrained cross section of weft yarn

*Material model tfs1*
Chapter 4. JOINT ELEMENT CURVES

This section describes the force-displacement curves available in ADAPTIC for use by joint elements. Each curve is referred to by a unique name, displayed at the top of the following pages, and requires the specification of a number of parameters.
**lin**

<table>
<thead>
<tr>
<th><strong>Description</strong></th>
<th>Linear elastic curve type.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Parameters</strong></td>
<td>$k_0$</td>
</tr>
<tr>
<td><strong>Characteristics</strong></td>
<td>Linear elastic curve.</td>
</tr>
<tr>
<td><strong>Application</strong></td>
<td>Elastic joint action characteristics.</td>
</tr>
<tr>
<td><strong>Restrictions</strong></td>
<td></td>
</tr>
</tbody>
</table>

![Force-displacement curve lin](image)
**smtr**

**Description**
Trilinear symmetric elasto-plastic curve type.

**Parameters**
k₀, d₀, k₁, d₁ & k₂, specified in this order.

**Characteristics**
Trilinear symmetric elasto-plastic curve.
Unloading is performed kinematically to the extension of the second branch of the curve.

**Application**
Elasto-plastic joint action.

**Restrictions**
k₀ and k₁ must be positive.
k₁ & k₂ must not be more than k₀.

---

**Force-displacement curve smtr**
Description: Trilinear asymmetric elasto-plastic curve type.

Parameters: \((k_0, d_0, k_1, d_1, k_2)^+ \) & \((k_0, d_0, k_1, d_1, k_2)^-\) specified in this order.

Characteristics: Trilinear asymmetric elasto-plastic curve.
Unloading is performed kinematically to the extension of the second branch of the reloading curve.

The following parameters represent a curve with zero resistance until a specific negative displacement \(-D\) is achieved:
\((?, 0, 0, ?, 0, 0, -D, ?)\)

Restrictions: \(k_0\) and \(k_1\) must be positive. \(k_1\) & \(k_2\) must not be more than \(k_0\) for the positive and negative displacement regions.

Force-displacement curve astr
**rigid**

**Description**
Rigid curve type.

**Parameters**
None.

**Characteristics**
Rigid curve.

**Application**
Constrains a local freedom to zero.
Avoids numerical problems that can occur with the **lin** curve type using a large stiffness.

**Restrictions**

---

*Force-displacement curve rigid*
**contact**

<table>
<thead>
<tr>
<th><strong>Description</strong></th>
<th>Contact curve type.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Parameters</strong></td>
<td>( d_0^- ) &amp; ( d_0^+ ).</td>
</tr>
<tr>
<td><strong>Characteristics</strong></td>
<td>Gap-contact curve, with a gap between ( d_0^- ) and ( d_0^+ ).</td>
</tr>
<tr>
<td><strong>Application</strong></td>
<td>Modelling of gaps with arbitrary lower/upper limits.</td>
</tr>
<tr>
<td><strong>Restrictions</strong></td>
<td></td>
</tr>
</tbody>
</table>

*Force-displacement curve* **contact**
plastic

**Description**  Plastic curve type.

**Parameters**  \( F^-_0 \) & \( F^+_0 \).

**Characteristics**  Rigid plastic curve, with plastic limits \( F^-_0 \) & \( F^+_0 \).

**Application**  Modelling of rigid response with arbitrary lower/upper plastic limits.

**Restrictions**

---

*Force-displacement curve plastic*

---
**radcont**

<table>
<thead>
<tr>
<th><strong>Description</strong></th>
<th>Radial contact curve.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Parameters</strong></td>
<td>((d_v^− &amp; d_v^+)) or ((d_w^− &amp; d_w^+)).</td>
</tr>
<tr>
<td><strong>Characteristics</strong></td>
<td>Coupled gap-contact curve between local (v) and (w) freedoms. Elliptical gap.</td>
</tr>
<tr>
<td><strong>Application</strong></td>
<td>Contact between concentric circular tubular members, for which the gap is defined by a circle.</td>
</tr>
<tr>
<td><strong>Restrictions</strong></td>
<td>Element type <strong>jel3</strong>. To be used simultaneously for local (v) and (w) freedoms.</td>
</tr>
</tbody>
</table>

*Contact gap for curve radcont*
**pzshm**

<table>
<thead>
<tr>
<th><strong>Description</strong></th>
<th>Smooth Hysteretic model for the panel zone response developed by Kim and Engelhardt [1].</th>
</tr>
</thead>
</table>
| **Parameters**  | Specified in this order: Ke = Stiffness of the elastic branch  
|                 | My = Yielding moment  
|                 | K1 = Stiffness of the 1st post elastic branch  
|                 | M1 = Moment at the end of the 1st post elastic branch  
|                 | K2 = Stiffness of the 2nd post elastic branch  
|                 | M2 = Moment at the end of the 2nd post elastic branch  
|                 | K3 = Stiffness of the 3rd post elastic branch  
|                 | Mcf = Reference Moment for the column flange  
|                 | Ur = Ultimate rotation  
|                 | CSI = Csi Parameter for the steady loops 1.1:1.2. |
| **Characteristics** | Smooth Hysteretic model with cyclic hardening, softening and relaxation. See reference [1] for a complete description of the model and it's formulation. |
| **Application**  | Beam to column welded joint modelling (as a rotational spring)  
|                 | Panel zone Modelling (as an axial spring). |
| **Restrictions** | All parameters must be positive with: K3<K2<K1<Ke  
|                 | M2>M1>My |
Inelastic curve

$\alpha \cdot My$

$Ke$

Moment

Bound Line

Ultimate rotation

Rotation

Inelastic curve

$Kpbl$

$My$

$M1$

$K1$

$M2$

$K2$

Forcedisacement curve $pzshm$
Polygonal Hysteretic model for the equivalent T-stub developed by Clemente et al. [1].

Parameters

Specified in this order:
- $K_e$ = Stiffness of the elastic branch
- $F_y$ = Yielding force
- $K_1$ = Stiffness of the 1st post elastic branch
- $F_1$ = Force at the end of the 1st post elastic branch
- $K_2$ = Stiffness of the 2nd post elastic branch
- $U_d$ = Ultimate displacement
- $K_c$ = Compression stiffness
- $\gamma$ = 1st strength degradation parameter
- $\delta$ = 2nd strength degradation parameter
- $\Delta u_m$ = Monotonic ultimate displacement (used only for the strength degradation)
- $\epsilon$ = 3rd strength degradation parameter
- $\alpha$ = Takeda’s stiffness degradation parameter.

Characteristics

Polygonal Hysteretic model with strength and stiffness degradation.

Application

Equivalent T-stub modeling.

Restrictions

All first seven parameters must be positive ($> 0$)
- $0 < K_2 \leq K_1 < K_e$
- $F_1 > F_y > 0$
- $U_d > 0$
- $K_c > 0$

All strength degradation parameters must be non negative ($\geq 0$)
- $1 > \gamma \geq 0$
- $\delta \geq 0$
- $\Delta u_m \geq 0$
- $\epsilon \geq 0$

Takeda’s stiffness degradation parameter must be:
- $1 > \alpha \geq 0$

References

Formulation

Stiffness degradation according to Takeda’s model:

\[ K_{\text{deg}} = \frac{F_{\text{max}}}{K_0} + \alpha \cdot U_p \]

where:
- \( K_0 \) = Initial Elastic Stiffness (Ke)
- \( F_{\text{max}} \) = Maximum Force Experienced
- \( U_{\text{max}} \) = Maximum Displacement
- \( U_p \) = Plastic deformation
- \( \alpha \) = Degradation parameter (0 \( \leq \) \( \alpha \) < 1)

Multi-Parametric Strength Degradation:

\[ \Delta F = F_y \cdot \gamma \cdot \left[ 1 - \left( 1 - \left( \frac{E_p}{E_{\text{um}} + E_p} \right)^\delta \right) \cdot \left( 1 - \left( \frac{U_{\text{max}}}{\Delta_{\text{um}}} \right)^\varepsilon \right) \right] \]

where:
- \( F_y \) = Yielding force
- \( \gamma \) = 1\(^{st}\) strength degradation parameter (0 < \( \gamma \) < 1)
- \( E_p \) = Dissipated energy
- \( E_{\text{um}} \) = Dissipated Energy in a Monotonic Loading
- \( U_{\text{max}} \) = Maximum displacement
- \( \Delta_{\text{um}} \) = Ultimate Displacement in a Monotonic Loading
- \( \delta \) = 2\(^{nd}\) Strength degradation parameter
- \( \varepsilon \) = 3\(^{rd}\) Strength degradation parameter.
Force-displacement curve \textit{tstub}
Polygonal hysteretic model based on the pivot rule proposed by Park et al. [1], modified to prevent stiffness increase in decreasing load cycles [2].

Parameters

Specified in this order:
- $K_{ep}$ = positive elastic branch stiffness
- $F_{yp}$ = positive yielding force
- $K_{pp}$ = second positive branch stiffness
- $F_{pp}$ = force at the end of the second positive branch
- $K_{hp}$ = stiffness of the third positive branch
- $K_{en}$ = negative elastic branch stiffness
- $F_{yn}$ = negative yielding force
- $K_{pn}$ = second negative branch stiffness
- $F_{pn}$ = force at the end of the second negative branch
- $K_{hn}$ = stiffness of the third negative branch
- $U_{up}$ = ultimate positive displacement
- $U_{un}$ = ultimate negative displacement
- $\alpha_1$ = pivot parameter ($\alpha > 1$)
- $\beta_1$ = pivot parameter ($0 < \beta < 1$)
- $\gamma_1$ = positive strength degradation parameter
- $\alpha_2$ = pivot parameter ($\alpha > 1$)
- $\beta_2$ = pivot parameter ($0 < \beta < 1$)
- $\gamma_2$ = negative strength degradation parameter
- $\varepsilon_1$ = positive strength degradation parameter (energy)
- $\varepsilon_2$ = negative strength degradation parameter (energy)
- $U_{mp}$ = positive monotonic ultimate displacement for strength degradation
- $U_{mn}$ = negative monotonic ultimate displacement for strength degradation
- $\delta_1$ = positive strength degradation parameter (displacement)
- $\delta_2$ = negative strength degradation parameter (displacement).

Characteristics

Polygonal Hysteretic model based on the “Pivot Rule” proposed by Park et al. and modified to prevent stiffness increase in decreasing load cycles and using multi-parametric strength degradation.

Application

General symmetric or non-symmetric model with pinching and stiffness degradation.

Restrictions

All stiffness parameters must be positive ($> 0$)
- $0 < K_{hp} < K_{pp} < K_{ep}$
- $0 < K_{hn} < K_{pn} < K_{en}$
Positive forces and displacement must be positive ($> 0$)
- $F_{pp} > F_{yp} > 0$
- $U_{up} > 0$
Negative forces and displacement must be negative ($< 0$)
Fpn<Fyn<0
Uun<0

Pivot rule parameters must be:
\( \alpha_1 > 1 \)
\( 0 < \beta_1 < 1 \)
\( \alpha_2 > 1 \)
\( 0 < \beta_2 < 1 \)

Multi-parametric strength degradation parameters must be:
\( 0 \leq \gamma_1 < 1 \): If \( \gamma_1 = 0 \) no strength degradation will occur in the positive range (tension) and \( \varepsilon_1 \), \( U_{mp} \), \( \delta_1 \) will be ignored
\( 0 \leq \gamma_2 < 1 \): If \( \gamma_2 = 0 \) no strength degradation will occur in the negative range (compression) and \( \varepsilon_2 \), \( U_{mp} \), \( \delta_2 \) will be ignored
\( \varepsilon_1 \geq 0 \)
\( \varepsilon_2 \geq 0 \)
\( U_{mp} \geq 0 \): If \( U_{mp} = 0 \) and \( \gamma_1 > 0 \) the \( U_{up} \) value will be used instead of \( U_{mp} \)
\( U_{mn} \leq 0 \): If \( U_{mn} = 0 \) and \( \gamma_2 > 0 \) the \( U_{un} \) value will be used instead of \( U_{mn} \)
\( \delta_1 \geq 0 \)
\( \delta_2 \geq 0 \).

References

Formulation
Multi-Parametric Strength Degradation

\[ \Delta F = F_y \cdot \gamma \left[ 1 - \left( 1 - \left( \frac{E_p}{E_{um} + E_p} \right)^{\varepsilon} \right) \cdot \left( 1 - \left( \frac{u_{max}}{\Delta_{um}} \right)^{\delta} \right) \right] \]

where:
\( F_y \) = Yielding force
\( \gamma \) = 1\textsuperscript{st} strength degradation parameter \((0 < \gamma < 1)\)
\( E_p \) = Dissipated energy
\( E_{um} \) = Dissipated Energy in a Monotonic Loading
\( U_{max} \) = Maximum displacement
\( \Delta_{um} \) = Ultimate Displacement in a Monotonic Loading
\( \varepsilon \) = 2\textsuperscript{nd} Strength degradation parameter
\( \delta \) = 3\textsuperscript{rd} Strength degradation parameter.
Force-displacement curve \textit{pivot}
**Description**

Masonry decoupled pivot model for the equivalent frame modelling of 2D masonry walls.

**Parameters**

Specified in this order:

- \( K_e \) = Stiffness of the elastic branch
- \( \frac{F_y}{V_r} \) = Ratio between the yielding force (or moment) and the shear (or bending) resistance \( V_r \) (or \( M_r \))
- \( K_p \) = Stiffness of the 1st post elastic branch
- \( \frac{F_p}{V_r} \) = Ratio between the force (or moment) at the end of the first post elastic branch and the shear (or bending) resistance \( V_r \) (or \( M_r \))
- \( K_h \) = Stiffness of the 2nd post elastic branch
- \( U_d \) = Ultimate displacement (or rotation)
- \( \alpha \) = Pivot parameter \((\alpha>1)\)
- \( \beta \) = Pivot parameter \((1>\beta>0)\)
- \( \gamma \) = Strength degradation parameter \((0 \leq \gamma < 1)\)
- \( \delta \) = Strength degradation parameter (displacement)
- \( \varepsilon \) = Strength degradation parameter (energy)
- \( U_m \) = Ultimate monotonic displacement
- \( E_{\text{ener}} \) = Ultimate monotonic dissipated energy
- \( V_{r\min} \) = Minimum shear (or bending) resistance
- \( c \) = Coulomb’s mortar coesion
- \( \mu \) = Coulomb’s tangent of the friction angle of the mortar
- \( F_{\text{BT}} \) = Ultimate traction stress of the bricks
- \( D \) = Wall width
- \( T \) = Wall thickness
- \( F_u \) = Ultimate compression stress of the masonry
- \( K \) = Stress distribution factor
- \( F_{tu} \) = Ultimate traction stress of the masonry
- \( b \) = Turnsek’s shape parameter \( b=1.5 \) if \( H/D > 1.5 \), \( b=1 \) if \( H/D < 1 \) or \( b=H/D \) if \( 1<H/D<1.5 \)
- \( \text{cod} \) = strength criteria code

**Characteristics**

Polygonal Hysteretic model based on the “Pivot Rule” proposed by Park and modified to prevent stiffness increase in decreasing load cycles and using multi-parametric strength degradation.

This model also uses a combination of simplified strength criteria to determine the shear (or bending) resistance \( V_r \).

**Formulation**

Multi-Parametric Strength Degradation:

\[
\Delta F = F_y \cdot \gamma \cdot \left[ 1 - \left( 1 - \left( \frac{E_p}{E_{\text{um}} + E_p} \right)^\varepsilon \right)^\delta \right] \cdot \left( 1 - \left( \frac{u_{\text{um}}}{u_{\text{max}}} \right)^\delta \right)
\]

where:

- \( F_y \) = Yielding force
\[ \gamma = 1^{st} \text{ strength degradation parameter} \ (0 < \gamma < 1) \]
\[ \text{Ep} = \text{Dissipated energy} \]
\[ \text{Eum} = \text{Dissipated Energy in a Monotonic Loading} \]
\[ \text{Umax} = \text{Maximum displacement} \]
\[ \Delta u_m = \text{Ultimate Displacement in a Monotonic Loading} \]
\[ \varepsilon = 2^{nd} \text{ Strength degradation parameter} \]
\[ \delta = 3^{rd} \text{ Strength degradation parameter.} \]

Failure due to diagonal cracking of the mortar layers:

\[ V_{rd1} = D \cdot t \cdot \left( c + \mu \frac{N}{D \cdot t} \right) \left( 1 + \frac{M}{V \cdot D} \right) \]

Failure due to diagonal cracking of the bricks:

\[ V_{rd2} = D \cdot t \cdot \frac{f_{bt}}{2.3 \cdot \left( 1 + \frac{M}{V \cdot D} \right)} \cdot \sqrt{1 + \frac{N}{D \cdot t \cdot f_{bt}}} \]

Failure due to base shear distortion:

\[ V_{rd3} = D \cdot t \cdot \left( 1.5 + \mu \frac{N}{D \cdot t} \right) \left( 1 + 3 \cdot c \frac{N}{M} \right) \]

Failure due to bending:

\[ V_{rd4} = \frac{M_{ru}}{H_0} = \frac{N \cdot D}{H_0 \cdot 2} \left( 1 - \frac{N}{k \cdot f_{uk} \cdot D \cdot t} \right) = \frac{N}{2} \cdot \frac{M}{V \cdot D} \left( 1 - \frac{N}{k \cdot f_{uk} \cdot D \cdot t} \right) \]

Failure due to diagonal cracking accordingly to Turnsek and Cacovic criteria:

\[ V_{rd5} = D \cdot t \cdot \frac{f_{mu}}{b} \cdot \sqrt{1 + \frac{N}{D \cdot t \cdot f_{mu}}} \]

Failure due to pure shear:

\[ V_{rd6} = D \cdot t \cdot c \]

where:

\[ H_0 = \frac{M}{V} \] is the distance of the null point in the bending moment diagram from the section that we are looking at (see figure)
\[ D = \text{width of the wall} \]
\[ t = \text{thickness of the wall} \]
\[ N = \text{axial force} \]
\[ V = \text{shear force} \]
$M =$ bending moment
$c, e, \mu =$ parameters that define the strength of the mortar in the Coulomb’s model
$fbt =$ ultimate traction stress of the bricks
$fu =$ ultimate compression stress of the masonry
$k =$ parameter that defines the ratio between the pressure in an equivalent stress distribution and the maximum pressure in the compression zone (usually $k=0.9$, see figure)
$ftu =$ ultimate tensile stress of the masonry
$b =$ Turnsek’s shape parameter: $b=1.5$ if $H/D > 1.5$ or $b=1$ if $H/D < 1$ or $b=H/D$ if $1 < H/D < 1.5$

The shear strength will be computed as follows:

$$V_{rd} = \max(V_{r_{min}}; \min(V_{rd1}; V_{rd2}; V_{rd3}; V_{rd4}; V_{rd5}; V_{rd6}))$$

By means of the strength criteria code (cod) it is possible to specify which strength criteria account for and which strength criteria has to be neglected.

cod is defined as the sum of the exclusion code associated with the strength criteria to neglect:

<table>
<thead>
<tr>
<th>Exc. Code</th>
<th>Strength criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Failure due to diagonal cracking of the mortar layers</td>
</tr>
<tr>
<td>2</td>
<td>Failure due to diagonal cracking of the bricks</td>
</tr>
<tr>
<td>4</td>
<td>Failure due to base shear distortion</td>
</tr>
<tr>
<td>8</td>
<td>Failure due to bending</td>
</tr>
<tr>
<td>16</td>
<td>Failure due to diagonal cracking accordingly to Turnsek and Cacovic criteria</td>
</tr>
<tr>
<td>32</td>
<td>Failure due to pure shear</td>
</tr>
</tbody>
</table>

For instance to exclude the Failure criteria due to pure shear and the Failure criteria due to diagonal cracking of the bricks, cod has to be defined as cod=$32+2=34$ and Vrd will be obtained as follows:

$$V_{rd} = \max(V_{r_{min}}; \min(V_{rd1}; V_{rd2}; V_{rd3}; V_{rd4}; V_{rd5}))$$

If the exclusion code is set to 63 (cod=63) then all strength criteria will be neglected and $V_{rd} = V_{r_{min}}$

Note: to compute the shear strength the model uses the values of the section forces $N, V$ and $M$ at the start of the integration step so to obtain an accurate response the integration step has to be small enough.

**Application**
Modelling of non linear behaviour of 2D masonry walls in the equivalent frame approach.

**Restrictions**
All parameters must be non negative
All stiffness parameters must be positive ($>0$)
0<Kh<Kp<Ke
Force ratios and displacement must be positive (>0)
Fp/Vr>Fy/Vr>0
Ud>0
Pivot rule parameters must be:
\[ \alpha > 1 \]
\[ 0 < \beta < 1 \]
Multi-parametric strength degradation parameters must be:
\[ 0 \leq \gamma < 1 \]
If \( \gamma = 0 \) no strength degradation will occur and \( \varepsilon, U_m, \delta \) will be ignored
\[ U_m \geq 0 \]
If \( U_m = 0 \) and \( \gamma > 0 \) the Ud value will be used instead of \( U_m \)
\[ \delta \geq 0 \]
\[ \varepsilon \geq 0 \]
Turnsek’s shape parameter
\[ 1.5 \geq b \geq 1.0 \]
Exclusion code has to be an integer
\[ 63 \geq cod \geq 0 \]

References
Pivot rule initially proposed in:

Further development of the Pivot hysteretic model can be found in:
Mechanical model for curve masonry

Force-displacement curve masonry
**Description**
Masonry decoupled S-shaped model for the equivalent frame modeling of 2D masonry walls.

**Parameters**
Specified in this order:
- Ke = Stiffness of the elastic branch
- Fy/Vr = Ratio between the yielding force (or moment) and the shear (or bending) resistance Vr (or Mr)
- Kp = Stiffness of the 1st post elastic branch
- Fp/Vr = Ratio between the force (or moment) at the end of the first post elastic branch and the shear (or bending) resistance Vr (or Mr)
- CC = Parameter governing parallelism of branch 5 (or 50 - see img.) to branch 2 (or 20)
- CF = Parameter governing unloading from skeleton curve
- α = Parameter governing stiffness degradation (<1)
- CD = Parameter governing stiffness change after branch 5 (or 50)
- du = Ultimate displacement (or rotation)
- Pmin = Axial compression in masonry strips
- type = Pier (1) or strip (0)
- Fvk0 = Pure shear strength
- B = Base width of the panel
- T = Thickness of the panel
- Fm = Compressive strength of masonry material
- H = Height of the panel
- Ftu = Tensile strength of masonry material
- Free parameter = used for compatibility with masonry tom model
- UltForce = No residual force after collapse (0) – Residual force after collapse (1)
- Upar = Parameter dividing the stiffness of first unloading branch
- UltDisp = Calculate automatically ultimate displacement (0) – Fixed ultimate displacement from input (1)
- Rs = Residual strength

**Characteristics**
Polygonal hysteretic model based on the S-shaped law deduced from literature.
This model also uses a combination of simplified strength criteria to determine the shear (or bending) resistance Vr.

**Formulation**
Stiffness Degradation: linear with the displacement, it depends on factor CK

\[
C_K = \frac{\frac{K_e}{K_e} - 1}{\frac{d_u}{d_{cr}} - 1}
\]
where:

- \( K_u \) = Ultimate stiffness
- \( K_e \) = Elastic stiffness
- \( d_u \) = Ultimate displacement
- \( d_{cr} \) = Displacement at elastic limit

The unloading stiffness at a given displacement is calculated with:

\[
K_d = K_e \left[ 1 + C_K \left( \frac{d_{\text{max}}}{d_{cr}} - 1 \right) \right]
\]

where:

- \( d_{\text{max}} \) = maximum displacement reached
- \( K_d \) = Unloading stiffness

Strength criteria: The model can use any combination of the following simplified strength criteria to determine the shear (or bending) resistance \( V_r \) (or \( M_r \)).

Failure due to rocking:

\[
V_1 = \frac{b}{h_0} N \left( 1 - \frac{N}{0.85 b \cdot t \cdot f_m} \right)
\]

Failure due to sliding:

\[
V_2 = \frac{1.5 b \cdot t \cdot f_{vk0} + 0.4 N}{1 + \frac{3 h_0 \cdot f_{vk0}}{N}}
\]

Failure due to diagonal cracking according to Turnsek-Cacovic criteria:

\[
V_3 = \frac{1.5 f_{td} \cdot b \cdot t}{\xi} \sqrt{1 + \frac{N}{f_{td} \cdot b \cdot t}}
\]

Failure due to pure shear:

\[
V_4 = f_{vk0} \cdot B \cdot T
\]

Failure due to rocking in strips:

\[
V_5 = \frac{h}{b} P_{\text{min}} \left( 1 - \frac{P_{\text{min}}}{0.85 b \cdot t \cdot f_m} \right)
\]

where:

- \( h_0 = \frac{M}{V} \) is the distance of the null point in the bending moment diagram from the section that we are looking at
- \( h \) is the height of the wall
b is the width of the wall
t is the thickness of the wall
N is the axial force
V is the shear force
M is the bending moment
f_{vk0} is the pure shear strength
f_{tu} is the ultimate tensile stress of the masonry
f_{m} is the ultimate compression stress of the masonry
\chi is Turnsek’s shape parameter (=1.5 if H/D >1.5 or =1 if H/D<1 or =H/D otherwise)

The shear strength will be computed as follows:

$$V_{rd} = \min(V_{rd1}, V_{rd2}, V_{rd3})$$

For strips the strength is the pure shear strength for the shear force, and the rocking strength (calculated on P_{min}) for bending moment.

Note: to compute the shear strength the model uses the values of the section forces N, V and M at the start of the integration step so to obtain an accurate response the integration step has to be small enough.

**Application**

Modelling of non linear behaviour of 2D masonry walls in the equivalent frame approach.

**Restrictions**

All parameters must be non negative.
All stiffness parameters must be positive (>0)
0<K_{p}<K_{e}
Force ratios and displacement must be positive (>0)
F_{p}/V_{r}>F_{y}/V_{r}>0
d_{u}>0
Degradations parameters must be:
\alpha<1
\beta<1
and U_{par}>1

**References**

Rinaldin, G.
“Seismic analysis of masonry structures through non-linear analysis”
Graduation Thesis, supervisor Prof. Ing. C. Amadio,
University of Trieste 2009 (in Italian)
Force-displacement curve ssh
### Description
Masonry decoupled Tomazevic’s model for the equivalent frame modeling of 2D masonry walls.

### Parameters
Specified in this order:
- $K_e$: Stiffness of the elastic branch
- $F_y/V_r$: Ratio between the yielding force (or moment) and the shear (or bending) resistance $V_r$ (or $M_r$)
- $K_p$: Stiffness of the 1st post elastic branch
- $F_p/V_r$: Ratio between the force (or moment) at the end of the first post elastic branch and the shear (or bending) resistance $V_r$ (or $M_r$)
- $K_h$: Stiffness of the 2nd post elastic branch
- $C_F$: Parameter governing unloading from skeleton curve
- $\alpha$: Parameter governing stiffness degradation ($<1$)
- $\beta$: Parameter governing strength degradation ($<1$)
- $d_u$: Ultimate displacement (or rotation)
- $P_{min}$: Axial compression in masonry strips
- $\text{type}$: Pier (1) or strip (0)
- $F_{vk0}$: Pure shear strength
- $B$: Base width of the panel
- $T$: Thickness of the panel
- $F_m$: Compressive strength of masonry material
- $H$: Height of the panel
- $F_{tu}$: Tensile strength of masonry material
- $U_F\%$: Percentage of the maximum force after which panel collapse, used to calculate ultimate displacement automatically
- $\text{UltForce} = \text{No residual force after collapse (0)} - \text{Residual force after collapse (1)}$
- $U_{par}$: Parameter dividing the stiffness of first unloading branch
- $\text{UltDisp} = \text{Calculate automatically ultimate displacement (0)} - \text{Fixed ultimate displacement from input (1)}$
- $R_s$: Residual strength

### Characteristics
Polygonal hysteretic model based on the Tomazevic’s proposal (1996). This model also uses a combination of simplified strength criteria to determine the shear (or bending) resistance $V_r$.

### Formulation
Stiffness Degradation: linear with the displacement, it depends on factor $C_K$

$$C_K = \frac{\frac{K_u}{K_e} - 1}{\frac{d_u}{d_{cr}} - 1}$$

where:
- $K_u$ = Ultimate stiffness
Ke = Elastic stiffness
du = Ultimate displacement
dcr = Displacement at elastic limit

The unloading stiffness at a given displacement is calculated with:

\[ K_d = K_e \left[ 1 + C_k \left( \frac{d_{max}}{d_{cr}} - 1 \right) \right] \]

where:
\[ d_{max} = \text{maximum displacement reached} \]
\[ K_d = \text{Unloading stiffness} \]

Strength Degradation: it is taken into account by considering an additional displacement related to the arrival in the skeleton curve inelastic branches.

\[ \delta d^+ = \beta \left( \frac{dE^+}{H_{max}} \right) \]

or, for negative increments:

\[ \delta d^- = \beta \left( \frac{dE^-}{H_{max}} \right) \]

where:
\[ dE^+/\- = \text{dissipated energy in a cycle} \]
\[ H_{max} = \text{maximum force reached by the skeleton curve} \]
\[ \beta = \text{strength degradation parameter} \]
\[ \delta d^+/\- = \text{displacement increment} \]

Strength criteria: The model can use any combination of the following simplified strength criteria to determine the shear (or bending) resistance \( V_r \) (or \( M_r \)).

Failure due to rocking:

\[ V_1 = b \frac{N}{h_0} \left( 1 - \frac{N}{0.85 \cdot b \cdot t \cdot f_{w}} \right) \]

Failure due to sliding:

\[ V_2 = \frac{1.5 b \cdot t \cdot f_{ak,0} + 0.4 N}{1 + \frac{3 h_0 \cdot t \cdot f_{ak,0}}{N}} \]

Failure due to diagonal cracking according to Turnsek-Cacovic criteria:

\[ V_3 = \frac{1.5 f_{ld} \cdot b \cdot t}{\xi} \left( 1 + \frac{N}{f_{ld} \cdot b \cdot t} \right) \]
Failure due to pure shear:

\[ V_4 = f_{vk0} \cdot B \cdot T \]

Failure due to rocking in strips:

\[ V_5 = \frac{h}{b} P_{\text{min}} \left( 1 - \frac{P_{\text{min}}}{0.85b \cdot t \cdot f_m} \right) \]

where:

- \( h_0 = M/V \) is the distance of the null point in the bending moment diagram from the section that we are looking at
- \( h \) is the height of the wall
- \( b \) is the width of the wall
- \( t \) is the thickness of the wall
- \( N \) is the axial force
- \( V \) is the shear force
- \( M \) is the bending moment
- \( f_{vk0} \) is the pure shear strength
- \( f_{tu} \) is the ultimate tensile stress of the masonry
- \( f_m \) is the ultimate compression stress of the masonry
- \( \chi \) is Turnsek’s shape parameter (=1.5 if \( H/D > 1.5 \) or =1 if \( H/D < 1 \) or =\( H/D \) otherwise)

The shear strength will be computed as follows:

\[ V_{rd} = \min(V_{rd1}, V_{rd2}, V_{rd3}) \]

For strips the strength is the pure shear strength for the shear force, and the rocking strength (calculated on \( P_{\text{min}} \)) for bending moment.

Note: to compute the shear strength the model uses the values of the section forces \( N,V \) and \( M \) at the start of the integration step so to obtain an accurate response the integration step has to be small enough.

**Application**

Modelling of non linear behaviour of 2D masonry walls in the equivalent frame approach.

**Restrictions**

All parameters must be non negative.
All stiffness parameters must be positive (>0)
\[ 0 < K_h < K_p < K_e \]
Force ratios and displacement must be positive (>0)
\[ F_p/V_r > F_y/V_r > 0 \]
\[ \Delta u > 0 \]
Degradations parameters must be:
\[ \alpha < 1 \]
\[ \beta < 1 \]
and $U_{par} \geq 1$

**References**

“Seismic Behaviour of Masonry Walls: Modeling of Hysteretic Rules”  
Journal of Structural Engineering, September 1996, pp.1048-1054

Rinaldin, G.  
“Seismic analysis of masonry structures through non-linear analysis”  
Graduation Thesis, supervisor Prof. Ing. C. Amadio, University of Trieste 2009 (in Italian)
Chapter 5. CROSS-SECTION TYPES

The ADAPTIC library also includes a number of pre-defined cross-section types described briefly below:

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>rss</td>
<td>Rectangular solid section</td>
</tr>
<tr>
<td>chs</td>
<td>Circular hollow section</td>
</tr>
<tr>
<td>isec</td>
<td>General purpose I- or T-section</td>
</tr>
<tr>
<td>pnci</td>
<td>Partially encased composite I-section</td>
</tr>
<tr>
<td>fncl</td>
<td>Fully encased composite I-section</td>
</tr>
<tr>
<td>recs</td>
<td>Reinforced concrete column section</td>
</tr>
<tr>
<td>rects</td>
<td>Reinforced concrete T-section</td>
</tr>
<tr>
<td>flxw</td>
<td>Reinforced concrete flexural wall section</td>
</tr>
</tbody>
</table>

The degree of accuracy in modelling the above sections depends on the formulation utilising the cross-section.

Cubic formulations (cbp2, cbp3) provide detailed modelling of a cross-section through its discretisation into a number of areas where the uniaxial material response is monitored according to the previous material models.

Plastic-hinge formulations (gph2, gph3) derive a plastic interaction surface between the cross-sectional bending moments and axial force, which is combined with the associated flow rule to provide approximate modelling of steel members. The plastic hinge capability is not extended to reinforced concrete sections.

Elastic formulations utilise constant elastic rigidities for bending, axial and torsional actions derived for given cross-sectional configurations. As such they are only accurate for steel members, since they do not account for concrete cracking.

This section describes the cross-section types available in ADAPTIC. Each type is referred to by a unique name, displayed at the top of the following pages, and requires the specification of a number of materials and dimensions in the order indicated.
Description: Rectangular solid section.
No. of materials: 1
No. of dimensions: 2
Dimensions:
- Width (b)
- Depth (d)
Application: Rectangular solid sections of uniform material.

Section rss
**chs**

<table>
<thead>
<tr>
<th>Description</th>
<th>Thin circular hollow section.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>No. of materials</strong></td>
<td>1</td>
</tr>
<tr>
<td><strong>No. of dimensions</strong></td>
<td>2</td>
</tr>
</tbody>
</table>

**Dimensions**

- Outer diameter \( (D) \)
- Tube thickness \( (t) \)

**Application**

Circular hollow sections of uniform material.

---

*Section chs*
**Description**  General purpose I- or T-section.

**No. of materials**  1

**No. of dimensions**  6

**Dimensions**
- Bottom flange width $(b_{f1})$
- Bottom flange thickness $(t_{f1})$
- Top flange width $(b_{f2})$
- Top flange thickness $(t_{f2})$
- Web depth $(d_w)$
- Web thickness $(t_w)$

**Application**  I- or T-sections of uniform material.
Section $isec$
**oplt**

**Description**
General purpose thin-walled open cross-section.

**No. of materials**
1

**No. of dimensions**
$4 \times s$, where $s$ is the number of cross-section segments.

**Dimensions**
For each segment $(i)$ in order:

- Width $(b_i)$
- Thickness $(t_i)$
- Angle in degrees $(\theta_i)$
- Number of forking segments at end $(n_i)$

**Application**
Open thin-walled I-, T- or C-sections of uniform material.

---

*Section oplt (illustration for cross-section with 5 segments)*
**Description**  
Partially encased composite I-section.

**No. of materials**  
4, specified in this order:
- I-section
- Unconfined region
- Partially confined region
- Fully confined region

**No. of dimensions**  
6

**Dimensions**
- Flange width  \( (b_f) \)
- Flange thickness  \( (t_f) \)
- Web depth  \( (d_w) \)
- Web thickness  \( (t_w) \)
- Unconfinement ratio  \( (r_{uc})^* \)
- Partial confinement ratio  \( (r_{pc})^* \)

**Application**  
Partially encased composite I-sections, with three different concrete materials to represent confinement effects.

\[(*) \quad r_{uc} = 2 \frac{t_{uc}}{(b_f - t_w)} \quad \& \quad r_{pc} = 2 \frac{t_{pc}}{(b_f - t_w)}, \text{ where } t_{uc} \text{ and } t_{pc} \text{ are the thickness of the unconfined and confined parts of the section, respectively.} \]
Section pnci
**fnci**

**Description**
Fully-encased composite I-section.

**No. of materials**
4, specified in this order:
- I-section
- Unconfined region
- Partially confined region
- Fully confined region

**No. of dimensions**
9

**Dimensions**
- Flange width \( (b_f) \)
- Flange thickness \( (t_f) \)
- Web depth \( (d_w) \)
- Web thickness \( (t_w) \)
- Partial confinement ratio \( (r_{pc})^* \)
- Stirrup width \( (b_{c1}) \)
- Section width \( (b_{c2}) \)
- Stirrup depth \( (h_{c1}) \)
- Section depth \( (h_{c2}) \)

**Application**
Fully encased composite I-sections, with three different concrete materials to represent confinement effects.

\[ (*) \] \( r_{pc} = 2 \frac{t_{pc}}{b_f - t_w} \), where \( t_{pc} \) is the depth of the partially confined part beyond the section flange.
Section $f_{nci}$
<table>
<thead>
<tr>
<th>Description</th>
<th>Flexural wall section.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>No. of materials</strong></td>
<td>4, specified in this order:</td>
</tr>
<tr>
<td></td>
<td>Reinforcement</td>
</tr>
<tr>
<td></td>
<td>Unconfined region</td>
</tr>
<tr>
<td></td>
<td>Partially confined region</td>
</tr>
<tr>
<td></td>
<td>Fully confined region</td>
</tr>
<tr>
<td><strong>No. of dimensions</strong></td>
<td>2D analysis:</td>
</tr>
<tr>
<td></td>
<td>$5 + 2$ (Reinforcement layers on one side of z-axis)</td>
</tr>
<tr>
<td></td>
<td>3D analysis:</td>
</tr>
<tr>
<td></td>
<td>$5 + 3$ (Reinforcement bars in one y-z quadrant)</td>
</tr>
<tr>
<td><strong>Dimensions</strong></td>
<td>Wall width $B$</td>
</tr>
<tr>
<td></td>
<td>Confined width $b$</td>
</tr>
<tr>
<td></td>
<td>Wall thickness $T$</td>
</tr>
<tr>
<td></td>
<td>Confined thickness $t$</td>
</tr>
<tr>
<td></td>
<td>Depth of fully confined region $C$</td>
</tr>
<tr>
<td><strong>Application</strong></td>
<td>Symmetric flexural walls.</td>
</tr>
<tr>
<td><strong>Restrictions</strong></td>
<td>Section is assumed symmetric about the y-z origin, hence only one side of the reinforcement need to be specified.</td>
</tr>
</tbody>
</table>
Section $f_{lxw}$
### Description
Reinforced concrete column section.

### No. of materials
3, specified in this order:
- Reinforcement
- Unconfined region
- Confined region

### No. of dimensions
2D analysis:
\[ 4 + 2 \] (Reinforcement layers on one side of z-axis)

3D analysis:
\[ 4 + 3 \] (Reinforcement bars in one y-z quadrant)

### Dimensions
<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section depth</td>
<td>( h_{c1} )</td>
</tr>
<tr>
<td>Stirrup depth</td>
<td>( h_{c2} )</td>
</tr>
<tr>
<td>Section width</td>
<td>( b_{c1} )</td>
</tr>
<tr>
<td>Stirrup width</td>
<td>( b_{c2} )</td>
</tr>
</tbody>
</table>

2D analysis:
\[ (A_i, y_i) \] for each reinforcement layer on one side of the z-axis.

3D analysis:
\[ (A_i, y_i, z_i) \] for each reinforcement bar in the positive y-z quadrant.

### Application
Symmetric reinforced concrete columns.

### Restrictions
Section is assumed symmetric about the y-z origin, hence only one side of the reinforcement need to be specified.
Section \textit{recs}
<table>
<thead>
<tr>
<th><strong>Description</strong></th>
<th>Reinforced concrete T-section.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>No. of materials</strong></td>
<td>3, specified in this order:</td>
</tr>
<tr>
<td></td>
<td>Reinforcement</td>
</tr>
<tr>
<td></td>
<td>Unconfined region</td>
</tr>
<tr>
<td></td>
<td>Confined region</td>
</tr>
<tr>
<td><strong>No. of dimensions</strong></td>
<td>2D analysis:</td>
</tr>
<tr>
<td></td>
<td>$8 + 2$ (Reinforcement layers)</td>
</tr>
<tr>
<td></td>
<td>3D analysis:</td>
</tr>
<tr>
<td></td>
<td>$8 + 3$ (Reinforcement bars on one side of y-axis)</td>
</tr>
<tr>
<td><strong>Dimensions</strong></td>
<td>Slab thickness ($D_r$)</td>
</tr>
<tr>
<td></td>
<td>Beam depth ($D_w$)</td>
</tr>
<tr>
<td></td>
<td>Confined depth in slab ($d_r$)</td>
</tr>
<tr>
<td></td>
<td>Confined depth in beam ($d_w$)</td>
</tr>
<tr>
<td></td>
<td>Slab effective width ($B_r$)</td>
</tr>
<tr>
<td></td>
<td>Beam width ($B_w$)</td>
</tr>
<tr>
<td></td>
<td>Confined width in slab ($b_r$)</td>
</tr>
<tr>
<td></td>
<td>Confined width in beam ($b_w$)</td>
</tr>
<tr>
<td><strong>Application</strong></td>
<td>Modelling of R/C beams with an effective slab width.</td>
</tr>
<tr>
<td><strong>Restrictions</strong></td>
<td>Symmetric section about the y-axis.</td>
</tr>
<tr>
<td></td>
<td>(*$d_i$ is the distance of reinforcement layer/bar (i) from the bottom fibre of the section.)</td>
</tr>
</tbody>
</table>
Section \textit{rcs}
**rcgs**

<table>
<thead>
<tr>
<th><strong>Description</strong></th>
<th>General purpose reinforced concrete I- or T-section.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>No. of materials</strong></td>
<td>2, specified in this order:</td>
</tr>
<tr>
<td></td>
<td>Reinforcement</td>
</tr>
<tr>
<td></td>
<td>Concrete</td>
</tr>
<tr>
<td><strong>No. of dimensions</strong></td>
<td>2D analysis:</td>
</tr>
<tr>
<td></td>
<td>$6 + 2$ (Reinforcement layers)</td>
</tr>
<tr>
<td><strong>Dimensions</strong></td>
<td>Bottom flange width $(b_{f1})$</td>
</tr>
<tr>
<td></td>
<td>Bottom flange thickness $(t_{f1})$</td>
</tr>
<tr>
<td></td>
<td>Top flange width $(b_{f2})$</td>
</tr>
<tr>
<td></td>
<td>Top flange thickness $(t_{f2})$</td>
</tr>
<tr>
<td></td>
<td>Web depth $(d_w)$</td>
</tr>
<tr>
<td></td>
<td>Web thickness $(t_w)$</td>
</tr>
<tr>
<td>2D analysis:</td>
<td>$(A_i, d_i^*)$ for each reinforcement layer.</td>
</tr>
<tr>
<td><strong>Application</strong></td>
<td>General reinforced concrete I- or T-sections.</td>
</tr>
<tr>
<td><strong>Restrictions</strong></td>
<td>Symmetric section about the y-axis.</td>
</tr>
<tr>
<td></td>
<td>$(*) d_i$ is the distance of reinforcement layer/bar (i) from the bottom fibre of the section.</td>
</tr>
</tbody>
</table>
Section regs
<table>
<thead>
<tr>
<th><strong>Description</strong></th>
<th>Composite floor slab section</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>No. of materials</strong></td>
<td>4 specified in this order:</td>
</tr>
<tr>
<td></td>
<td>Deck - horizontal</td>
</tr>
<tr>
<td></td>
<td>Deck – inclined on rib sides</td>
</tr>
<tr>
<td></td>
<td>Reinforcement</td>
</tr>
<tr>
<td></td>
<td>Concrete</td>
</tr>
<tr>
<td><strong>No. of dimensions</strong></td>
<td>12</td>
</tr>
<tr>
<td><strong>Dimensions</strong></td>
<td>Depth of cover:</td>
</tr>
<tr>
<td></td>
<td>( t )</td>
</tr>
<tr>
<td></td>
<td>Depth of rib</td>
</tr>
<tr>
<td></td>
<td>( h )</td>
</tr>
<tr>
<td></td>
<td>Rib geometric ratio</td>
</tr>
<tr>
<td></td>
<td>( r )</td>
</tr>
<tr>
<td></td>
<td>Thickness of steel deck</td>
</tr>
<tr>
<td></td>
<td>( t_d )</td>
</tr>
<tr>
<td></td>
<td>Reinforcement area per unit length in local x-direction (spanning in y-direction)</td>
</tr>
<tr>
<td></td>
<td>( t_x )</td>
</tr>
<tr>
<td></td>
<td>Location of reinforcement in x-direction above (+)/below (−) reference mid-plane</td>
</tr>
<tr>
<td></td>
<td>( d_x )</td>
</tr>
<tr>
<td></td>
<td>Reinforcement area per unit length in local y-direction (spanning in x-direction)</td>
</tr>
<tr>
<td></td>
<td>( t_y )</td>
</tr>
<tr>
<td></td>
<td>Location of reinforcement in y-direction above (+)/below (−) reference mid-plane</td>
</tr>
<tr>
<td></td>
<td>( d_y )</td>
</tr>
<tr>
<td></td>
<td>The remaining 4 dimensions are for two additional reinforcement layers in x and y-directions.</td>
</tr>
<tr>
<td><strong>Application</strong></td>
<td>Composite floor slab cross-section consisting of ribbed reinforced concrete acting compositely with trapezoidal steel decking.</td>
</tr>
</tbody>
</table>
Section cslb
<table>
<thead>
<tr>
<th>Description</th>
<th>Thin plate section.</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of materials</td>
<td>1</td>
</tr>
<tr>
<td>No. of dimensions</td>
<td>1</td>
</tr>
<tr>
<td>Dimensions</td>
<td>Plate thickness (t)</td>
</tr>
<tr>
<td>Application</td>
<td>Plate bending and membrane analysis.</td>
</tr>
</tbody>
</table>
Chapter 6. **ELEMENT TYPES**

This section describes the element types available in ADAPTIC. Each type is referred to by a unique name, displayed at the top of the following pages, and requires the specification of a number of entries for its groups, connectivity and other modules.
**cbe2**

**Description**  
Cubic 2D elastic element with uncoupled bending and axial actions.

**Nodes**  
2

**Characteristics**  
Accounts for large nodal displacements, but requires a number of elements to represent a member with significant beam-column action.

**Application**  
Elastic analysis of plane frames

**Restrictions**  
Unable to model concrete cracking.

**Group header**  
sec.name: An identifier referring to one of the cross-sections declared in the sections module.

---

**Element configuration before and after deflection**

**Element forces**

*Configuration and forces in local system of element type cbe2*
**Description**
Cubic elasto-plastic 2D beam-column element.

**Monitoring points**
25 points usually adequate; depends on section type.

**Nodes**
2

**Characteristics**
Geometric and material nonlinearities.

Numerical integration performed over two Gauss points.

A number of monitoring areas used at each Gauss section to monitor material direct stress and strains.

Predicts global member behaviour based on a material stress-strain relationship.

A number of elements per member, usually over 5, must be used for reasonable accuracy in inelastic modelling.

**Application**
Modelling of inelastic members in plane frames.

**Restrictions**

**Group header**
- `sec.name`: An identifier referring to one of the cross-sections declared in the sections module.
- `monitoring.points`: Defines the number of points for monitoring stresses and strains within a cross-section.

---

**Element configuration**
before and after deflection

**Element forces**

*Configuration and forces in local system of element type cbp2*
**qel2**

<table>
<thead>
<tr>
<th><strong>Description</strong></th>
<th>Quartic elastic 2D beam-column element.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nodes</strong></td>
<td>2</td>
</tr>
<tr>
<td><strong>Imperfections</strong></td>
<td>( V_{0.25L}, V_{0.5L}, V_{0.75L} ) can be specified.</td>
</tr>
<tr>
<td><strong>Characteristics</strong></td>
<td>Geometric nonlinearities. Large displacements and beam-column effect of perfect/imperfect members. One element type <em>qel2</em> is usually sufficient to represent the beam-column effect and large displacement response of a whole elastic member.</td>
</tr>
<tr>
<td><strong>Application</strong></td>
<td>Geometric nonlinearities in elastic plane frames.</td>
</tr>
<tr>
<td><strong>Restrictions</strong></td>
<td>Unable to model concrete cracking.</td>
</tr>
<tr>
<td><strong>Group header</strong></td>
<td><code>sec.name</code>: An identifier referring to one of the cross-sections declared in the sections module.</td>
</tr>
</tbody>
</table>

---

**Configuration and forces in local system of element type qel2**
**qph2**

<table>
<thead>
<tr>
<th><strong>Description</strong></th>
<th>Quartic plastic hinge 2D beam-column element with an option for automatic subdivision.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nodes</strong></td>
<td>2</td>
</tr>
<tr>
<td><strong>Subdivision</strong></td>
<td>Automatic subdivision into two elements if a plastic hinge is detected within the element may be requested.</td>
</tr>
<tr>
<td><strong>Imperfections</strong></td>
<td>$V_{0.25L}$, $V_{0.5L}$, $V_{0.75L}$ can be specified.</td>
</tr>
<tr>
<td><strong>Characteristics</strong></td>
<td>Geometric and material nonlinearities. Suitable for members in which the spread of plasticity is not important and the section response is elastic-plastic without strain-hardening. Rotational and axial plastic hinge displacements are allowed at the two ends of the element. One element type qph2 is usually sufficient to model a whole member, and the option of subdivision allows for the case of member buckling.</td>
</tr>
<tr>
<td><strong>Application</strong></td>
<td>Large displacement plastic-hinge analysis of plane frames</td>
</tr>
<tr>
<td><strong>Restrictions</strong></td>
<td>Not applicable to reinforced concrete or composite members.</td>
</tr>
</tbody>
</table>
| **Group header** | sec.name: An identifier referring to one of the cross-sections declared in the sections module. Subdivision: Gives the option for automatic subdivision plastic hinge elements:  
  
  $t | true$ consider element subdivision  
  $f | false$ ignore element subdivision |

---


Element configuration before and after deflection

Element forces

*Configuration and forces in local system of element type qph2*
### Description
Quartic elastic 2D beam-column element utilising automatic mesh refinement.

### Subdivision pattern
Relative lengths in ratio form of zones where inelasticity is checked for automatic mesh refinement.

### Nodes
2

### Imperfections
$V_{0.25L}$, $V_{0.5L}$, $V_{0.75L}$ can be specified

### Characteristics
Geometric and material nonlinearities.

Large displacement and beam-column effect of perfect/imperfect members.

One element type $\textit{qdp2}$ is usually sufficient to represent a whole member.

Element $\textit{qdp2}$ subdivides into elements $\textit{cbp2}$, specified under $\textit{cbp2.grp.name}$, if inelasticity is detected in the zones defined by the subdivision pattern $\textit{pat.name}$.

Accuracy increases with the number of sub-elements type $\textit{cbp2}$ specified in the subdivision pattern.

After subdivision, elements $\textit{cbp2}$ are inserted in the inelastic zones, while the elastic zones are kept as element type $\textit{qdp2}$.

### Application
Adaptive modelling of inelastic members in plane frames.

### Restrictions
Applies only to cross-sections with materials $\textit{stl1}$, $\textit{stl2}$ & $\textit{stl3}$.

### Group header
$\textit{cbp2.grp.name}$: Specifies the group identifier of elements type $\textit{cbp2}$ used in automatic mesh refinement.

$\textit{pat.name}$: An identifier referring to a subdivision pattern in the $\textit{patterns}$ module.
Element configuration before and after deflection

Element forces

Configuration and forces in local system of element type qdp2
**Ink2**

**Description**  
2D link element with discrete axial/rotational springs.

**Nodes**  
2

**Characteristics**  
Geometric nonlinearity.

3 independent spring stiffnesses, each taking either a constant numerical value or a rigid value.

**Application**  
Rigid link.  
Elastic bar with pinned ends.

**Restrictions**  

**Group header**  
`stiffness.parameters`: numerical or `rigid` values for each of the spring stiffnesses, $k_{θ1}$, $k_{θ2}$ and $k_Δ$, in this order.

---

**Element configuration** before and after deflection  

**Element forces**

*Configuration and forces in local system of element type Ink2*
**Description**
Linear 2D nodal spring element.

**Stiffness parameters**
Two global translational stiffnesses and one rotational stiffness can be specified in the following order:

\[ K_x, K_y, K_{zz} \]

**Nodes**
1

**Characteristics**
Models elastic boundaries for plane frame analysis.
Requires the definition of only one node, with the other node assumed fixed against translation and rotation.

**Application**
Plane frame boundaries.

**Restrictions**
Cannot be used to join two elements. For that purpose use jel2.

**Group header**
`stiffness.parameters`: Defines stiffness parameters.

---

**Forces for element type spe2**

![Forces diagram](image-url)
**jel2**

<table>
<thead>
<tr>
<th><strong>Description</strong></th>
<th>2D joint element with uncoupled axial, shear and moment actions.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Curve types</strong></td>
<td>Models used for the joint force-displacement curves, specified for F (axial), V (shear) and M (moment), respectively. Each of these models may be any of those described in Chapter 4.</td>
</tr>
<tr>
<td><strong>Parameters</strong></td>
<td>Parameters for each of the three models specified for F, V and M.</td>
</tr>
<tr>
<td><strong>Nodes</strong></td>
<td>3</td>
</tr>
<tr>
<td><strong>Characteristics</strong></td>
<td>Nodes (1) and (2) can be initially coincident, but not necessarily. Node (3) is only used to define the x-axis of the joint and can be a non-structural node. It can be identical to node (2) if it is offset from node (1). The orientation of the joint x-axis after deformation is determined by its initial orientation and the global rotation of node (1).</td>
</tr>
<tr>
<td><strong>Application</strong></td>
<td>Plane frame analysis. Can be used to model pin joints, inclined supports, elasto-plastic joint behaviour, soil-structure interaction and structural gaps, through employing appropriate joint curves.</td>
</tr>
<tr>
<td><strong>Restrictions</strong></td>
<td>Element has a zero initial length, since nodes (1) and (2) must be coincident. Cannot be used to model coupled axial, shear and moment actions.</td>
</tr>
</tbody>
</table>

**Group header**

curvel.types: Defines curve types for joint elements.
parameters: Defines parameters for the joint elements.
Forces for element type \textit{jel2}
**cnm2**

**Description**
Concentrated (lumped) 2D mass element.

**Nodes**
1

**Characteristics**
Models lumped mass for dynamic analysis.
Allows full $2 \times 2$ translational mass matrix to be defined.
Lumped element mass, specified according to one of:

- $M_x$ (default $M_y = M_x$ & $M_{xy} = 0$)
- $M_x, M_y$ (default $M_{xy} = 0$)
- $M_x, M_y, M_{xy}$

Rotational mass:

$M_{zz}$

Allows specification of mass-proportional damping at group level.

**Application**
Dynamic analysis of plane frames.
Rotational mass may be required for connected elements to be **explicit**.

Off-diagonal mass is reset to zero ($M_{xy} = 0$) if **lumped.mass** is **true** in the **default.parameters** module.

**Restrictions**

**Group header**

- **mass**: element mass.
- **[rotational.mass]**: optional rotational mass.
- **[damping.parameter]**: optional parameter for mass-proportional Rayleigh damping; defaults to the value of **mass.damping.parameter** specified in the **default.parameters** module.
Forces for element type cnm2
**cnd2**

**Description**
Concentrated (dashpot) 2D viscous damping element.

**Damping parameters**
Two translational and one rotational damping coefficients, specified in this order:

\[ C_x, C_y, C_{zz} \]

**Nodes**
1

**Characteristics**
Models nodal viscous damping for dynamic analysis.

**Application**
Dynamic analysis of plane frames.

**Restrictions**

**Group header**
`damping.parameters`: Defines dashpot damping parameters.

---

**Forces for element type cnd2**

\[ F_x, F_y, F_{zz} \]
**lnm2**

**Description**
Linear 2D mass element.

**Nodes**
2

**Characteristics**
Simplified modelling of uniformly distributed mass for dynamic analysis. Assumes the mass to lie on a rigid straight line between the two end nodes.

Rotational mass may be required for connected elements to be `explicit`.

Element can be `explicit` provided `lumped.mass` is `true` (as specified or by default).

Allows specification of mass-proportional damping at group level.

**Application**
Dynamic analysis of plane frames.

**Restrictions**
**Group header**
- `mass/length`: mass per unit length.
- `[rotational.mass/length]`: optional rotational mass per unit length.
- `[damping.parameter]`: optional parameter for mass-proportional Rayleigh damping; defaults to the value of `mass.damping.parameter` specified in the `default.parameters` module.
- `[lumped.mass]`: optional (true/false) flag indicating whether mass is to be lumped; defaults to value of `lumped.mass` in the `default.parameters` module.

*Forces for element type lnm2*
**cbm2**

<table>
<thead>
<tr>
<th><strong>Description</strong></th>
<th>Cubic 2D distributed mass element</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nodes</strong></td>
<td>2</td>
</tr>
<tr>
<td><strong>Characteristics</strong></td>
<td>Models uniformly distributed mass in dynamic analysis. Uses an Updated Lagrangian formulation with a cubic shape function for the transverse displacement and a linear distribution for the axial displacement. Allows different axial (m_a) and transverse (m_t) distributed mass. Mass per unit length, specified according to one of: m_a (default m_t = m_a) m_a, m_t Allows specification of mass-proportional damping at group level.</td>
</tr>
<tr>
<td><strong>Application</strong></td>
<td>Dynamic analysis of plane frames.</td>
</tr>
<tr>
<td><strong>Restrictions</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Group header</strong></td>
<td>mass/length: Mass per unit length. [damping.parameter]: optional parameter for mass-proportional Rayleigh damping; defaults to the value of mass.damping.parameter specified in the default.parameters module.</td>
</tr>
</tbody>
</table>

**Forces for element type cbm2**
### rld2

**Description**
Rayleigh damping 2D element

**Mass/length**
Mass per unit length

**Parameters**
Two proportionality constants ($a_1$ & $a_2$) of mass and stiffness respectively, specified in that order.

**Nodes**
2

**Characteristics**
Models Rayleigh damping effects.

All rld2 elements must have the same constant ($a_1$ & $a_2$) to model conventional Rayleigh damping.

**Application**
Dynamic analysis of plane frames.

**Restrictions**
($a_1$) should be set to zero for dynamic analysis involving ground excitation, otherwise damping would be proportional to absolute rather than relative frame velocity.

**Group header**
- **sec.name**: An identifier referring to one of the cross-sections declared in the sections module.
- **mass/length**: Mass per unit length.
- **parameters**: Defines parameters of Rayleigh damping elements.

---

**Forces for element type rld2**

![Diagram of forces for element type rld2]
**Description**

2D/3D joint element with coupling between axial force and moment but uncouple with shear.

**Types**

Three entries are required:

1) ‘steel’ for bare steel or ‘composite’ for composite connection.

2) connection type:
   - ‘flush.endplate’
   - ‘extended.endplate’
   - ‘web.angles’
   - ‘top.and.seat’
   - ‘combined.web/top/seat’
   - ‘finplate’

3) behaviour of panel zone, either ‘rigid’ if panel zone behaviour is omitted or ‘flexible’ if the flexibility of the panel zone is included.

**Material name**

Three material properties are required by using material model gen1. The first material provides the properties of the connecting elements e.g. plates, angle. The second material is the properties of bolts. The third material is the properties of the connected member i.e. column and beam.

**Parameters**

Number of parameters vary according to connection type:

- Flush end plate (13 parameters)
- Extended end plate (26 parameters)
- Double web angles (12 parameters)
- Top and seat angles (23 parameters)
- Combination of top, seat and web angles (34 parameters)
- Finplate (8 parameters)

1. Flush end plate
   - Bolt diameter,
   - Area of bolt shank,
   - Thickness of bolt head,
   - Thickness of nut,
   - Thickness of washer,
   - Distance from endplate edge to bolt head/nut/washer edge,
   - Distance of bolt head/nut /washer whichever is appropriate,
   - Distance from edge of bolt head/nut/ washer to fillet of endplate to beam web,
   - Total depth of endplate,
   - Thickness of endplate,
   - Endplate width,
• Minimum bolt pitch,
• Coefficient for the computation of the effective width for the bolt-row below the beam tension flange.

2. Extended end plate
The geometrical properties of the extended endplate are double the properties of the flush endplate, accounting for different orientation of the T-stub components, but the details and order are the same. The only exception is for the last parameter, where the length of the extended part of the endplate is required.

3. Double web angles
• Bolt diameter,
• Area of bolt shank,
• Total depth of angle,
• Angle thickness,
• Gauge length of beam leg,
• Bolt clearance,
• Minimum bolt pitch,
• Gauge length of column leg,
• Distance from bolt line to free edge of column leg,
• Distance from bolt line to free edge of beam leg,
• Angle radius,
• Diameter of M16 bolts.

4. Top and seat angels
For top angle (12 parameters):
• Bolt diameter,
• Area of bolt shank,
• Total depth of angle,
• Angle thickness,
• Gauge length of beam leg,
• Bolt clearance,
• Minimum bolt pitch,
• Gauge length of column leg,
• Distance from bolt line to free edge of column leg,
• Distance from bolt line to free edge of beam leg,
• Angle radius,
• Diameter of M16 bolts.

Similar dimensions are needed for seat angle (11 parameters) except for the diameter of M16 bolts.

5. Combination of top, seat and web angles
Connection parameters for this type are the combination of web angle and top and seat angles.
6. Finplate
   - Bolt diameter,
   - Bolt hole diameter,
   - Total depth of plate,
   - Plate thickness,
   - Gauge length,
   - Width of plate,
   - Minimum bolt pitch,
   - Diameter of M16 bolts.

After the connection parameters are entered, another 14 parameters are needed: 11 parameters for the connected members, followed by Poisson ratio, number of layers and a flag to indicate preload or non-preload condition of the bolts. Connected member parameters are:
   - Column depth,
   - Column flange width,
   - Thickness of column flange,
   - Thickness of column web,
   - Column radius,
   - Bolt pitch in column,
   - Distance from bolt line to free edge of column flange,
   - Distance from bolt line to fillet of column flange,
   - Beam depth,
   - Thickness of beam flange,
   - Thickness of beam web.

**Nodes**
3 (2D) used similar to jel2
4 (3D) used similar to jel3

**Application**
Plane frame analysis.
Space frame analysis.
Can be used to model steel and composite joints.

**Restrictions**
Element has a zero initial length, since nodes (1) and (2) must be coincident.

**Group header**
- **type**: Defines the type of connection and contribution of shear panel
- **mat.name(s)**: Defines the material for the connecting elements, bolts and connected member
- **parameters**: Defines parameters for the joint and depends on the connection types.
**cbp3**

<table>
<thead>
<tr>
<th><strong>Description</strong></th>
<th>Cubic elasto-plastic 3D beam-column element.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Monitoring points</strong></td>
<td>100 points usually adequate; depends on section type.</td>
</tr>
<tr>
<td><strong>Nodes</strong></td>
<td>3</td>
</tr>
<tr>
<td><strong>Characteristics</strong></td>
<td>Geometric and material nonlinearities.</td>
</tr>
<tr>
<td></td>
<td>Numerical integration performed over two Gauss points.</td>
</tr>
<tr>
<td></td>
<td>A number of monitoring areas used at each Gauss section to monitor material direct stress and strains.</td>
</tr>
<tr>
<td></td>
<td>Predicts global member behaviour based on a material stress-strain relationship.</td>
</tr>
<tr>
<td></td>
<td>A number of elements per member, usually over 5, must be used for reasonable accuracy in inelastic modelling.</td>
</tr>
<tr>
<td></td>
<td>Nodes (1) and (2) define the element connectivity and its local x-axis. The y-axis lies in a plane defined by the x-axis and node (3), which can be a non-structural node.</td>
</tr>
<tr>
<td><strong>Application</strong></td>
<td>Modelling of inelastic members in space frames.</td>
</tr>
<tr>
<td><strong>Restrictions</strong></td>
<td>The elastic torsional rigidity is used, which is approximate for composite and R/C sections. Warping strains are not accounted for.</td>
</tr>
</tbody>
</table>

**Group header**

- `sec.name`: An identifier referring to one of the cross-sections declared in the sections module.
- `monitoring.points`: Defines the number of points for monitoring stresses and strains within a cross-section.
Forces in local system of element type \textit{cbp3}
**Description**  
Quartic elastic 3D beam-column element.

**Nodes**  
3

**Imperfections**  
$V_{y\cdot0.25L}$, $V_{y\cdot0.5L}$, $V_{y\cdot0.75L}$, $V_{z\cdot0.25L}$, $V_{z\cdot0.5L}$, and $V_{z\cdot0.75L}$ can be specified.

**Characteristics**  
Geometric nonlinearities.

Large displacements and beam-column effect of perfect/imperfect members.

One element type *qel3* is usually sufficient to represent the beam-column effect and large displacement response of a whole elastic member.

Nodes (1) and (2) define the element connectivity and its local x-axis. The y-axis lies in a plane defined by the x-axis and node (3), which can be a non-structural node.

**Application**  
Geometric nonlinearities in elastic space frames.

**Restrictions**  
Unable to model concrete cracking.

Warping strains are not accounted for.

**Group header**  
`sec.name`: An identifier referring to one of the *cross-sections* declared in the sections module.

---

![Imperfection and forces in local system of element type *qel3*](image)

(a) x-y plane  
(b) x-z plane

*Imperfection and forces in local system of element type *qel3*
**qph3**

<table>
<thead>
<tr>
<th><strong>Description</strong></th>
<th>Quartic plastic hinge 3D beam-column element with an option for automatic subdivision.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nodes</strong></td>
<td>3</td>
</tr>
<tr>
<td><strong>Subdivision</strong></td>
<td>Automatic subdivision into two elements if a plastic hinge is detected within the element may be requested.</td>
</tr>
<tr>
<td><strong>Imperfections</strong></td>
<td>$V_{y0.25L}$, $V_{y0.5L}$, $V_{y0.75L}$, $V_{z0.25L}$, $V_{z0.5L}$, and $V_{z0.75L}$ can be specified.</td>
</tr>
<tr>
<td><strong>Characteristics</strong></td>
<td>Geometric and material nonlinearities. Suitable for members in which the spread of plasticity is not important and the section response is elastic-plastic without strain-hardening. Rotational and axial plastic hinge displacements are allowed at the two ends of the element. One element type <em>qph3</em> is usually sufficient to model a whole member, and the option of subdivision allows for the case of member buckling. Nodes (1) and (2) define the element connectivity and its local x-axis. The y-axis lies in a plane defined by the x-axis and node (3), which can be a non-structural node.</td>
</tr>
<tr>
<td><strong>Application</strong></td>
<td>Large displacement plastic-hinge analysis of space frames</td>
</tr>
<tr>
<td><strong>Restrictions</strong></td>
<td>Not applicable to reinforced concrete or composite members. Warping strains are not accounted for.</td>
</tr>
</tbody>
</table>
| **Group header** | `sec.name`: An identifier referring to one of the *cross-sections* declared in the *sections* module. `subdivision`: Gives the option for automatic subdivision plastic hinge elements: 

\[
= (t \mid \text{true}) \quad \text{consider element subdivision}
\]

\[
= (f \mid \text{false}) \quad \text{ignore element subdivision}
\]
Imperfection and forces in local system of element type qph3
Description: Quartic elastic 3D beam-column element utilising automatic mesh refinement.

Subdivision pattern: Relative lengths in ratio form of zones where inelasticity is checked for automatic mesh refinement.

Nodes: 3

Imperfections: \( V_{0.25L}, V_{0.5L}, V_{0.75L}, V_{0.25L}, V_{0.5L}, \) and \( V_{0.75L} \) can be specified.

Characteristics: Geometric and material nonlinearities.
Large displacement and beam-column effect of perfect/imperfect members.

One element type \( qdp3 \) is usually sufficient to represent a whole member.

Element \( qdp3 \) subdivides into elements \( cbp3 \), specified under \( cbp3.grp.name \), if inelasticity is detected in the zones defined by the subdivision pattern \( pat.name \).

Accuracy increases with the number of sub-elements type \( cbp3 \) specified in the subdivision pattern.

After subdivision, elements \( cbp3 \) are inserted in the inelastic zones, while the elastic zones are kept as element type \( qdp3 \).

Nodes (1) and (2) define the element connectivity and its local x-axis. The y-axis lies in a plane defined by the x-axis and node (3), which can be a non-structural node.

Application: Adaptive modelling of inelastic members in space frames.

Restrictions: Applies only to cross-sections with materials \( stl1, stl2, \) & \( stl3 \).
Warping strains are not

Group header: \( cbp3.grp.name \): Specifies the group identifier of elements type \( cbp3 \) used in automatic mesh refinement.
\( pat.name \): An identifier referring to a subdivision pattern in the \( patterns \) module.
Imperfection and forces in local system of element type qdp3
### Description
Cubic elasto-plastic 3D beam-column element for thin-walled open cross-sections with warping.

### Monitoring points
100 points usually adequate; depends on section type.

### Nodes
3

### Characteristics
Geometric and material nonlinearities.

Numerical integration performed over two Gauss points.

A number of monitoring areas used at each Gauss section to monitor material direct stress and strains.

Works with uniaxial material models (stl1, stl3), and with biaxial material models (bnsi, bnsk) which consider the influence of plasticity on twisting rigidity.

Predicts global member behaviour based on a material stress-strain relationship.

Lateral torsional buckling including Wagner effect.

A number of elements per member, usually over 5, must be used for reasonable accuracy in inelastic modelling.

Nodes (1) and (2) define the element connectivity and its local x-axis. The y-axis lies in a plane defined by the x-axis and node (3), which can be a non-structural node.

### Application
Modelling of inelastic thin-walled members with open cross-sections in space frames.

Warping freedoms (wp1, wp2) can be coupled for adjacent elements to model torsion with non-uniform warping, using:

**coupled.additional.freedoms**

### Restrictions
Uses the oplt thin-walled cross-section.

Elastic twisting rigidity is considered when employing uniaxial material models.

### Group header
**sec.name:** An identifier referring to the oplt cross-section.

**monitoring.points:** Defines the number of points for monitoring stresses and strains within a cross-section.

**Options:** optional heading which specifies whether the Wagner effect is to be excluded [no.wagner.effect], whether residual strains defined for the cross-section are to be considered [residual.strains], and the number of monitoring points over the thickness [thickness.points #] (Default = 1).
Forces in local system of element type \textit{pwp3}
**Description**
3D link element with discrete axial/rotational springs.

**Nodes**
3

**Characteristics**
Geometric nonlinearity.

Nodes (1) and (2) define the element connectivity and its local x-axis. The y-axis lies in a plane defined by the x-axis and node (3), which can be a non-structural node.

**Application**
Rigid link.
Elastic bar with pinned ends.

**Restrictions**

**Group header**
**stiffness.parameters:** numerical or **rigid** values for each of the spring stiffnesses, $k_{\theta y1}$, $k_{\theta z1}$, $k_{\theta y2}$, $k_{\theta z2}$, $k_\Delta$ and $k_{\theta T}$ in this order.

---

![Diagram](image)

Stiffness parameters and forces in local system of element type **lnk3**
**Inks**

**Description**
3D link element linking 6 DOF to 5 DOF nodes.

**Nodes**
3.

**Characteristics**
Geometric nonlinearity.

Nodes (1) and (2) define the element connectivity and its local x-axis. The y-axis lies in a plane defined by the x-axis and node (3), which can be a non-structural node.

**Application**
Beam to slab connection.

The second node is a 5 DOF node belonging to plate/shell elements with only two rotational DOF’s, including *csl4* elements.

**Restrictions**

**Group header**

*stiffness.parameters*: numerical or rigid values for each of the spring stiffnesses, $k_{0y1}$, $k_{0z1}$, $k_{0y2}$, $k_{0z2}$ and $k_\Delta$ in this order.

---

*Stiffness parameters and forces in local system of element type Inks*
**jel3**

<table>
<thead>
<tr>
<th><strong>Description</strong></th>
<th>3D joint element with uncoupled axial, shear and moment actions.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Curve types</strong></td>
<td>Models used for the joint force-displacement curves, specified for $F_x$ (axial), $F_y$ &amp; $F_z$ (shear) and $M_x$, $M_y$ &amp; $M_z$ (moment), respectively. Each of these models may be any of those described in Chapter 4.</td>
</tr>
<tr>
<td><strong>Parameters</strong></td>
<td>Parameters for each of the six models specified for $F_x$, $F_y$, $F_z$, $M_x$, $M_y$, $M_z$.</td>
</tr>
<tr>
<td><strong>Nodes</strong></td>
<td>4</td>
</tr>
<tr>
<td><strong>Characteristics</strong></td>
<td>Nodes (1) and (2) can be initially coincident, but not necessarily. Node (3) is only used to define the x-axis of the joint and can be a non-structural node. It can be identical to node (2) if it is offset from node (1). The y-axis lies in a plane defined by the x-axis and node (4), which also can be a non-structural node. The orientation of the joint x-axis after deformation is determined by its initial orientation and the global rotations of node (1).</td>
</tr>
<tr>
<td><strong>Application</strong></td>
<td>Space frame analysis. Can be used to model pin joints, inclined supports, elastoplastic joint behaviour, soil-structure interaction and structural gaps, through employing appropriate joint curves.</td>
</tr>
<tr>
<td><strong>Restrictions</strong></td>
<td>Element has a zero initial length, since nodes (1) and (2) must be coincident. Cannot be used to model coupled axial, shear and moment actions.</td>
</tr>
<tr>
<td><strong>Group header</strong></td>
<td><strong>curve.types</strong>: Defines curve types for joint elements. <strong>parameters</strong>: Defines parameters for the joint elements.</td>
</tr>
</tbody>
</table>
Configuration and forces for element type jel3
### cnm3

<table>
<thead>
<tr>
<th>Description</th>
<th>Concentrated (lumped) 3D mass element.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nodes</td>
<td>1</td>
</tr>
<tr>
<td>Characteristics</td>
<td>Models lumped mass for dynamic analysis. Allows full 3×3 translational mass matrix to be defined.</td>
</tr>
<tr>
<td></td>
<td>Lumped element mass, specified according to one of:</td>
</tr>
<tr>
<td></td>
<td>( M_x ) (default ( M_y = M_z = M_x ) &amp; ( M_{xy} = M_{xz} = M_{yz} = 0 ))</td>
</tr>
<tr>
<td></td>
<td>( M_x, M_y, M_z ) (default ( M_{xy} = M_{xz} = M_{yz} = 0 ))</td>
</tr>
<tr>
<td></td>
<td>( M_x, M_y, M_z, M_{xy}, M_{xz}, M_{yz} )</td>
</tr>
<tr>
<td>Diagonal rotational mass specified as follows:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Only ( M_x ) is specified above:</td>
</tr>
<tr>
<td></td>
<td>( M_{xx} ) (default ( M_{yy} = M_{zz} = M_{xx} ))</td>
</tr>
<tr>
<td></td>
<td>otherwise:</td>
</tr>
<tr>
<td></td>
<td>( M_{xx}, M_{yy}, M_{zz} )</td>
</tr>
<tr>
<td>Application</td>
<td>Dynamic analysis of space frames, shells and 3D continuum/membrane structures.</td>
</tr>
<tr>
<td></td>
<td>Rotational mass may be required for connected elements to be <a href="#">explicit</a>.</td>
</tr>
<tr>
<td></td>
<td>Off-diagonal mass is reset to zero (( M_{xy} = M_{xz} = M_{yz} = 0 )) if ( \text{lumped.mass} ) is <a href="#">true</a> in the <a href="#">default.parameters</a> module.</td>
</tr>
<tr>
<td>Restrictions</td>
<td><a href="#">rotational.mass</a>: optional rotational mass.</td>
</tr>
<tr>
<td>Group header</td>
<td>( \text{mass} ): element mass.</td>
</tr>
<tr>
<td></td>
<td><a href="#">damping.parameter</a>: optional parameter for mass-proportional Rayleigh damping; defaults to the value of ( \text{mass.damping.parameter} ) specified in the <a href="#">default.parameters</a> module.</td>
</tr>
</tbody>
</table>

---

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Forces for element type \textit{cnm3}
## cnd3

<table>
<thead>
<tr>
<th>Description</th>
<th>Concentrated (dashpot) 3D viscous damping element.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Damping parameters</strong></td>
<td>Three translational and three rotational damping coefficients, specified in this order:</td>
</tr>
<tr>
<td></td>
<td>$C_x, C_y, C_z$</td>
</tr>
<tr>
<td></td>
<td>$[C_{xx}, C_{yy}, C_{zz}]$</td>
</tr>
<tr>
<td><strong>Nodes</strong></td>
<td>1</td>
</tr>
<tr>
<td><strong>Characteristics</strong></td>
<td>Models nodal viscous damping for dynamic analysis.</td>
</tr>
<tr>
<td><strong>Application</strong></td>
<td>Dynamic analysis of space frames and shells.</td>
</tr>
<tr>
<td></td>
<td>Dynamic analysis of 3D continuum/membrane structures.</td>
</tr>
<tr>
<td><strong>Restrictions</strong></td>
<td>$[C_{xx}, C_{yy}, C_{zz}]$ are only optional for 3D continuum/membrane analysis.</td>
</tr>
<tr>
<td></td>
<td>$C_{xx}, C_{yy}, C_{zz}$ should be zero for use with csl4 elements.</td>
</tr>
<tr>
<td><strong>Group header</strong></td>
<td><strong>damping.parameters</strong>: Defines dashpot damping parameters.</td>
</tr>
</tbody>
</table>

**Forces for element type cnd3**

```
X
F_x

Y
F_y

Z
F_z

F_{xx} F_{yy} F_{zz} F_z F_y F_x
```

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**lnm3**

**Description**
Linear 3D mass element.

**Nodes**
2

**Characteristics**
Simplified modelling of uniformly distributed mass for dynamic analysis.

Assumes the mass to lie on a rigid straight line between the two end nodes.

Rotational mass may be required for connected elements to be **explicit**.

Element can be **explicit** provided `lumped.mass` is **true** (as specified or by default).

Allows specification of mass-proportional damping at group level.

**Application**
Dynamic analysis of space frames.

**Restrictions**

**Group header**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>mass/length</strong></td>
<td>Mass per unit length.</td>
</tr>
<tr>
<td><strong>[rotational.mass/length]</strong></td>
<td>Optional rotational mass per unit length.</td>
</tr>
<tr>
<td><strong>[damping.parameter]</strong></td>
<td>Optional parameter for mass-proportional Rayleigh damping; defaults to the value of <code>mass.damping.parameter</code> specified in the <code>default.parameters</code> module.</td>
</tr>
<tr>
<td><strong>[lumped.mass]</strong></td>
<td>Optional (true</td>
</tr>
</tbody>
</table>
Forces for element type \textit{lnm3}
### cbm3

<table>
<thead>
<tr>
<th><strong>Description</strong></th>
<th>Cubic 3D distributed mass element.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nodes</strong></td>
<td>2</td>
</tr>
<tr>
<td><strong>Characteristics</strong></td>
<td>Models uniformly distributed mass in dynamic analysis.</td>
</tr>
<tr>
<td></td>
<td>Uses an Updated Lagrangian formulation with a cubic shape function for the transverse displacement and a linear distribution for the axial displacement.</td>
</tr>
<tr>
<td></td>
<td>Allows different axial ((m_a)) and transverse ((m_t)) distributed mass.</td>
</tr>
<tr>
<td></td>
<td>Mass per unit length, specified according to one of:</td>
</tr>
<tr>
<td></td>
<td>(m_a) (default (m_t = m_a))</td>
</tr>
<tr>
<td></td>
<td>(m_a, m_t)</td>
</tr>
<tr>
<td><strong>Application</strong></td>
<td>Dynamic analysis of space frames.</td>
</tr>
<tr>
<td><strong>Restrictions</strong></td>
<td>Mass per unit length.</td>
</tr>
<tr>
<td><strong>Group header</strong></td>
<td>Mass/length: Mass per unit length.</td>
</tr>
<tr>
<td></td>
<td>[damping.parameter]: optional parameter for mass-proportional Rayleigh damping; defaults to the value of mass.damping.parameter specified in the default.parameters module.</td>
</tr>
</tbody>
</table>
Forces for element type *cbm3*
**rld3**

<table>
<thead>
<tr>
<th>Description</th>
<th>Rayleigh damping 3D element</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass/length</td>
<td>Mass per unit length</td>
</tr>
<tr>
<td>Parameters</td>
<td>Two proportionality constants ((a_1 &amp; a_2)) of mass and stiffness respectively, specified in that order.</td>
</tr>
<tr>
<td>Nodes</td>
<td>3</td>
</tr>
<tr>
<td>Characteristics</td>
<td>Models Rayleigh damping effects. All rld3 elements must have the same constant ((a_1 &amp; a_2)) to model conventional Rayleigh damping. Nodes (1) and (2) define the element connectivity and its local x-axis. The y-axis lies in a plane defined by the x-axis and node (3), which can be a non-structural node.</td>
</tr>
<tr>
<td>Application</td>
<td>Dynamic analysis of plane frames.</td>
</tr>
<tr>
<td>Restrictions</td>
<td>((a_1)) should be set to zero for dynamic analysis involving ground excitation, otherwise damping would be proportional to absolute rather than relative frame velocity.</td>
</tr>
<tr>
<td>Group header</td>
<td><strong>sec.name</strong>: An identifier referring to one of the cross-sections declared in the sections module. <strong>mass/length</strong>: Mass per unit length. <strong>parameters</strong>: Defines parameters of Rayleigh damping elements.</td>
</tr>
</tbody>
</table>
Forces for element type *rld3*
**Description**  
2-D flat shell element for composite floor slabs.

**Nodes**  
4

**Characteristics**  
Geometrically orthotropic slab.

4-noded composite and R/C slab element with additional rib and cover freedoms. It deals with the nonlinear analysis of composite floor slabs, enabling the modelling of material nonlinearities and geometric orthotropy through a modification of the Reissner-Mindlin hypothesis.

The element can be used in a basic form employing bilinear shape functions or in a higher-order form employing quadratic shape functions for the normal rotations. This is achieved through the use of hierarchic additional freedoms, which are defined in this order:

\[
\{ \tilde{\mathbf{w}} \}_{1\rightarrow 4}, \{ \mathbf{u}, \mathbf{v} \}_{1\rightarrow 2}, \{ \mathbf{\bar{u}}, \mathbf{\bar{v}}, \mathbf{\bar{\theta}}, \mathbf{\bar{\phi}} \}_{1\rightarrow 4}, \{ \mathbf{\bar{u}}, \mathbf{\bar{v}} \}_{1\rightarrow 3}\]

For the bilinear form, only the first 8 additional freedoms are used, with the remaining 26 additional freedoms employed in addition for the quadratic form. Individual additional freedoms may be restrained as described in the restraints module.

Elevated temperature may be specified using element load type tmp7 specified in this order:

\[\{ T_1, \Delta T_1, T_2, \Delta T_2, T_3, \Delta T_3, T_4, \Delta T_4, T_5, \Delta T_5, T_6, \Delta T_6, T_7, T_8 \}\]

where \( T_i \) and \( \Delta T_i \) indicate respectively temperatures and temperature increments between the bottom of the cover and the top of the slab.

**Application**  
Realistic modeling of composite floor slabs under extreme loading, including fire conditions.

**Restrictions**

**Group header**  
- **sec.name**: An identifier referring to a cross-section of type **cslb** declared in the sections module.
- **type**: one of the following: **left.edge.rib**, **cover**, **central.rib**, and **right.edge.rib**.
- **gauss.points**: 3 entries representing number of gauss points in the local x, y and z directions, respectively.
- **[options]**: optional parameter indicating the element order **[bilinear|quadratic]**; defaults to **bilinear**.
Element types for csl4: (I) left.edge.rib; (II) cover; (III) central.rib; (IV) right.edge.rib

Additional freedoms for element csl4

Temperature distribution for csl4
**cbl2**

**Description**
Linear cable element with variable length.

**Nodes**
2

**Characteristics**
Accounts for large displacements in the small strain range.
Allows transfer of material across adjacent connected elements.
The element has no bending capacity.
Exact integration.

**Application**
Cable and tension fabric structures.
Requires specification of:
- unst\_strained\_element\_dimension(s)
- cou\_pled\_additional\_freedoms

**Restrictions**
Only allows use of linear elastic materials.
Limited to small strain problems.
Starting configuration must be close to equilibrium configuration.

**Group header**
sec.name: An identifier referring to one of the cross-sections declared in the sections module. Only the elastic axial rigidity EA is used.

---

**Configuration and global forces for element type cbl2**
**cbl3**

**Description**  
Quadratic cable element with variable length.

**Nodes**  
3

**Characteristics**  
Accounts for large displacements in the small strain range.
Allows transfer of material across adjacent connected elements and mid node.
The element has no bending capacity.
Numerical integration is performed over 3 Gauss points.

**Application**  
Cable and tension fabric structures.
Requires specification of:
- `unstrained.element.dimension(s)`
- `coupled.additional.freedoms`

**Restrictions**  
Only allows use of linear elastic materials.
Limited to small strain problems.

**Group header**  
`sec.name`: An identifier referring to one of the `cross-sections` declared in the `sections` module. Only the elastic axial rigidity `EA` is used.

`sliding.internal`: Declaration of whether internal sliding is allowed or prevented.

`damping.parameter`: Specification of damping parameter used in dynamic relaxation solution procedure.

---

There are also displacements in the global Z direction

Element configuration before and after deflection

There are also forces in the global Z direction

Element forces

*Configuration and global forces for element type cbl3*
**mem3**

**Description**  
Linear membrane element.

**Nodes**  
3

**Characteristics**  
Accounts for large displacements in the small strain range.  
The element has no bending capacity.  
Integration is exact.

**Application**  
Tension fabric structures.  
Requires specification of:  
unstrained.element.dimension(s)

**Restrictions**  
Only allows use of linear elastic materials.  
Limited to small strain problems.  
Starting configuration must be close to equilibrium configuration.

**Group header**  
sec.name: An identifier referring to a cross-section of type **thpl** declared in the sections module.

---

Configuration and global forces for element type **mem3**

There are also displacements in the global Z direction  
There are also forces in the global Z direction

Element configuration before and after deflection  
Element forces
### mem6

**Description**
Quadratic membrane element.

**Nodes**
6

**Characteristics**
Accounts for large displacements in the small strain range. The element has no bending capacity. Numerical integration performed over four Gauss points.

**Application**
Tension fabric structures. Requires specification of:

```
unstrained.element.dimension(s)
```

**Restrictions**
Allows use advanced fabric material model **tfs1**. Limited to small strain problems.

**Group header**
`sec.name`: An identifier referring to a cross-section of type **thpl** declared in the sections module.

`Strain.field`: Specifies whether a **conforming** or **assumed** strain field is to be used.

---

**Configuration and global forces for element type mem6**

---

[Diagrams showing element configuration and forces]
### Description

**bk20**: 20 noded 3D brick element.

**tt10**: 10 noded 3D tetrahedral element.

**wd15**: 15 noded 3D wedge element.

**pd13**: 13 noded 3D pyramid element.

### Nodes

20, 10, 15, 13

### Characteristics

Models 3D continuum large displacement problems using Green’s strain.

Applies to static, dynamic and elevated temperature analysis.

 Allows direct specification of material density and Rayleigh damping parameters for dynamic analysis.

Elements can be explicit provided `lumped.mass` is true (as specified or by default).

### Application

Static/dynamic analysis of 3D continuum problems.

### Restrictions

Works with material models `beth`, `bnsi`, `bnsk` and `tpth`.

### Group header

`mat.name`: An identifier referring to one of the `materials` declared in the `materials` module.

`[gauss.points]`: optional total number of gauss points; defaults to 27 (ie. $3\times3\times3$) for `bk20`.

`[density]`: optional material density used for dynamic analysis; defaults to zero.

`[damping.parameters]`: two optional parameters for mass- and stiffness-proportional Rayleigh damping, respectively; default to the values of `mass.damping.parameter` and `stiffness.damping.parameter` specified in the `default.parameters` module.

`[lumped.mass]`: optional (true|false) flag indicating whether mass is to be lumped; defaults to value of `lumped.mass` in the `default.parameters` module.
Nodal ordering for \textit{bk20}

Nodal ordering for \textit{tt10}
Nodal ordering for \textit{wd15}

Nodal ordering for \textit{pd13}
**cpl2**

**Description** 2-noded coupling element applicable to different types of analysis (2D, 3D, etc.).

**Stiffness parameters** Stiffness parameters for each of the global nodal freedoms which can be numerical (constant stiffness), rigid or contact.

**Nodes** 2

**Characteristics** A numerical stiffness value for a specific global freedom implies linear elastic spring connectivity between the two nodes in this freedom. A rigid value implies fully rigid connectivity, whereas a contact value implies rigid connectivity if node (2) moves towards node (1) in the negative direction of the freedom and no connectivity otherwise.

**Application** All types of analysis.

**Restrictions** Global nodal freedoms are coupled independently.

**Group header** `stiffness.parameters`: Defines the stiffness parameters for each of the global freedom directions.

---

*Element type cpl2 (illustrated for 3D analysis)*
**Description**
Multi-noded spreader element applicable to different types of analysis (2D, 3D, etc.).

**Nodes**
n-noded: 1 slave node and n-1 master (spread) nodes.

**Characteristics**
Independent constraints/force spreading applied in each of the global translational directions, according to specified ratios.

**Application**
Spreading of global force applied to slave node (1) to the remaining (n-1) master nodes according to specified ratios, allowing time history static/dynamic with prescribed displacement at node (1) while keeping specific force ratios at the remaining (n-1) master nodes.

Constraining weighted average of master node displacements in specific global direction to the corresponding displacement of slave node (1) according to the specified ratios.

Use in static analysis with proportional loading to control relative displacements of several nodes by applying displacement control to slave node; this is particularly useful for problems with a softening post-cracking response, enabling the direct control of crack opening using standard displacement control (where arc-length control may suffer convergence problems).

**Restrictions**
Only global translations and global forces can be constrained and spread, respectively.

**Group header**
direction: global translational direction(s) of constraint and force spreading (e.g. x+z). Note that if slave node (1) is not connected to other elements, its rotational and unconstrained translational freedoms should be restrained.

[equilibrating]: optional (true|false) flag, (default = true), indicating whether the element should be self-equilibrating, in which case the ratios.of.spread are automatically normalised to a unit total. This is only possible if the original total is not relatively small or zero. If the element cannot be equilibrating, then the force transmitted at the slave node (1) is not equilibrated by the forces at the remaining nodes; this case is mainly useful in displacement control of slave node (1) under proportional loading so as to control relative displacements of the master nodes, in which case no loading should be applied at the slave node.

spread.nodes: number of master/spread nodes (ie. n-1).

ratios.of.spread: (n-1) ratios of spread for the respective master nodes. These are normalised to a unit total for the self-equilibrating element case; if the original total is relatively
small or zero, then normalisation is ignored, and the element cannot be self-equilibrating.

Configuration of element type *sprd*
Chapter 7. **DATA SYNTAX**

### 7.1 Introduction

A header-oriented syntax is utilized in ADAPTIC data files. Data modules are identified by means of unique headers, and only the first four characters in the header key words are necessary. However, if more than four characters of a key word are employed, the ADAPTIC data input module checks for the consistency of all characters.

Names or numbers employed, for example, as identifiers for elements or nodes can be up to 8 character long. However, if this number is exceeded only the first 8 characters are considered.

The following symbols are used for describing the ADAPTIC data syntax. Note that these symbols are used in the rest of this manual only for delivering information, and they must not be used within an ADAPTIC data file.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( ...... )</td>
<td>Parantheses used to include a list of items.</td>
</tr>
<tr>
<td></td>
<td>Exclusive OR. For example ( 2d</td>
</tr>
<tr>
<td>[ ...... ]</td>
<td>Brackets used to include optional item(s). For example [z] means that entry z is optional.</td>
</tr>
<tr>
<td>&lt; entry &gt;</td>
<td>Specifies the entry type. For example &lt; integer &gt; indicates an integer data entry.</td>
</tr>
<tr>
<td>^</td>
<td>Indicates that the entries for the previous key word in the header can be defined by assignment outside the header line. For example,</td>
</tr>
</tbody>
</table>

```
mat. name   model^   properties
```

indicates that the following two data modules, |

```
mat.name   model   properties
m1         stl1     210e9 300e6 0.01
```

and,

```
model = stl1
mat. name   properties
m1          210e9 300e6 0.01
```

are equivalent.
7.2 General Facilities

This sections describes general facilities which are available with all data modules, unless indicated otherwise.
7.2.1 Continuation

The ampersand ( & ) symbol can be used to continue data entry on the next line.
7.2.2 Comments

Comments can be added anywhere in the data file using the hash ( # ) symbol. All entries following a ( # ) on the current line are ignored.
7.2.3 Incrementation

The automatic incrementation facility can be used with some data modules. This is indicated where applicable. The general syntax is given below:

<table>
<thead>
<tr>
<th>Syntax</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>f</em></td>
<td><em>&lt; entry {1} &gt; . . . . . . . . &lt; entry {n} &gt;</em></td>
</tr>
<tr>
<td><em>r</em></td>
<td><em>&lt; inc. {1,1} &gt; . . . . . . . . &lt; inc. {n,1} &gt; &lt; rep. {1} &gt;</em></td>
</tr>
<tr>
<td><em>r [&lt;range{2}&gt;]</em></td>
<td><em>&lt; inc. {1,2} &gt; . . . . . . . . &lt; inc. {n,2} &gt; &lt; rep. {2} &gt;</em></td>
</tr>
<tr>
<td><em>r [&lt;range{m}&gt;]</em></td>
<td><em>&lt; inc. {1,m} &gt; . . . . . . . . &lt; inc. {n,m} &gt; &lt; rep. {m} &gt;</em></td>
</tr>
</tbody>
</table>

*<entry {i}>*  
ith entry on the first data line used for generation.

*<range {j}>*  
Range of previously generated lines to be used for further incrementation.

Syntax of *<range {j}>* is *([<first {j}>]: [<last {j}>] [: <step {j}>])*, for example 2:7 or 4:10:2.

*<inc. {i,j}>*  
The increment to be used in the generation of the *i*th entries.

If *<entry {i}>* is a character string then *<inc {i,j}>* must be a dash (*–*).

*<rep. {j}>*  
The number of times each line in the range *<range {j}>* is incremented.

Notes

The defaults for optional arguments are:

*<range {j}>* = *1*(total number of lines generated so far)

*<first {j}>* = *1*

*<last {j}>* = total number of lines generated so far

*<step {j}>* = *1*
7.3 Input Modules

This sections describes the input modules available within ADAPTIC.
7.3.1 Analysis

This module specifies the analysis type.

<table>
<thead>
<tr>
<th>analysis ( 2d</th>
<th>3d ) ( eigenvalue</th>
<th>dynamic [explicit]</th>
<th>static )</th>
</tr>
</thead>
<tbody>
<tr>
<td>2d</td>
<td>Two dimensional analysis.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3d</td>
<td>Three dimensional analysis.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>eigenvalue</td>
<td>Eigenvalue analysis.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>dynamic</td>
<td>Dynamic analysis.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>explicit</td>
<td>Explicit time-integration for dynamic analysis.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>static</td>
<td>Static analysis.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes Dynamic analysis is performed using implicit time-integration, unless the explicit option is used.
7.3.2 Default.parameters

This module specifies some default parameters.

```
default.parameters
mass.damping.parameter = < real >
stiffness.damping.parameter = < real >
normals.coincidence.angle = < real >
lumped.mass = (true|false)
```

- **mass.damping.parameter**: Parameter used to specify mass-proportional damping, without the need for damping elements. Applies to mass elements `cnm2`, `lnm2`, `cbm2`, `cnm3`, `lnm3`, `cbm3` and `bk20`.

- **stiffness.damping.parameter**: Parameter used to specify stiffness-proportional damping, without the need for damping elements. Applies to elements `bk20`.

- **normals.coincidence.angle**: An angle tolerance which determines whether two normals from adjacent elements are coincident; defaults to $\cos^{-1}(0.9999)$.

- **lumped.mass**: Indicates whether the mass of applicable elements is to be lumped; defaults to `true` with explicit dynamic analysis and `false` otherwise.

Notes
### 7.3.3 Materials

This module specifies material identifiers referring to a particular model and model properties.

<table>
<thead>
<tr>
<th>mat.name</th>
<th>model</th>
<th>properties</th>
</tr>
</thead>
</table>

- **mat.name**: A material identifier referring to the specified model and properties. The material name can be any alphanumeric string.
- **model**: The material model used. The model should be one of those specified in Chapter 3.
- **properties**: The material model properties. The number of properties must be as indicated in Chapter 3 for the corresponding model.

**Notes**
### 7.3.4 Sections

This module specifies cross-section identifiers referring to a section type, constituent materials and section dimensions.

<table>
<thead>
<tr>
<th>sections</th>
</tr>
</thead>
<tbody>
<tr>
<td>sec.name</td>
</tr>
</tbody>
</table>

- **sec.name**: The name of the section which has the given properties. The name can be any alphanumeric string.
- **type**: The section type. This must be one of the available types given in Chapter 5.
- **mat.name**: Specifies the material(s) used. The specified entry(s) should be one of the material identifiers declared in the materials module.
- **dimensions**: Dimensions of the section. The number of dimension must be as defined in Chapter 5 for the corresponding section type.

**Notes**
7.3.5 Patterns

This module defines subdivision patterns utilized in automatic mesh refinement. The specified ratios indicate the number of potential subelements and their relative lengths.

<table>
<thead>
<tr>
<th>pat.name</th>
<th>ratios</th>
</tr>
</thead>
<tbody>
<tr>
<td>A pattern identifier.</td>
<td></td>
</tr>
<tr>
<td>Integer values denoting relative lengths of zones where inelasticity is checked. The number of integers implicitly defines the number of zones.</td>
<td></td>
</tr>
</tbody>
</table>

Notes
7.3.6 Groups

This module defines properties for element groups. The number and nature of group properties depend on the type of elements for which the group is being established.

```
groups

type.of.element = <element type>  grp.name = <group header>
```
7.3.7 **Structural.nodal.coordinates**

This module defines coordinates of structural nodes.

<table>
<thead>
<tr>
<th>structural.nodal.coordinates</th>
</tr>
</thead>
<tbody>
<tr>
<td>nod.name</td>
</tr>
</tbody>
</table>

- **nod.name** A node identifier which can be any alphanumeric string.
- **x, y, z** Global nodal coordinates.

**Notes**
- z is only required for 3D analysis.
- Incrementation can be used with this module.
7.3.8 Non.structural.nodal.coordinates

This module defines coordinates of structural nodes.

<table>
<thead>
<tr>
<th>non.structural.nodal.coordinates</th>
</tr>
</thead>
<tbody>
<tr>
<td>nod.name   x^   y^   [z^]</td>
</tr>
</tbody>
</table>

- **nod.name**: A node identifier which can be any alphanumeric string.
- **x, y, z**: Global nodal coordinates.

**Notes**
- *z* is only required for 3D analysis.
- Incrementation can be used with this module.
7.3.9 **Element.connectivity**

This module defines the connectivity of elements in a mesh configuration.

---

**element.connectivity**

<table>
<thead>
<tr>
<th><strong>elm.name</strong></th>
<th><strong>grp.name</strong></th>
<th><strong>nod.name(s)</strong></th>
</tr>
</thead>
</table>

- **elm.name**: An element identifier which can be any alphanumeric string.
- **grp.name**: An identifier referring to one of the groups declared in the **groups** module.
- **nod.name(s)**: The element end nodes defined in the

  - `structural.nodal.coordinates` or
  - `nonstructural.nodal.coordinates` modules.

**Notes**: Incrementation can be used with this module.
7.3.10 Imperfections

This module specifies imperfection levels within elements of specific types.

<table>
<thead>
<tr>
<th>imperfections</th>
</tr>
</thead>
<tbody>
<tr>
<td>elm.name</td>
</tr>
</tbody>
</table>

- **elm.name**: The element which has the specified imperfection values.
- **values**: The imperfection values for the element.

Notes
### 7.3.11 Coupled.additional.freedoms

This module specifies coupled additional freedoms for elements of specific types.

<table>
<thead>
<tr>
<th>coupled.additional.freedoms</th>
<th>elm.name(s)</th>
<th>[freedom.sets]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **elm.name(s)**: A pair of elements for which additional freedoms are to be coupled.
- **freedom.sets**: Specification of freedom sets to be coupled.

**Notes**

*freedom.sets* are used for coupling the additional freedoms of partition super-elements.
7.3.12 Restraints

This module defines nodal restraints.

<table>
<thead>
<tr>
<th>restraints</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ nod.name</td>
</tr>
<tr>
<td>[ elm.name</td>
</tr>
</tbody>
</table>

- **nod.name** The node to be restrained.
- **direction** Specifies the direction in which the defined node is restrained.
  - = x displacement along global X-axis.
  - = y displacement along global Y-axis.
  - = z displacement along global Z-axis.
  - = rx rotation about global X-axis.
  - = ry rotation about global Y-axis.
  - = rz rotation about global Z-axis.
- **elm.name** The element to be restrained.
- **freedom** The element additional freedom to be restrained.
  - = fa## (e.g. fa5 and fa12 for freedoms 5 and 12); or
  - = wp# (e.g. wp1 and wp2 for warping freedoms).

**Notes**
In two dimensional analysis, only x, y and rz directions can be specified.
Multiple freedoms can be specified by one entry (e.g. x+y+ry indicates restraints in the three directions x, y and ry).
Incrementation can be used with this module.
7.3.13 Conditions

This module specifies the conditions which govern the termination of the automatic control phase under a proportional static loading regime. These conditions are expressed in terms of limits on the load factor or displacements at specific freedoms.

\[
\text{conditions} = \begin{cases} 
    ( ( \text{lf.cnd.name limits} ) | \\
    ( \text{disp.cnd.name nod.name direction limits} ) 
\end{cases}
\]

- **lf.cnd.name**: Used for the load factor condition option, with the entry representing the condition identifier.
- **limits**: Specifies the minimum and maximum limits.
- **disp.cnd.name**: Used for the displacement condition option, with the entry representing the condition identifier.
- **nod.name**: The node name for which the displacement condition applies.
- **direction**: The direction for which the displacement condition applies.
  - = x: displacement along global X-axis.
  - = y: displacement along global Y-axis.
  - = z: displacement along global Z-axis.
  - = rx: rotation about global X-axis.
  - = ry: rotation about global Y-axis.
  - = rz: rotation about global Z-axis.

**Notes**

Multiple direction specification is not allowed in this module.

This module is only applicable when using **proportional.loads** in the **applied.loading** module.
7.3.14 Linear.curves

This module specifies piecewise linear load curves for dynamic or time history loading.

```plaintext
linear.curves

start.time  =  <real>
crv.name    =  <name>

( (time load.factor) |
  (file      =  <file name>) |
  [ delay     =  <real> ]
  [ first.line =  <integer> ]
  [ last.line =  <integer> ]
  [ format    =  <format specification> ] )
```

- **start.time** specifies the start time at which all load curves have a zero value. This entry must be less than the first `TIME` entry of all load curves.
- **crv.name** is a curve identifier.
- **time** is the time or pseudo-time column of entries.
- **load.factor** is the load factor column entries corresponding to the `time` entries.
- **file** is the name of the file in which the load curve is stored. This option can be used if the load curve is stored in a file.
- **delay** is the time delay from the start time before the load curve is applied.
  - Default = 0
- **first.line** is the line number in `file` corresponding to the first entry of the load curve.
  - Default = 1
- **last.line** is the line number in `file` corresponding to the last entry of the load curve.
  - Default = `<end of file>`
- **format** is a FORTRAN format specification by which the load curve entries are read from `file`.
  - Default = `<free format>`

**Notes**

Load factors of all load curves are taken as zero at the start time.
The time entries of a load curve recalled from a file are shifted by the value of delay which must always be positive. The load factor for such curves is zero between start.time and (start.time + delay).

This module is only applicable when using time.history.loads or dynamic.loads defined in the applied.loading module.
### 7.3.15 Integration.scheme

This module specifies the time integration scheme for dynamic analysis and its parameters.

```plaintext
integration.scheme

(scheme = newmark
 [beta = < real > ]
 [gamma = < real > ])

(scheme = hilber.hughes.taylor
 [alpha = < real > ]
 [beta = < real > ]
 [gamma = < real > ])
```

- **scheme**  
  The time integration scheme.
- **alpha**  
  HHT $\alpha$ parameter ($>-1/3$).  
  Default = 0.0 (Newmark)
- **beta**  
  Newmark/HHT $\beta$ parameter.  
  Default = $0.25(1-\alpha)^2$
- **gamma**  
  Newmark/HTT $\gamma$ parameter.  
  Default = $0.5-\alpha$

**Notes**  
This module is only applicable for dynamic analysis defined by the existence of `dynamic.loads` in the `applied.loading` module.
7.3.16 Applied.loading

This module specifies the type and the value of the applied loads.

```
applied.loading
[ initial.loads
 ( nod.name direction^ type^ value^ ) |
 ( elm.name type^ value^ ) ]
( proportional.loads
 ( nod.name direction^ type^ value^ ) |
 ( time.history.loads
 ( nod.name direction^ type^ crv.name^ value^ ) |
 ( elm.name type^ crv.name^ value^ ) |]
( dynamic.loads
 ( nod.name direction^ type^ crv.name^ value^ ) |
 ( elm.name type^ crv.name^ value^ ) ) )
```

**initial.loads**  These are static loads that are applied prior to any variable load. They can be forces or prescribed displacements applied at nodes in the global directions.

**proportional.loads**  These are static loads having proportional variation. The magnitude of a load at any step is given by the product of its nominal value and the current load factor. Proportional loads may be forces or prescribed displacements applied at nodes in the global directions.

**time.history.loads**  These are static loads varying according to different load curves in the pseudo-time domain. The magnitude of a load at any given pseudo-time is given by the product of its nominal value and the load factor obtained from its load curve at that pseudo-time. Time history loads may be forces or prescribed displacements applied at nodes in the global directions.

**dynamic.loads**  These are dynamic loads varying according to different load curves in the real time domain. The magnitude of a load at any given time is given by the product of its nominal value and the load factor obtained from its load curve at that time. Dynamic loads can be forces or
accelerations applied at the nodes in the global directions.

<table>
<thead>
<tr>
<th>nod. name</th>
<th>The node at which the load is applied.</th>
</tr>
</thead>
<tbody>
<tr>
<td>direction</td>
<td>The direction of the applied load:</td>
</tr>
<tr>
<td></td>
<td>= x  displacement along global X-axis.</td>
</tr>
<tr>
<td></td>
<td>= y  displacement along global Y-axis.</td>
</tr>
<tr>
<td></td>
<td>= z  displacement along global Z-axis.</td>
</tr>
<tr>
<td></td>
<td>= rx rotation about global X-axis.</td>
</tr>
<tr>
<td></td>
<td>= ry rotation about global Y-axis.</td>
</tr>
<tr>
<td></td>
<td>= rz rotation about global Z-axis.</td>
</tr>
<tr>
<td>type</td>
<td>Defines the type of the applied load</td>
</tr>
<tr>
<td></td>
<td>= (force</td>
</tr>
<tr>
<td></td>
<td>= (displacement</td>
</tr>
<tr>
<td></td>
<td>= (velocity</td>
</tr>
<tr>
<td></td>
<td>= (acceleration</td>
</tr>
<tr>
<td></td>
<td>= element specific keyword for element loads.</td>
</tr>
<tr>
<td>elm. name</td>
<td>The element subjected to loading.</td>
</tr>
<tr>
<td>value</td>
<td>Nominal value of the applied load.</td>
</tr>
<tr>
<td>crv. name</td>
<td>The load curve defining the variation of dynamic or time history loads. The load curve must be declared in the linear.curves module.</td>
</tr>
</tbody>
</table>

**Notes**

- **proportional.loads**, **time.history.loads** and **dynamic.loads** cannot be used in the same analysis.

- **initial.loads** can be used in static or dynamic analysis, but the module is optional. The load **type** can either be **force** or **displacement** for both static and dynamic analysis. In dynamic analysis only, **velocity** and **acceleration** can be used to indicate initial conditions, but these are only applicable to dynamic freedoms (i.e. those associated with mass/damping elements or support excitation).

- **proportional.loads** or **time.history.loads** must be used in static analysis, for which the load **type** can either be **force** or **displacement**.

- **dynamic.loads** must be used in dynamic analysis, for which the load **type** can either be **force** or **acceleration**.

Element loads cannot be applied as **proportional.loads**.
7.3.17 **Equilibrium.stages**

This module defines stages of time intervals at which structural equilibrium is established.

| equilibrium.stages
| end.of.stage   | steps |

- **end.of.stage**: Defines the end time of a stage.
- **steps**: The number of steps within a stage.

**Notes**

The time-step size for a stage is equal to the difference between the end time of the current stage and that of the previous stage divided by the number of steps of the current stage. For the first stage, the time step size is equal to the difference between the end of the first stage and the start time defined in linear.curves.

This module is only applicable when using time.history.loads or dynamic.loads defined in the applied.loading module.
7.3.18 Phases

This module defines the control phases used to trace the load deflection curve for proportional loading. Three types of control are available: load, displacement and automatic control.

<table>
<thead>
<tr>
<th>phases</th>
</tr>
</thead>
<tbody>
<tr>
<td>( ( load.control increment path steps )</td>
</tr>
</tbody>
</table>

- **load.control** Represents the load-control option.
- **displacement.control** Represents the displacement-control option.
- **automatic.control** Represents the automatic displacement-control option.
- **increment** Specifies the increment in the load factor for load.control, the increment of displacement for displacement.control, or the increment of arc length.
- **path** Specifies the sign of the increment
  - (continue | c) = follow the previous loading path.
  - (reverse | r) = unload relative to the previous loading path.
  - (keep | k) = keep the sign of the increment as specified. This cannot be used for arc-length control.
- **steps** The number of steps used to apply the increment.
- **(nod.name | elm.name )** The name of the node or element used for displacement control. Omission of this implies arc-length control. Note that arc-length control cannot be used for the first phase.
- **direction** The global direction in which the displacement control will be applied.
- **type** The automatic.control type:
(nod.control | elm.control | arc.length.control)

(translation | rotation | x+y+z).

The direction specification x+y+z is used only for arc.length.control, and can represent any combination of the available translational freedoms (x, y and/or z).

**cnd.name**

The name of the stopping condition used in the automatic-control option. The specified condition should be declared in the *conditions* module.

**Notes**

The **path** entry, always be **keep** for the first phase.

**automatic.control** can not be the first phase.
7.3.19 Iterative.strategy

This module specifies the iterative strategy applied during a load or a time step.

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>number.of.iterations</td>
<td>The maximum number of iterations performed for each increment.</td>
<td>Default = 10</td>
</tr>
<tr>
<td>initial.reformations</td>
<td>The number of initial reformations of the tangent stiffness matrix within an increment.</td>
<td>Default = 10</td>
</tr>
<tr>
<td>step.reduction</td>
<td>The step reduction factor used when convergence is not achieved.</td>
<td>Default = 5</td>
</tr>
<tr>
<td>divergence.iteration</td>
<td>The iteration after which divergence checks are performed.</td>
<td>Default = 6</td>
</tr>
<tr>
<td>scaled.iterations</td>
<td>Number of iterations (&gt; 2) after divergence over which the iterative displacement corrections are gradually scaled from zero to their full value.</td>
<td>Default = 1 (scaling off)</td>
</tr>
<tr>
<td>tol.relax.level</td>
<td>Step-reduction level (0 to 3) from and above which tolerance relaxation (between tolerance and maximum.tolerance) is allowed.</td>
<td>Default = 0</td>
</tr>
<tr>
<td>maximum.convergence</td>
<td>The maximum convergence value allowed for any iteration</td>
<td>Default = 1000</td>
</tr>
</tbody>
</table>
arc.flow.iteration Iteration number after which the normal flow method is applied with arc-length control.

Default = number.of.iterations

Notes

Using a number of initial.reformations equal to the number.of.iterations is equivalent to the Newton- Raphson strategy.

Using a number of initial.reformations equal to 0 is equivalent to the modified Newton- Raphson strategy.

The solution is considered to be diverging if after the divergence.iteration the convergence of the current iteration is greater than that of the previous iteration. This check is not applied during the scaled.iterations stage and for a number of subsequent iterations equal to divergence.iteration, or if a relaxed solution within maximum.tolerance has been found. Scaling of iterative displacement corrections is applied after divergence if the remaining number of iterations exceeds scaled.iterations; this technique can be used to overcome convergence oscillations.

The increment is reduced by the step.reduction factor if convergence (full or relaxed) is not achieved, divergence occurs or maximum.convergence is exceeded. The original increment can be reduced for up to three levels.

The normal flow option for arc-length control can improve convergence characteristics, but does not guarantee that the displacement increments correspond exactly to the specified arc length.
7.3.20 Convergence.criteria

This module defines convergence criteria for the iterative procedures. The convergence criteria is based either on the out-of-balance norm or the maximum iterative displacement increment.

<table>
<thead>
<tr>
<th>convergence.criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>tolerance = &lt; real &gt;</td>
</tr>
<tr>
<td>( force.ref = &lt; real &gt; )</td>
</tr>
<tr>
<td>( moment.ref = &lt; real &gt; )</td>
</tr>
<tr>
<td>( displacement.ref = &lt; real &gt; )</td>
</tr>
<tr>
<td>( rotation.ref = &lt; real &gt; )</td>
</tr>
<tr>
<td>( work.ref = &lt; real &gt; )</td>
</tr>
<tr>
<td>[ maximum.tolerance = &lt; real &gt; ]</td>
</tr>
</tbody>
</table>

- **tolerance**  
The required convergence tolerance for each load or time step.

- **force.ref**  
The force reference value used in calculating the convergence. Applicable to convergence criteria based on the out-of-balance norm.

- **moment.ref**  
The moment reference value used in calculating the convergence. Applicable to convergence criteria based on the out-of-balance norm.

- **displacement.ref**  
The displacement reference value used in calculating the convergence. Applicable to convergence criteria based on the maximum iterative displacement increment.

- **rotation.ref**  
The rotation reference value used in calculating the convergence. Applicable to convergence criteria based on the maximum iterative displacement increment.

- **work.ref**  
The work reference value used in calculating the convergence. Applicable to convergence criteria based on the energy norm.

- **maximum.tolerance**  
The maximum tolerance to which a solution may be relaxed to if the specified tolerance could not be satisfied with the iterative.strategy. This is used in conjunction with tol.relax.level.  
  Default = 0
Notes  A tolerance and maximum tolerance equal to zero is equivalent to an iterative procedure in which a fixed number of iterations is performed for each load or time step without consideration of convergence.
### 7.3.21 Output

This module specifies the frequency of numerical output.

<table>
<thead>
<tr>
<th>output</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>frequency</strong> &lt; integer&gt; [<strong>stress</strong>] [<strong>local.displacements</strong>]</td>
</tr>
<tr>
<td><strong>no.local.displacements</strong></td>
</tr>
</tbody>
</table>

**frequency**
- Provides the frequency of the numerical output.
  - = 0 all equilibrium steps including step reduction levels.
  - = 1 all equilibrium steps without step reduction levels.
  - = n output every "n" equilibrium steps.

**stress**
- Specified if element stresses are required. Applicable only to specific element types.

**[no.]local.displacements**
- Indicates whether the local displacements of elements are output, which is true by default.

**eigenvalue.interval**
- Indicates the output interval for eigenvalue analysis during dynamic analysis.
7.3.22  Lanczos.eigenvalue

This module specifies the number of required eigenvalues and the range of natural frequencies of interest. The Lanczos eigenvalue algorithm is utilized.

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>lanczos.eigenvalue</code></td>
<td></td>
</tr>
<tr>
<td><code>number.of.eigenvalues</code></td>
<td>The number of required eigenvalues.</td>
</tr>
<tr>
<td><code>steps</code></td>
<td>The number of Lanczos steps to converge to the eigenvectors.</td>
</tr>
<tr>
<td><code>w.min</code></td>
<td>Minimum natural frequency of interest.</td>
</tr>
<tr>
<td><code>w.max</code></td>
<td>Maximum natural frequency of interest.</td>
</tr>
<tr>
<td><code>shift</code></td>
<td>The frequency shift during the solution of the eigenvalue problem.</td>
</tr>
<tr>
<td><code>starting.vector</code></td>
<td>Initial vector used by the Lanczos algorithm to derive eigenvectors.</td>
</tr>
<tr>
<td><code>nod.name</code></td>
<td>Node name considered in the starting vector.</td>
</tr>
<tr>
<td><code>direction</code></td>
<td>The global direction which is given the specified values.</td>
</tr>
<tr>
<td><code>value</code></td>
<td>The value of the entry in the starting vector corresponding to the nod.name in the global direction.</td>
</tr>
</tbody>
</table>
Notes

The number of steps must be less or equal to the total number of freedoms for the structure.

\( w_{\text{min}}, w_{\text{max}} \) and \( \text{shift} \) are in rd/sec.

\( \text{shift} \) must be between \( w_{\text{min}} \) and \( w_{\text{max}} \).

A random starting vector is generated if the starting vector module is not specified.
Chapter 8. POST-PROCESSING

8.1 Start-Up

After the analysis has been completed, a post-processing application may be started to study the structural response graphically. Two graphics post-processing applications are available:

1) **ADAPTIC_graphs** for plotting X-Y graphs. This is activated as follows

   (prompt) adaptic -g [filename|.dat|.svg]

2) **ADAPTIC_shapes** for plotting deflected shapes. This is activated as follows

   (prompt) adaptic -s [filename|.dat|.svs]

The above applications are discussed separately in the following sections.
8.2 ADAPTIC_graphs

8.2.1 General Facilities

The main items of the graphics region in the ADAPTIC_graphs application are shown in Figure 8.2.1. The mouse buttons can be used to manipulate the appearance, size and position of each of the components, as discussed below.

Moving

Each of the items may be moved using the left mouse button with a single click to activate moving followed by a click and drag to move to the desired position.

Resizing

This facility only applies to the "Graph Area" item. It can be performed using the right mouse button with a single click to active resizing followed by a click and drag of the bottom right corner to the desired position.

Figure 8.2.1. Graphics region of ADAPTIC_graphs application
8.2.2 File

This menu option offers the following facilities discussed with reference to the initiating buttons.

Data File

This invokes a form which allows the selection of the data file corresponding to the analysis that has been performed. Select the file filename.dat from the list of files in the directory where the analysis has been performed, where filename stands for the file identifier (e.g. one_storey).

Save

This button provides the means for storing plot information in a plot file for later retrieval. This is quite important for storing a permanent description of the plot, so that future modification can be performed with relative ease. Save files for the ADAPTIC_graphs application are automatically given a "_.svg" extension.

Retrieve

This button retrieves "_.svg" plot files that have been previously saved.

Print/Export

This button allows i) the output of the plot description to an Encapsulated PostScript (EPS) file, which can be imported into word processing applications, or ii) the export of numerical data as X-Y columns within a text file, which can be used for further processing and plotting in spreadsheet applications.

Exit

This allows the ADAPTIC_graphs application to be terminated. Before exiting, make sure you have saved your plot file, if necessary.
8.2.3 Graphs

Three facilities can be accessed using this menu option, as discussed below.

New Curve
This allows the selection of X and Y entities for a new line graph. After selecting the entities, described hereafter, the **Done** button must be pressed followed by the **Plot** button for displaying the new line graph.

- **TIME/LOAD FACTORS**: Allows the selection of time or load factor, depending on the type of analysis, as well as CPU time and output number for plotting. The output numbers are explicitly indicated for the various steps of the nonlinear analysis in the output file *filename.out*.

- **FORCES AT PRESCRIBED FREEDOMS**: Allows the selection of forces at restrained or prescribed freedoms. The latter are defined as any freedom subject to a displacement or time-history acceleration load.

- **NODAL ENTITIES**: This covers nodal displacements, velocities and accelerations. The last two should only be requested for dynamic analysis.

- **ELEMENT ENTITIES**: This covers i) local element entities (e.g. element forces and local displacements which depend on the element type), and ii) stresses and strains, the availability of which depend on the element type.

- **ENERGY GROUPS**: This allows the selection of energy components determined for pre-defined energy groups.

- **ARITHMETIC EXPRESSIONS**: This is a general utility which allows the combination of entities corresponding to previous line graphs in arithmetic expressions. The following definitions are valid combinations, referring to the Y coordinate of line graph 1, the X coordinate of line graph 3 and the Y coordinate of line graph 2:

  \[
  Y1-2-X3/6 \\
  Y2**2-Y1*X3 \\
  Y2-Y1
  \]

  Such expressions should be typed in the dialogue box.

  One application of this utility is for generating entities representing relative displacements rather than absolute nodal displacements.

Delete Curves
This allows previous line graphs to be deleted. This may be desirable if a curve is no longer required, especially if it was originally intended for providing X and Y coordinates to be manipulated by the ARITHMETIC EXPRESSIONS utility described above.

Clear All
This facility clears the contents of the current plot. This allows the construction of a new plot.
8.2.4 Customize

This option facilitates the customisation of the graph characteristics.

Fonts
This allows the modification of the font name, size and style for the axes titles, axes labels and legend text.

Axes
This facility can be used to modify the axes attributes, including thickness, colour, etc. It also allows individual axes to be modified in terms of minimum and maximum values, step size, scaling factor, etc.

Lines
Each line graph can be customised using this facility with regard to thickness, style, colour, the use of points, activation/de-activation, the output range of interest, the corresponding legend text, etc.

Legend
The legend can be customised with regard to visibility as well as the number of legend columns.
8.3 ADAPTIC_shapes

8.3.1 General Facilities

The main components of the ADAPTIC_shapes application are shown in Figure 8.3.1. The functionality of each component is described hereafter.

**Graphics Display Area**

This is the main graphics area where the structure is displayed. Each of the three mouse buttons has a *click-and-drag* functionality, which is modified by the Shift, and which depend on whether normal or perspective *view* is selected.

*For normal view:*
- Left button: rotate about planar axes, origin centred in structure.
- Left button + Shift: rotate about out-of-plane axis.
- Right button: zoom in.
- Right button + Shift: zoom out.
- Middle button: move.
- Middle button + Shift: pan.

*For perspective view:*
- Left button: rotate camera about planar axes, origin centred at focal point.
- Left button + Shift: rotate camera about out-of-plane axis.
- Right button: move camera forwards/backwards.
- Right button + Shift: zoom camera in/out.
- Middle button: pan camera in plane.
- Middle button + Shift: move scene in plane.

The three mouse buttons can also be combined with the Control key to select partitions in partitioned modelling.
- Left button + Control: select parent partition.
- Right button + Control: select nearest first-level child partition.
- Middle button + Control: select root partition.

**Orientation Tool**

This tool displays the orientation of the global structural reference axes in the current view. The four arrow buttons can be used to change this orientation by i) selecting a global axis for incremental rotation, ii) specifying the increment of rotation, iii) applying positive rotation increments, and/or iv) applying negative rotation increments.

A single click with the mouse buttons on the orientation display area has the following functionality:
- Left button: controlled customisation of current *view*.
- Right button: turn on/off axes orientation in the Graphics Display Area.

**View Indicator**

This displays the current view number (1, 2 or 3). The presence of (+) indicates that the current view is a subsequent modification of a stored view, whereas (−) indicates that the
current view is a precursor to a stored view. Furthermore, (N) indicates a normal view, whereas (P) indicates a perspective view.

**Output Number Indicator**

This displays the current output number, as well as the corresponding eigenvalue mode if any, in view. For example, “Output: 3” refers to the actual deflected shape in output number 3, “Output: 5 [M2]” refers to mode 2 of output number 5 with auto display/slider control given to varying the output number, while “Output: [5] M2” refers to the same mode and output number with auto display/slider control given to varying the mode number.

A single click with the left mouse button enables specification of output number and eigenvalue mode.

**Output Number Selector**

This allows output number selection using a slider, which is more convenient for a quick browse through the deflected shapes.

**Auto Display Speed Selector**

This enables the speed of automatic display for deflected shapes to be controlled using a slider.

**Contour Display Area**

This area displays the contour colours and scale, and is activated by the **General Settings** button.

A single click with the mouse buttons on the contour display area has the following functionality:

- **Left button:** customisation of **contours**.
- **Right button:** turn on/off contour information in the Graphics Display Area.
8.3.2 File

This menu option offers the following facilities discussed with reference to the initiating buttons.

Data File
This allows the selection of the data filename, provided the application is started on the command line without a filename specification, i.e.:

(prompt) adaptic -s

Save
This button provides the means for storing plot information in a plot file for later retrieval. This is quite important for storing a permanent description of the plot, so that future modification can be performed with relative ease. Save files for the ADAPTIC_shapes application are automatically given a ".svs" extension.

Retrieve
This button retrieves ".svs" plot files that have been previously saved.

Print
This button allows the output of the plot description to an Encapsulated PostScript (EPS) file, which can be imported into word processing applications.

Movie
Where supported, this button allows the capture of Auto Display as a ".m1v" movie.

General Settings
This button enables/disables the display of i) the initial shape alongside the deflected shape, ii) node and element labels, iii) contours, and iv) customisation of auto display/slider control.

The initial shape and labels are enabled by default for the undeflected configuration.

Control can be given to Auto Display and the Output Number Selector (Slider) to vary either the output number for a specific mode or the mode number for a specific output number. Also, a increment of output/mode numbers can be specified for Auto Display.

Exit
This allows the ADAPTIC_shapes application to be terminated. Before exiting, make sure you have saved your plot file, if necessary.
8.3.3 Shapes

This menu option offers the following facilities discussed with reference to the initiating buttons.

Output Number

This specifies the output and mode numbers to be displayed.

Output number 0 refers to the initial undeflected configuration, with other numbers referring to various equilibrium states obtained during nonlinear analysis.

For a specific output number, mode number 0 refers to the actual deflected shape of the equilibrium state, while other mode numbers refer to eigenvalue modes if any have been obtained for this equilibrium state.

Auto Display

This enables an animation of the structural response or the eigenvalue modes through sequential automatic display of deflected shapes/modes.

Animation control can be given in the General Settings over varying the output numbers for a specific mode (0 for the deflected shape) or the mode numbers for a specific output number (0 for the initial configuration).

The speed of animation is controlled by the Auto Display Speed Selector. The animation can be interrupted with a single mouse click with any button anywhere within the application window.

Customize

This allows the display of various element types to be customised, mainly in terms of i) basic or full plotting, ii) range of element to be excluded from view, iii) plotting divisions over element, iv) line colour, v) fill colour, vi) line thickness and vii) appearance of nodal and element labels. For partitioned modelling, the customisation can be applied at the level of the selected partition with/without child partitions or alternatively for all partitions. The customisation can also be applied selectively for individual element types or uniformly for all element types, where the latter offers the option of propagating specific customisations to all types at various partition levels, except for the element range which is only propagated over the currently selected partition.

Select Partition

This is used in partitioned modelling to select a new current partition. This can be specified 1) as the parent of the current partition, 2) by local name in the current partition, or 3) by rank (i.e. process rank as reflected in the "#nnn" extension to the base file name).
8.3.4 Contours

This menu option offers the following facilities discussed with reference to the initiating buttons.

Select Entities

This allows the selection of entities associated with specific element types for contour plotting. Note that this facility may not be available for some element types. Furthermore, the plotting of contours in the Graphics Display Area is controlled by the specification under General Settings.

Customize

This enables the specification of the number of contours, the associated colours and the corresponding numerical range, whether manual or automatic. An automatic contour range is established from the maximum and minimum values of the entities to be plotted.
8.3.5 View

This menu option offers the following facilities discussed with reference to the initiating buttons.

Scale

This specifies the displacement/mode scale to be used.

Two independent scale values can be specified for plotting the deflected shape (i.e. mode = 0) and the eigenvalue modes (i.e. mode > 0).

For large displacement analysis, the scale for the deflected shape (mode = 0) is normally specified as (1).

For eigenvalue analysis, a large scale (>>1) may need to be specified to distinguish the mode shape from the initial undeflected shape.

Different scales can be specified for the global X, Y and Z displacement components (e.g. 1 for X and 0 for Y & Z to consider only the X displacements), though identical scales are commonly used for realistic deflected shapes.

Select

This allows the selection of any of the three stored views in addition to the previous view. By default, the three views correspond to normal views of the i) X-Y, ii) X-Z and iii) Y-Z planes.

Store

This allows the storage of the current view into one of the three available views.

Customize

This enables customisation of the current view, including i) axes orientation, ii) zoom centre, iii) zoom scale, and iv) normal/perspective specification.
Chapter 9. Examples

9.1 Space dome subject to vertical apex load

The dome space structure shown in the figure has been widely considered in the verification of nonlinear analysis methods for 3D frames. The aim here is to be able to predict the lowest buckling mode of the dome.

![Diagram of a space dome]

In order to illustrate the behaviour of the structure under an increasing load, here is going to be used ADAPTIC, which has the capability of predicting the large displacements static and dynamic behaviour of elastic and inelastic plane and space frames.

figure 9.1. Configuration of space dome subject to vertical apex load.
9.1.1 Data file

# analysis 3d static  (a)
#
# materials     (b)
mat.name    model      properties
mat1       beth   20690  0.172  0.0

# sections     (c)
type = rss
sec.name    mat.name   dimensions
sect1      mat1       0.76  1.22

# groups      (d)
type = qel3
grp.name       sec.name
   gpl         sect1

# structural   (e)

nod.n     x       y   z
  1      0         0        0
 11     6.286   -10.886   -1.551
 12    12.572     0.002   -1.552
 13     6.288    10.888   -1.553
 14    -6.287    10.887   -1.552
 15   -12.573     0.003   -1.553
 16    -6.286   -10.886   -1.551
 21    12.190    -21.115   -6.10
 22    24.380     0       -6.10
 23    12.190     21.115   -6.10
 24   -12.190     21.115   -6.10
 25   -24.380     0       -6.10
 26   -12.190   -21.115   -6.10

# non.structural   (f)

nod.name x         y        z
   1011     6.286   -10.886   10
   1012    12.572     0.002   10
   1013     6.288    10.888   10
   1014    -6.287    10.887   10
   1015   -12.573     0.003   10
   1016    -6.286   -10.886   10

# restraints      (g)
direction = x+y+z+rx+ry+rz

f    21
r    1    5

# element.connectivity   (h)

grp.name = gpl
elem.name   nod.name
f    1       21   11   1011
r    1        1    1      1  5

#
f    11       11    1  1011
r    1        1    0      1  5

#
f    21       11   12  1011
r    1        1    1      1  4

191
# applied.loading (i)
proportional

type = force

<table>
<thead>
<tr>
<th>nod.name</th>
<th>direction</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>z</td>
<td>-1</td>
</tr>
</tbody>
</table>

# phases (j)

load.control

<table>
<thead>
<tr>
<th>increment</th>
<th>path</th>
<th>steps</th>
</tr>
</thead>
<tbody>
<tr>
<td>70</td>
<td>k</td>
<td>14</td>
</tr>
</tbody>
</table>

displacement.control

<table>
<thead>
<tr>
<th>nod.name</th>
<th>dire</th>
<th>increment</th>
<th>path</th>
<th>steps</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>rz</td>
<td>-0.24</td>
<td>k</td>
<td>30</td>
</tr>
<tr>
<td>1</td>
<td>z</td>
<td>-3</td>
<td>k</td>
<td>20</td>
</tr>
</tbody>
</table>

# iterative.strategy (k)

number = 10
initial.reformations = 10
step.reduction = 10
divergence.iteration = 8
maximum.convergence = 1e+8

# convergence.criteria (l)

tolerance = 0.1e-5
force.ref = 1
moment.ref = 1

# output (m)

frequency 1 local

# end
### 9.1.2 Structural behaviour

The nonlinear analysis is undertaken using one element per member, the response shown in the figure illustrate the ability of this method to predict the lowest buckling mode and to trace the associated post buckling path when an imperfect dome is considered. Here is been obtained how the vertical apex deflection varies while the load increases.

![Figure 9.1.2.a. Response of space dome structure.](image)

As is shown in the figure there is a first path where the displacements of the structure are almost proportional to the load, but when is arrived to a certain value of load, the displacement are nonlinear, and they increase more than the load.

It is evident that the introduction of small imperfections activates the lowest buckling mode, which involves a planar rotational mode, like is shown in the figure. In the absence of these imperfections the dome deflects fully symmetric about the dome apex (papers).
figure 9.1.2.b. Final deflected shape of space imperfect dome.
9.1.3 Output file

ADAPTIC also give an output file, where can be found the way that the program calculates the structure.

```
ELEMENT ASSEMBLY ORDER

1 11 21 26 2 12 22 23 4
14 15 16 6 25 3 24 5

MAXIMUM FRONT: (NODAL = 5) - (ADDITIONAL FREEDOMS = 0)

PHASE NUMBER = 1
TYPE = LOAD CONTROL
INCREMENT FACTOR = 0.700000E+02
NUMBER OF STEPS = 14

VARIABLE LOAD

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>LOAD</th>
<th>OUTPUT FACTOR</th>
<th>LEVEL</th>
<th>CONV.-NORM</th>
<th>ITERATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.50000000E+01</td>
<td>0</td>
<td>0.546E-10</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.10000000E+02</td>
<td>0</td>
<td>0.883E-10</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.15000000E+02</td>
<td>0</td>
<td>0.162E-09</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.20000000E+02</td>
<td>0</td>
<td>0.293E-09</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.25000000E+02</td>
<td>0</td>
<td>0.568E-09</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.30000000E+02</td>
<td>0</td>
<td>0.118E-08</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0.35000000E+02</td>
<td>0</td>
<td>0.266E-08</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0.40000000E+02</td>
<td>0</td>
<td>0.659E-08</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>0.45000000E+02</td>
<td>0</td>
<td>0.185E-07</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>0.50000000E+02</td>
<td>0</td>
<td>0.613E-07</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>11</td>
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9.2 K-frame subject to vertical load

The k-frame, shown in the figure, is subjected to an end force $P$, where load application in the middle of the upper frame. The buckling forces for this frame where also obtained with ADAPTIC, where the following values were reported using 4 elements.

Transverse beam:
\[ \Phi 219 \times 4.37 \text{mm}^2 \]
\[ E = 210 \times 10^3 \text{N/mm}^2 \]
\[ \sigma_y = 414 \text{N/mm}^2 \]

Diagonal members:
\[ \Phi 101.7 \times 3.3 \text{mm}^2 \]
\[ E = 210 \times 10^3 \text{N/mm}^2 \]
\[ \sigma_y = 335 \text{N/mm}^2 \]

figure 9.2.a Geometric configuration of K-frame.
9.2.1 Data file

# analysis 2d statics

# materials
mat.name    model  properties
mat1       stl1  0.210e6 0.335e3 0.00
mat2       stl1  0.210e6 0.414e3 0.00

# sections
type = chs
sec.name    mat.name   dimensions
sect1      mat1       101.7  3.30
sect2      mat2       219.0  4.37

# groups
type = qph2
grp.name  sec.name      subdivision
grp1          sect1  t
grp2          sect2  f

# structural.nodal
nod.n       x     y
f 1     0000.0    0000.0
r 1     2790.0      0000.0 1
f 3     0000.0      4600.0
r 1     1395.0  0000.0 2

# restraints
nod.name direction
f 1        x+y
r 1       -    1
f 3             x+y+rz
r 2               -      1

# element.connectivity
elm.name     grp.name nod.name
f 1         grp1  1  4
r 1           -  3 -2   1
f 3         grp2  3  4
r 1           -  1  1   1

# imperfection
elm.name             values
1         -3.6  -4.8 -3.6
2   3.6   4.8  3.6

# applied.loading
proportional
nod.name  direction type    value
 4     y   force  -0.100e+7

# condition
disp.cnd.name nod.name direction limits
 1    4     y  -300.0 0.0

# phases
load.control
increment path steps
Note The following picture shows the names that have been given to the nodes and elements in the data file.

*figure 9.2.1 Nodes and elements of the K-frame.*
9.2.2 Structural behaviour

The nonlinear analysis is undertaken using one element per member, the response shown in the figure 9.2.2a shows the static response of K-frame.

![Graph showing static response of K-frame](image)

*figure 9.2.2a Static response of K-frame*

Here is shown the ability of this method to predict the lowest buckling mode and to trace the associated post-buckling path when an imperfect K-frame is considered.

The figure illustrates that the higher displacements of the structure are in the X-direction of the frame. When is arrived to a certain value of load, the displacement increase with fewer loads, and with minor load you can obtain higher displacements.

The following figure illustrates the response of modelling K-frame with the plastic-hinge approach.
It is evident that the introduction of small imperfections activates the lowest buckling mode, which involves a deflection shape, like is shown in the figure. In the absence of these imperfections the K-frame deflects fully symmetric about symmetry axes.
9.2.3  Output file

This is the output file given by ADAPTIC.

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ELEMENT ASSEMBLY ORDER
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1    2    3    4
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+++++++++++++++++++

V A R I A B L E    L O A D I N G
+++++++++++++++++++++++++++++++

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Phase (1) terminated
+++++++++++++++++++++++

PHASE NUMBER = 2
NODAL DISPLACEMENT CONTROL
GLOBAL DIRECTION = Y
CONTROLLED NODE = 4

<table>
<thead>
<tr>
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<th>OUTPUT</th>
<th>INCREMENT</th>
<th>FACTOR</th>
<th>LEVEL</th>
<th>CONV.-NORM</th>
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```

203
### Subdivision of Element 1

**Number of Nodes Created**

- **#n1**: 1 node

<table>
<thead>
<tr>
<th>Node Name</th>
<th>Coordinates (x, y) Relative to End(1) of Subdivided Element</th>
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</thead>
<tbody>
<tr>
<td>#n1</td>
<td>0.537226E+03, 0.175588E+04</td>
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</tbody>
</table>

**Number of Elements Created**

- **#e1**: 1 element
- **#e2**: 1 element

<table>
<thead>
<tr>
<th>Element Name</th>
<th>Type of Element</th>
<th>Node Names</th>
</tr>
</thead>
<tbody>
<tr>
<td>#e1</td>
<td>qph2</td>
<td>#n1</td>
</tr>
<tr>
<td>#e2</td>
<td>qph2</td>
<td>#n1, 4</td>
</tr>
</tbody>
</table>

**Number of Imperfect Elements**

- **#e1**: 2 imperfect elements
- **#e2**: 2 imperfect elements

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<tr>
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<th>TH1I</th>
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<th>TI</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.152581E-02</td>
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<td>-246847E-02</td>
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<td>-.183324E+01</td>
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Plastic hinge formed for element #e3 at node 4

Plastic hinge formed for element #e2 at node #n1

### Subdivision of Element 2

**Number of Nodes Created**

- **#n2**: 1 node

<table>
<thead>
<tr>
<th>Node Name</th>
<th>Coordinates (x, y) Relative to End(1) of Subdivided Element</th>
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</thead>
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**Number of Elements Created**

- **#e3**: 1 element
- **#e4**: 1 element

<table>
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<th>Type of Element</th>
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</thead>
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<td>qph2</td>
<td>4, #n2</td>
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<tr>
<td>#e4</td>
<td>qph2</td>
<td>#n2, 2</td>
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**Number of Imperfect Elements**

- **#e3**: 1 imperfect element
- **#e4**: 1 imperfect element

<table>
<thead>
<tr>
<th>Element Name</th>
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<th>TH2I</th>
<th>TI</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.183647E+01</td>
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<td>#e4</td>
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Plastic hinge formed for element 3 at node 4

Plastic hinge formed for element 4 at node 3
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<th>Y-Coordinate</th>
<th>Z-Coordinate</th>
<th>Temperature</th>
<th>Elemental Damage</th>
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Plastic hinge closed for element #e2 at node 4

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<th>Elemental Damage</th>
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Plastic hinge formed for element 4 at node 4

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Plastic hinge formed for element 4 at node 4

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<th>Y-Coordinate</th>
<th>Z-Coordinate</th>
<th>Temperature</th>
<th>Elemental Damage</th>
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</table>
9.3 Lee’s frame

The Lee’s frame, shown in the figure 9.3, is subjected to an end force $P$. The buckling forces for this frame were also obtained with ADAPTIC, where the following values were reported using 3 elements.

- $L=120\text{cm}$
- $E=720\text{ ton/cm}^2$
- Mass per unit length = $0.24 \times 10^{-5} \text{ ton} \cdot \text{sec}^2/\text{cm}^2$

$figure\ 9.3\ Geometry\ and\ loading\ of\ Lee’s\ frame.$
## 9.3.1 Data file

```plaintext
# analysis 2d statics       (a)
# control start
#
# materials
mat.name model properties
mat1 stl1 0.720e3 0.100e1 0.00
#
# sections
  type = rss
sec.name mat.name dimensions
sect1 mat1 3.0 2.0
#
# groups
type.of.element = qel12
grp.name sec.name
grp1 sect1
#
# structural

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<th>y</th>
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</tr>
<tr>
<td>4</td>
<td>120.00</td>
<td>120.00</td>
</tr>
</tbody>
</table>
#
# restraints

<table>
<thead>
<tr>
<th>nod.name direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 x+y</td>
</tr>
<tr>
<td>4 x+y</td>
</tr>
</tbody>
</table>
#
# element.connectivity
elm.name grp.name nod.
  f 1 grp1 1 2
  r 1 - 1 1 2
#
# applied.loading
proportional.loads
  nod.name direction type value
    3 y force -0.10e+1
#
# condition
lf.cnd.name limits
  1 -2.0 2.0
disp.cnd.name nod.name direction limits
  2 3 x -0.12e+3 0.12e+3
  3 3 y -0.12e+3 0.12e+3
#
# phases
load.control
  increment path steps
    0.2e+1 k 20
automatic.control
type path cnd.name
nodal translation c 1 2 3
#
# iterative.strategy
  number = 5
```

207
initial.reformations = 5
step.reduction = 5
divergence.iteration = 4
maximum.convergence = 0.1e3
#
convergence.criteria
    tolerance = 0.1e-5
    force = 0.2e+1
    mome = 0.1e+3
#
output
    frequency 0
#
end

**Note:** The elements and the nodes that are used are shown in the figure 9.3.1.

*figure 9.3.1 Nodes and elements of Lee’s frame.*
9.3.2 Structural behaviour

The nonlinear analysis is undertaken using one element per member. The following figures show the static response of Lee’s frame.

The node 1 only experiments rotation, as could be seen in the figure. It has the same behaviour as the node 4.

The nodes 2 and 3 have similar behaviour,

![Figure 9.3.2a Static response of Lee’s frame at node 3.](image)

This is the deformed shape of the Lee’s frame. As it could be seen, nodes 1 and 4 only experiment rotation, and the displacements of node 2 are bigger than the displacements of node 3, even the develop in the time follows the same tendency.
The real deflected shape of Lee’s frame when the load increase vary like is shown in the following figure.
## 9.3.3 Output file

**ELEMENT ASSEMBLY ORDER**

```
1 2 3
```

**MAXIMUM FRONT:** (NODAL = 2) - (ADDITIONAL FREEDOMS = 0)

```
VARIABLE LOADING
```

**PHASE NUMBER = 1**

**TYPE = LOAD CONTROL**

**INCREMENT FACTOR = 0.200000E+01**

**NUMBER OF STEPS = 20**

<table>
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<tr>
<th>VARIABLE LOAD</th>
<th>OUTPUT</th>
<th>FACTOR</th>
<th>LEVEL</th>
<th>CONV.-NORM</th>
<th>ITERATIONS</th>
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**PHASE NUMBER = 2**

**NODAL DISPLACEMENT CONTROL**

**GLOBAL DIRECTION = X**

**CONTROLLED NODE = 2**

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**Phase (1) terminated**

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211


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Current control type terminated

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NODAL DISPLACEMENT CONTROL
GLOBAL DIRECTION = Y
CONTROLLED NODE = 3

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Current control type terminated

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GLOBAL DIRECTION = Y
CONTROLLED NODE = 2

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<td>0.116E-10</td>
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</table>
9.4 Fixed ended beam-column

The fixed ended beam-column, shown in the figure 9.4, is subjected to two vertical symmetric forces $P$, and to an horizontal force. The buckling forces for this frame were obtained using 3 elements.

![Figure 9.4 Geometry of fixed ended beam-column.](image)

*Figure 9.4 Geometry of fixed ended beam-column.*
9.4.1 Data file

# analysis 2d statics (a)

# materials (b)

<table>
<thead>
<tr>
<th>mat.name</th>
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<th>properties</th>
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<td>mat1</td>
<td>stl2</td>
<td>42 properties for multisurface steel model follow</td>
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<td></td>
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<td>0.000000e+00 0.000000e+00 0.000000e+00</td>
</tr>
</tbody>
</table>

sections (c)

# circular hollow section

sec.name | mat.name | dimensions |
sect1    | mat1     | 114.0 2.3 |

patterns (p)

# subdivision patterns for elements "qdp2"

pat.name | ratios |
pat1     | 1 2 3 4 5 |
pat2     | 3 2 1 2 3 |

# groups (d)

type = cbp2

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<tr>
<th>grp.name</th>
<th>sec.name</th>
<th>monitoring.points</th>
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type = qdp2

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<td>pat1</td>
</tr>
<tr>
<td>grp3</td>
<td>grp1</td>
<td>pat2</td>
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# structural.nodal (e)

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<th>y</th>
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<td>0.0</td>
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<tr>
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<tr>
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</tr>
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</table>

# restraints (g)

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<th>direction</th>
</tr>
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<tbody>
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<td>x+y+rz</td>
</tr>
<tr>
<td>4</td>
<td>y+rz</td>
</tr>
</tbody>
</table>

215
element.connectivity

elm.name    grp.name nod.name
1        grp2  1  2
2        grp3  2  3
3        grp2  4  3

# linear.curves  # curves for time history loads
start.time = 0.0
crv.name = c1
time    load.factor
1        -1.0
3        1.0
5        -1.0

# applied.loading
initial

nod.name    direction type    value
f 2       y  force   -0.1005e+4
r 1       -    -      0.0     1

time.history

nod.name    direction type    crv.name value
4       x    disp     c1     40.0

# equilibrium.stages
end.of.stage steps
5.0  200

# use default iterative strategy

tolerance = 0.1e-5
force.ref = 0.1e+6
moment.ref = 0.1e+8

# output
frequency 0 stress  # all equilibrium steps including step reduction
levels

# end

Note  The following picture shows the names that have been given to the nodes and elements in the data file.

figure 9.4.1 Nodes and elements of fixed ended beam-column.
9.4.2 Structural behaviour

The nonlinear analysis is undertaken using one element per member. The following figures show the static response of fixed ended beam-column.

The nodes 1 and 4, only experiments rotation. The nodes 2 experiments a small displacement in X-axes and a bigger one in the Y-axes, and does not exist any rotation.

\textit{figure 9.4.2b Displacements of fixed ended beam-column.}

The deformed shape that experiments the beam subject at those loads is the following one:

\textit{figure 9.4.2b Deflected Shape of fixed ended beam-column.}
9.4.3 Output file

ELEMENT ASSEMBLY ORDER

---->>>> ---->>>> ---->>>> ---->>>> ---->>>> ---->>>> ---->>>> ---->>>>
1        2        3

MAXIMUM FRONT: (NODAL = 3) - (ADDITIONAL FREEDOMS = 0)

INITIAL LOADING

+++

INITIAL LOADINGS

+++++++  

OUTPUT FACTOR CURRENT OUTPUT ITERATIONS

1  0.10000000E+01  0.00000000E+00  0  0.303E-07  1

VARIABLE LOADING

+++++++  

CURRENT OUTPUT TIME LEVEL CONV.-NORM ITERATIONS

2  0.25000000E-01  0  0.326E-06  1
3  0.50000000E-01  0  0.584E-06  1
4  0.75000000E-01  0  0.155E-12  2

********************( SUBDIVISION OF ELEMENT 1 )********************

* * * NUMBER OF NODES CREATED *
* 3 *
* NOD.NAME COORD'S (X,Y) RELATIVE TO END(1) OF SUBDIVIDED ELEMENT *
* #n1  0.127333E+03  0.000000E+00 *
* #n2  0.382000E+03  0.000000E+00 *
* #n3  0.764000E+03  0.000000E+00 *
*----------------------------------------------------------------------*
* * * NUMBER OF ELEMENTS CREATED *
* 4 *
* ELM.NAME TYPE.OF.ELEMENT NOD.NAMES *
* #e1  cbp2 1 #n1 *
* #e2  cbp2 #n1 #n2 *
* #e3  cbp2 #n2 #n3 *
* #e4  qdp2 #n3 2 *
*----------------------------------------------------------------------*
* * * NUMBER OF IMPERFECT ELEMENTS *
* 0 *

**********************************************************************************

***********************************************************************

********************( SUBDIVISION OF ELEMENT 2 )********************

* * * NUMBER OF NODES CREATED *
* 4 *
* NOD.NAME COORD'S (X,Y) RELATIVE TO END(1) OF SUBDIVIDED ELEMENT *
* #n4  0.518182E+03  0.000000E+00 *
* #n5  0.863636E+03  0.000000E+00 *
* #n6  0.103636E+04  0.000000E+00 *

***********************************************************************
* #n7                    0.138182E+04          0.000000E+00            *
*----------------------------------------------------------------------*
*                                                                      *
*NUMBER OF ELEMENTS CREATED                                            *
*             5                                                        *
* ELM.NAME   TYPE.OF.ELEMENT         NOD.NAMES                         *
* #e5           cbp2                 2         #n4                     *
* #e6           cbp2                 #n4       #n5                     *
* #e7           cbp2                 #n5       #n6                     *
* #e8           cbp2                 #n6       #n7                     *
* #e9           cbp2                 #n7       3                       *
*----------------------------------------------------------------------*
*                                                                      *
*NUMBER OF IMPERFECT ELEMENTS                                          *
*             0                                                        *
*----------------------------------------------------------------------*
*                                                                      *
*NUMBER OF IMPERFECT ELEMENTS                                          *
*             0                                                        *
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*------------------------------------------------------------------------*
**SUBDIVISION OF ELEMENT #e13**

*NUMBER OF NODES CREATED*

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<tr>
<th>NOD.NAME</th>
<th>COORD'S (X, Y) RELATIVE TO END(1) OF SUBDIVIDED ELEMENT</th>
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</thead>
<tbody>
<tr>
<td>#n12</td>
<td>-.509333E+03 0.000000E+00</td>
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</tbody>
</table>

*NUMBER OF ELEMENTS CREATED*

<table>
<thead>
<tr>
<th>ELM.NAME</th>
<th>TYPE.OF.ELEMENT</th>
<th>NOD.NAMES</th>
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</thead>
<tbody>
<tr>
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<td>cbp2</td>
<td>#n10 #n12</td>
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<tr>
<td>#e17</td>
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<td>#n12 3</td>
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*NUMBER OF IMPERFECT ELEMENTS*

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<th>UNITS</th>
<th>NOD (X, Y)</th>
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<th>MINTOT</th>
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<td>0.208E-08</td>
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<td>0.35000000E+00</td>
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<tr>
<td>17</td>
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<td>0.40000000E+00</td>
<td>0.508E-07</td>
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<tr>
<td>18</td>
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<td>0.42500000E+00</td>
<td>0.411E-07</td>
<td>2</td>
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<tr>
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<td>0.574E-07</td>
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<tr>
<td>21</td>
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<td>0.50000000E+00</td>
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<td>0.52500000E+00</td>
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<tr>
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<td>0.55000000E+00</td>
<td>0.841E-07</td>
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9.5 Two-storey frame

This example illustrates the influence of an earthquake on the resistance of steel frames.

*figure 9.5 Steel frames subject to earthquake.*
9.5.1 Data file

# analysis 2d dynamics
(a) #

# materials
(b)
mat.name   model   properties
mat1       stl1     0.210e12 0.300e9 0.100e-1

# sections
(c)
type = rss
sec.name   mat.name   dimensions
sect1      mat1       0.10 0.10

# patterns
(p)
pat.name   ratios
pat1       1 2 3 3 2 1

# groups
(d)
type = cbp2
grp.name   sec.name   monitoring.points
grp1       sect1      30


type = qdp2
grp.name   cbp2.grp.name   pat.name
grp2       grp1            pat1


type = cnm2
grp.name   mass
grp3       20000

# structural
(e)
nod.n   x   y
f 1     0.0  0.0
r 1     6.0  0.0 1
r 2     0.0  4.0 2

# restraints
(f)
direction = y+rz
nod.name
  1
  2

# element.connectivity
(g)
grp.name = grp2
elm.name   nod.name
f 1     1   3
r 1     1   1 1
r 2     2   2 1
  5     3   4
  6     5   6

grp.name = grp3
elm.name   nod.name
f 10    3
r 1     1   3

# integration
(r)
scheme = newmark
beta    = 0.25
gamma   = 0.5
Note The following picture shows the names that have been given to the nodes and elements in the data file.

figure 9.5.1 Nodes and elements of the two-storey.
9.5.2 Structural behaviour

The nonlinear analysis is undertaken using one element per member. The following figures show the dynamic response of the structure.

The displacements of the node 121 at the Y-axes are almost inexistent compare into the ones at the X-axes, which vary with the time.

\[ \text{figure 9.5.2b Displacements of two-storey.} \]

The deformed shape given by ADAPTIC is the one shown in the figure, where could be seen that the main effect of the earthquake is a translation of the structure.

\[ \text{figure 9.5.2b Deflected Shape of two-storey.} \]
### 9.5.3 Output file

**ELEMENT ASSEMBLY ORDER**

```
1 3 5 10 6 12 4 13
2 11
```

**MAXIMUM FRONT:** (NODAL = 4) - (ADDITIONAL FREEDOMS = 0)

++++++++++++++++

**VARIABLE LOADING**

++++++++++++++++++++++

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 ***************( SUBDIVISION OF ELEMENT 1 )***************
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*  #n1 0.000000E+00  0.333333E+00 *  
*----------------------------------------------------------------------*  
* *  
*NUMBER OF ELEMENTS CREATED *  
* 2  
* ELM.NAME TYPE.OF.ELEMENT NOD.NAMES  
* #e1  cbp2 1  #n1  
* #e2  qdp2 3  
*----------------------------------------------------------------------*  
* *  
*NUMBER OF IMPERFECT ELEMENTS *  
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  0  0.17000000E+01  0  0.317E-04   1
87  0.17400000E+01  0  0.374E-04   1

 ********************( SUBDIVISION OF ELEMENT 2 )********************
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* ELM.NAME TYPE.OF.ELEMENT NOD.NAMES  
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* #e4  qdp2 4  
*----------------------------------------------------------------------*  
* *  
*NUMBER OF IMPERFECT ELEMENTS *  
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 0  0.17300000E+01  0  0.317E-04   1
87  0.17400000E+01  0  0.374E-04   1

 ********************( SUBDIVISION OF ELEMENT #e2 )********************
* *  
*NUMBER OF NODES CREATED *  
* 1  
* NOD.NAME COORD'S (X,Y) RELATIVE TO END(1) OF SUBDIVIDED ELEMENT *  
*  #n3 0.000000E+00  0.333333E+01 *  
*----------------------------------------------------------------------*  
* *  
*NUMBER OF ELEMENTS CREATED *  
* 2  
* ELM.NAME TYPE.OF.ELEMENT NOD.NAMES  
* #e6  cbp2 3  #n3  
* #e5  qdp2  

*------------------------------------------------------------------------*
* NUMBER OF IMPERFECT ELEMENTS                                          *
* 0                                                                      *
*----------------------------------------------------------------------*

********************( SUBDIVISION OF ELEMENT #e4 )********************
* NUMBER OF NODES CREATED                                               *
* 1                                                                      *
* NOD.NAME    COORD'S (X,Y) RELATIVE TO END(1) OF SUBDIVIDED ELEMENT *
* #n4  0.000000E+00          0.333333E+01 *
*----------------------------------------------------------------------*

* NUMBER OF ELEMENTS CREATED                                            *
* 2                                                                      *
* ELM.NAME   TYPE.OF.ELEMENT         NOD.NAMES                         *
* #e8        cbp2                 #n4       4                          *
* #e7        qdp2                 #n2       #n4                          *
*----------------------------------------------------------------------*

* NUMBER OF IMPERFECT ELEMENTS                                          *
* 0                                                                      *
*----------------------------------------------------------------------*

0       0.17500000E+01         0      0.727E-04         1
88       0.17600000E+01         0      0.624E-04         1
0       0.17700000E+01         0      0.327E-04         1

********************( SUBDIVISION OF ELEMENT #e5 )********************
* NUMBER OF NODES CREATED                                               *
* 1                                                                      *
* NOD.NAME    COORD'S (X,Y) RELATIVE TO END(1) OF SUBDIVIDED ELEMENT *
* #n5  0.000000E+00          0.666667E+00 *
*----------------------------------------------------------------------*

* NUMBER OF ELEMENTS CREATED                                            *
* 2                                                                      *
* ELM.NAME   TYPE.OF.ELEMENT         NOD.NAMES                         *
* #e9        cbp2                 #n1       #n5                          *
* #e10       qdp2                 #n5       #n3                          *
*----------------------------------------------------------------------*

* NUMBER OF IMPERFECT ELEMENTS                                          *
* 0                                                                      *
*----------------------------------------------------------------------*

********************( SUBDIVISION OF ELEMENT #e7 )********************
* NUMBER OF NODES CREATED                                               *
* 1                                                                      *
* NOD.NAME    COORD'S (X,Y) RELATIVE TO END(1) OF SUBDIVIDED ELEMENT *
* #n6  0.000000E+00          0.666667E+00 *
*----------------------------------------------------------------------*

* NUMBER OF ELEMENTS CREATED                                            *
* 2                                                                      *
* ELM.NAME   TYPE.OF.ELEMENT         NOD.NAMES                         *
**NUMBER OF IMPERFECT ELEMENTS**
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********************( SUBDIVISION OF ELEMENT 5 )********************

**NUMBER OF NODES CREATED**
* 2

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* 3
* ELM.NAME   TYPE.OF.ELEMENT   NOD.NAMES
* #e13       cbp2              3      #n7
* #e15       cbp2              #n8     4
* #e14       qdp2              #n7    #n8
*
*NUMBER OF IMPERFECT ELEMENTS
* 0

***************************************************************************************
0  0.223000000E+01  0  0.809E-05  1
***************************************************************************************

********************( SUBDIVISION OF ELEMENT 3 )*******************

*NUMBER OF NODES CREATED
* 1
* NOD.NAME   COORD'S (X,Y) RELATIVE TO END(1) OF SUBDIVIDED ELEMENT
* #n9    0.000000E+00  0.366667E+01

***************************************************************************************

*NUMBER OF ELEMENTS CREATED
* 2
* ELM.NAME   TYPE.OF.ELEMENT   NOD.NAMES
* #e17       cbp2              #n9     5
* #e16       qdp2              3      #n9

***************************************************************************************

*NUMBER OF IMPERFECT ELEMENTS
* 0

********************( SUBDIVISION OF ELEMENT 4 )*******************

*NUMBER OF NODES CREATED
* 1
* NOD.NAME   COORD'S (X,Y) RELATIVE TO END(1) OF SUBDIVIDED ELEMENT
* #n10   0.000000E+00  0.366667E+01

***************************************************************************************

*NUMBER OF ELEMENTS CREATED
* 2
* ELM.NAME   TYPE.OF.ELEMENT   NOD.NAMES
* #e19       cbp2              #n10    6
* #e18       qdp2              4      #n10

***************************************************************************************

*NUMBER OF IMPERFECT ELEMENTS
* 0

********************( SUBDIVISION OF ELEMENT 6 )*******************

*NUMBER OF NODES CREATED
* 2
* NOD.NAME   COORD'S (X,Y) RELATIVE TO END(1) OF SUBDIVIDED ELEMENT
*
* #n11                   0.500000E+00          0.000000E+00            *
* #n12                   0.550000E+01          0.000000E+00            *
*----------------------------------------------------------------------*
*                                                                      *
*NUMBER OF ELEMENTS CREATED                                            *
*             3                                                        *
* ELM.NAME   TYPE.OF.ELEMENT         NOD.NAMES                         *
* #e20          cbp2                 5         #n11                    *
* #e22          cbp2                 #n12      6                       *
* #e21          qdp2                 #n11      #n12                    *
*----------------------------------------------------------------------*
*                                                                      *
*NUMBER OF IMPERFECT ELEMENTS                                          *
*             0                                                        *
************************************************************************

112       0.22400000E+01    0      0.608E-05         1
********************(  SUBDIVISION OF ELEMENT #e16     )****************
*                                                                      *
*NUMBER OF NODES CREATED                                               *
*           1                                                          *
* NOD.NAME      COORD'S (X,Y) RELATIVE TO END(1) OF SUBDIVIDED ELEMENT *
* #n13                   0.000000E+00          0.333333E+00            *
*----------------------------------------------------------------------*
*                                                                      *
*NUMBER OF ELEMENTS CREATED                                            *
*             2                                                        *
* ELM.NAME   TYPE.OF.ELEMENT         NOD.NAMES                         *
* #e23          cbp2                 3         #n13                    *
* #e24          qdp2                 #n13      #n9                     *
*----------------------------------------------------------------------*
*                                                                      *
*NUMBER OF IMPERFECT ELEMENTS                                          *
*             0                                                        *
************************************************************************

0       0.22500000E+01    0      0.183E-04         1
113       0.22600000E+01    0      0.814E-05         1
0       0.22700000E+01    0      0.951E-05         1
114       0.22800000E+01    0      0.257E-04         1
***************( SUBDIVISION OF ELEMENT #e24 )***************
  *  
  *NUMBER OF NODES CREATED  
  *  1  
  * NOD.NAME COORD'S (X,Y) RELATIVE TO END(1) OF SUBDIVIDED ELEMENT  
  * #n15 0.000000E+00 0.666667E+00  
  *---------------------------------------------------------------*  
  *  
  *NUMBER OF ELEMENTS CREATED  
  *  2  
  * ELM.NAME TYPE.OF.ELEMENT NOD.NAMES  
  * #e27 cbp2 #n13 #n15  
  * #e28 qdp2 #n15 #n9  
  *---------------------------------------------------------------*  
  *  
  *NUMBER OF IMPERFECT ELEMENTS  
  *  0  
  *******************************************************

***************( SUBDIVISION OF ELEMENT #e26 )***************
  *  
  *NUMBER OF NODES CREATED  
  *  1  
  * NOD.NAME COORD'S (X,Y) RELATIVE TO END(1) OF SUBDIVIDED ELEMENT  
  * #n16 0.000000E+00 0.666667E+00  
  *---------------------------------------------------------------*  
  *  
  *NUMBER OF ELEMENTS CREATED  
  *  2  
  * ELM.NAME TYPE.OF.ELEMENT NOD.NAMES  
  * #e29 cbp2 #n14 #n16  
  * #e30 qdp2 #n16 #n10  
  *---------------------------------------------------------------*  
  *  
  *NUMBER OF IMPERFECT ELEMENTS  
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***************( SUBDIVISION OF ELEMENT #e30 )***************
  *  
  *NUMBER OF NODES CREATED  
  *  1  
  * NOD.NAME COORD'S (X,Y) RELATIVE TO END(1) OF SUBDIVIDED ELEMENT  
  * #n17 0.000000E+00 0.200000E+01  
  *---------------------------------------------------------------*  
  *  
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  * ELM.NAME TYPE.OF.ELEMENT NOD.NAMES  
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124 0.24400000E+01 0 0.667E-06 1
125 0.24500000E+01 0 0.412E-05 1
126 0.24600000E+01 0 0.515E-05 1
127 0.24700000E+01 0 0.527E-06 1
128 0.24800000E+01 0 0.492E-05 1
129 0.24900000E+01 0 0.217E-04 1
130 0.25000000E+01 0 0.531E-06 1
131 0.25100000E+01 0 0.515E-06 1
132 0.25200000E+01 0 0.562E-06 1
133 0.25300000E+01 0 0.546E-06 1
134 0.25400000E+01 0 0.760E-06 1
135 0.25500000E+01 0 0.917E-06 1
136 0.25600000E+01 0 0.101E-05 1
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0       0.41500000E+01    0      0.369E-05         1
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0       0.41700000E+01    0      0.138E-04         1
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211       0.42200000E+01    0      0.495E-05         1
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0       0.42700000E+01    0      0.544E-05         1
214       0.42800000E+01    0      0.776E-05         1
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0       0.43100000E+01    0      0.139E-04         1
216       0.43200000E+01    0      0.405E-04         1
0       0.43300000E+01    0      0.139E-04         1
217       0.43400000E+01    0      0.116E-04         1

**************************************************( SUBDIVISION OF ELEMENT #e14 )**************************************************

*NUMBER OF NODES CREATED
*
* 2
*
* NOD.NAME      COORD'S (X,Y) RELATIVE TO END(1) OF SUBDIVIDED ELEMENT
*
* #n21                   0.100000E+01          0.000000E+00
* #n22                   0.400000E+01          0.000000E+00
*

*NUMBER OF ELEMENTS CREATED
*
* 3
*
* ELM.NAME   TYPE.OF.ELEMENT         NOD.NAMES
*
* #e39          cbp2                 #n7       #n21
* #e41          cbp2                 #n22      #n8
* #e40          qdp2                 #n21      #n22
*

*NUMBER OF IMPERFECT ELEMENTS
*
* 0

**************************************************************************

0       0.43500000E+01    0      0.253E-04         1
218       0.43600000E+01    0      0.844E-05         1
0       0.43700000E+01    0      0.258E-04         1
219       0.43800000E+01    0      0.280E-04         1
0       0.43900000E+01    0      0.492E-05         2
220       0.44000000E+01    0      0.956E-04         1
0       0.44100000E+01    0      0.657E-04         1
221       0.44200000E+01    0      0.168E-04         1
0       0.44300000E+01    0      0.231E-04         1
222       0.44400000E+01    0      0.218E-04         1
0       0.44500000E+01    0      0.181E-04         1
223       0.44600000E+01    0      0.190E-04         1
0       0.44700000E+01    0      0.463E-04         1
224       0.44800000E+01    0      0.983E-05         1
0       0.44900000E+01    0      0.137E-04         1
225       0.45000000E+01    0      0.326E-04         1
0       0.45100000E+01    0      0.339E-04         1
226       0.45200000E+01    0      0.130E-04         1
0       0.45300000E+01    0      0.143E-04         1
227     0.45400000E+01    0      0.412E-05         1
228     0.45600000E+01    0      0.160E-05         1
0       0.45700000E+01    0      0.261E-05         1
229     0.45800000E+01    0      0.177E-05         1
0       0.45900000E+01    0      0.127E-04         1
230     0.46000000E+01    0      0.126E-04         1
231     0.46200000E+01    0      0.412E-05         1
0       0.46300000E+01    0      0.560E-04         1
232     0.46400000E+01    0      0.954E-05         1
0       0.46500000E+01    0      0.691E-06         1
233     0.46600000E+01    0      0.327E-04         1
0       0.46700000E+01    0      0.215E-04         1
234     0.46800000E+01    0      0.927E-05         1
0       0.46900000E+01    0      0.492E-05         1
235     0.47000000E+01    0      0.192E-04         1
0       0.47100000E+01    0      0.181E-04         1
236     0.47200000E+01    0      0.403E-04         1
0       0.47300000E+01    0      0.225E-04         1
237     0.47400000E+01    0      0.831E-05         1
0       0.47500000E+01    0      0.135E-04         1
238     0.47600000E+01    0      0.316E-05         1
0       0.47700000E+01    0      0.132E-04         1
239     0.47800000E+01    0      0.456E-04         1
0       0.47900000E+01    0      0.689E-05         1
240     0.48000000E+01    0      0.684E-05         1
0       0.48100000E+01    0      0.460E-04         1
241     0.48200000E+01    0      0.436E-04         1
0       0.48300000E+01    0      0.520E-05         1
242     0.48400000E+01    0      0.196E-04         1
0       0.48500000E+01    0      0.443E-04         1
243     0.48600000E+01    0      0.218E-04         1
0       0.48700000E+01    0      0.104E-04         1
244     0.48800000E+01    0      0.256E-04         1
0       0.48900000E+01    0      0.252E-04         1
245     0.49000000E+01    0      0.317E-04         1

**************************( SUBDIVISION OF ELEMENT #e12 )**************************
* * *
*NUMBER OF NODES CREATED* *
* 1* *
* NOD.NAME COORD’S (X,Y) RELATIVE TO END(1) OF SUBDIVIDED ELEMENT* *
* #n23 0.0000000E+00 0.2000000E+01* *
*---------------------------------------------------------------*
* * *
*NUMBER OF ELEMENTS CREATED* *
* 2* *
* ELM.NAME TYPE.OF.ELEMENT NOD.NAMES* *
* #e43   cbp2     #n23     #n4* *
* #e42   qdp2     #n6      #n23* *
*---------------------------------------------------------------*
* * *
*NUMBER OF IMPERFECT ELEMENTS* *
* 0* *
*-----------------------------------------------------------------------------------*
0       0.49100000E+01    0      0.196E-04         1

**************************( SUBDIVISION OF ELEMENT #e10 )**************************

242
* NUMBER OF NODES CREATED
* 1
* NOD.NAME    COORD'S (X,Y) RELATIVE TO END(1) OF SUBDIVIDED ELEMENT
* #n24        0.000000E+00    0.200000E+01
*----------------------------------------------------------------------*

* NUMBER OF ELEMENTS CREATED
* 2
* ELM.NAME    TYPE.OF.ELEMENT    NOD.NAMES
* #e45        cbp2              #n24    #n3
* #e44        qdp2              #n5    #n24
*----------------------------------------------------------------------*

* NUMBER OF IMPERFECT ELEMENTS
* 0
*----------------------------------------------------------------------*

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9.6 Steel frame subject to explosion and fire loading

This example illustrates the considerable influence of explosion on the fire resistance of steel frames, even when the extent of structural damage due to explosion is relative small.

![Steel frames subject to explosion and fire loading](image)

Figure 9.6 Steel frames subject to explosion and fire loading.

There are going to be used elasto-plastic cubic elements to resolve this example. The material model of steel used in this example covers the effects of the elevated temperature, creep and high strain-rate.
9.6.1 Data file

# Here temperatures are incremental over ambient temperature (20C)
#
analysis 2d dynamics         (a)
#
materials                     (b)
mat.name    model   properties
mat1       stl8     31.19  4.65e-3  20    &
              2.1e5  0.84e5  80.  680.  1080. &
              399.  59.9   280.  680.  980. &
              0.0   0.032  280.  680.  980. &
              0.01022 0.01652 730. 731. 1180.

# sections                     (c)
    type = isec
mat.name = mat1
    sec.name    dimensions
sec1 254.5 21.0 254.5 21.0 645.6 13.2
sec2 152.4 6.8  152.4 6.8  138.8 6.1
sec3 203.2 11.0 203.2 11.0 181.2 7.3

# patterns                     (p)
pat.name     ratios
pat1 1 1 1 1 1 1 1 1 1 1

# groups                       (d)
type = cbp2
    grp.name  sec.name      monitoring.points
grp1c sec1 40
grp2c sec2 40
grp3c sec3 40
type = qdp2
    grp.name    cbp2.grp.name    pat.name
grp1 grp1c pat1
grp2 grp2c pat1
grp3 grp3c pat1
type = cnm2
    grp.name    mass
grpml 23.4
gpm2 46.8

# structural.nodal             (e)
nod.name       x      y
f   101          0.0       0.0
r   10          0.0      4000.0 3
r   100       6000.0        0.0  3

# restraints                  (g)
nod.name direction
f 101 x+y+rz
r 100 -     3

# element.connectivity        (h)
elm.name   grp.name    nod.name
f 101      grp1        111   211
r 1        -          100   100 2
r 3        -          10   10 2
elm.name  grp.name  nod.name
f  201      grp2        101 111
r  1        -          10 10 2
r  3        -          300 300 1
#

elm.name  grp.name  nod.name
f  301      grp3        201 211
r  1        -          10 10 2
r  3        -          100 100 1
#

grp.name = gpm1
elm.name  nod.name
f  1101      111
r  1        10 2
r  3        300 1
#

grp.name = gpm2
elm.name  nod.name
f  1201      211
r  1        10 2
r  3        100 1
#

linear.curves # curves for time history loads (q)
start.time = 18
crv.name = c1
time    load.factor
18.12    1.0
18.15    0.0
1220     0.0
crv.name = c2
time    load.factor
20       0.0
1220     1.2
#

applied.loading (i)
initial.load
elm.name  type      value
f  101       udl1      0   -75
r   1         -        0    0    2
r   3         -        0    0    2
#
dynamic.load
elm.name  type    crv.name   value
101       udl1    c1        0   -125
104       udl1    c1        0   125
202       udl1    c1        0   -125
302       udl1    c1        0  125
elm.name  type    crv.name   value
104       tmp2    c2        875  -0.3636 875  -0.3636 875  -0.3636
202       tmp2    c2        375  -1.6404 375  -1.6404 375  -1.6404
302       tmp2    c2        1000   0 1000   0 1000  0
equilibrium.stages
end.of.stage steps
18.2      50
20        45
640       62
670       30
#
integration
scheme = hilber
alpha = -0.3
beta = 1.21
gamma = 0.8

# iterative
number = 10
initial = 10
step = 10
dive = 10
maxi = 0.1e8

# convergence.critera
(1)
tolerance = 0.5e-3
force.ref = 300e3
moment.ref = 300e6

# output
(m)
frequency = 2

# end

Note

The following picture shows the names that have been given to the nodes and elements in the data file.

figure 9.6.1 Nodes and elements.
9.6.2 Structural behaviour

This example illustrates the considerable influence of explosion on the fire resistance of steel frames, even when the extent of structural damage due to explosion is relatively small.

For both loading scenarios, elevated temperatures initiate buckling in the internal column at \( T \approx 475^\circ C \). However, the explosion/fire scenario is associated with a much reduced overall fire resistance of \( (T \approx 642^\circ C) \) in comparison with that of the fire only scenario \( (T \approx 894^\circ C) \), representing a reduction of 28%. This reduction is mainly attributed to deterioration in vertical resistance of the side column due to explosion damage, leading to redistribution of vertical loading to the internal column and an earlier overall failure of the system. The deflected shapes for the two loading scenarios are shown in the following figure.

![Diagram showing deflected shapes for fire and explosion loading](image)

(a) fire loading

(b) explosion loading

*figure 9.6.2a Final deflected shape after: (a) fire loading; (b) explosion.*

The deformed shape if we consider explosion and fire loading given by ADAPTIC shows that the combination of both efforts.
In addition to the analysis of the structure it is going to be considered the CPU time demand over the displacements at the node 121, which is the one that experiments higher displacements.

---

**figure 9.6.2b Final deflected shape after explosion and fire loading.**
### 9.6.3 Output file

**ELEMENT ASSEMBLY ORDER**

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**MAXIMUM FRONT**: (NODAL = 6) - (ADDITIONAL FREEDOMS = 0)

**INITIAL LOADING**

**CURRENT LOADING**

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<th>LEVEL</th>
<th>CONV.-NORM</th>
<th>ITERATIONS</th>
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**CURRENT LOADING**

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<th>LEVEL</th>
<th>CONV.-NORM</th>
<th>ITERATIONS</th>
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**NUMBER OF NODES CREATED**

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**NUMBER OF ELEMENTS CREATED**

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<td>111</td>
</tr>
<tr>
<td>#e2</td>
<td>qdp2</td>
<td>#n1</td>
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**NUMBER OF IMPERFECT ELEMENTS**

0

---

***( SUBDIVISION OF ELEMENT 202 )***********
***************( SUBDIVISION OF ELEMENT #e2 )***************
*                  *
*NUMBER OF NODES CREATED                              *
*                1                                        *
* NOD.NAME      COORD'S (X,Y) RELATIVE TO END(1) OF SUBDIVIDED ELEMENT *
*       n2            0.000000E+00    0.320000E+04    *
*-------------------------------------------------------*
*                  *
*NUMBER OF ELEMENTS CREATED                            *
*                2                                        *
* ELM.NAME   TYPE.OF.ELEMENT         NOD.NAMES     *
*        e4             cbp2             n2       121      *
*        e3             qdp2             n1       n2      *
*-------------------------------------------------------*
*                  *
*NUMBER OF IMPERFECT ELEMENTS                          *
*                0                                        *
*-------------------------------------------------------*

    7    0.18048000E+02    0    0.168E-04    1
    0    0.18052000E+02    0    0.367E-04    1
    8    0.18056000E+02    0    0.155E-03    1
    9    0.18064000E+02    0    0.408E-03    1
   10    0.18068000E+02    0    0.233E-05    2

***************( SUBDIVISION OF ELEMENT #e3 )***************
*                  *
*NUMBER OF NODES CREATED                              *
*                3                                        *
* NOD.NAME      COORD'S (X,Y) RELATIVE TO END(1) OF SUBDIVIDED ELEMENT *
*       n3            0.000000E+00    0.120000E+04    *
*       n4            0.000000E+00    0.160000E+04    *
*       n5            0.000000E+00    0.200000E+04    *
*-------------------------------------------------------*
*                  *
*NUMBER OF ELEMENTS CREATED                            *
*                4                                        *
* ELM.NAME   TYPE.OF.ELEMENT         NOD.NAMES     *
*        e6             cbp2             n3       n4      *
*        e7             cbp2             n4       n5      *
*        e8             qdp2             n1       n3      *
*-------------------------------------------------------*
*                  *
*NUMBER OF IMPERFECT ELEMENTS                          *
*                0                                        *
*-------------------------------------------------------*

    0    0.18076000E+02    0    0.638E-04    2
   11    0.18080000E+02    0    0.130E-03    2
    0    0.18084000E+02    0    0.293E-03    2

***************( SUBDIVISION OF ELEMENT #e5 )***************
*                  *
*NUMBER OF NODES CREATED                              *
*                1                                        *
* NOD.NAME      COORD'S (X,Y) RELATIVE TO END(1) OF SUBDIVIDED ELEMENT *
*       n6            0.000000E+00    0.800000E+03    *
*-------------------------------------------------------*
* NUMBER OF ELEMENTS CREATED * 2 * ELM.NAME  TYPE.OF.ELEMENT  NOD.NAMES * #e10 cbp2  #n6  #n3 * #e9  qdp2  #n1  #n6 *----------------------------------------------------------------------* * NUMBER OF IMPERFECT ELEMENTS * 0 *----------------------------------------------------------------------*

***************( SUBDIVISION OF ELEMENT #e8 )***************
* NUMBER OF NODES CREATED * 1 * NOD.NAME  COORD'S (X,Y) RELATIVE TO END(1) OF SUBDIVIDED ELEMENT * #n7  0.000000E+00  0.400000E+03 *----------------------------------------------------------------------*

* NUMBER OF ELEMENTS CREATED * 2 * ELM.NAME  TYPE.OF.ELEMENT  NOD.NAMES * #e11 cbp2  #n5  #n7 * #e12  qdp2  #n7  #n2 *----------------------------------------------------------------------*

* NUMBER OF IMPERFECT ELEMENTS * 0 *----------------------------------------------------------------------*

12  0.18088000E+02  0  0.759E-05  3
13  0.18096000E+02  0  0.240E-05  3
14  0.18104000E+02  0  0.322E-04  3

***************( SUBDIVISION OF ELEMENT 302 )***************
* NUMBER OF NODES CREATED * 1 * NOD.NAME  COORD'S (X,Y) RELATIVE TO END(1) OF SUBDIVIDED ELEMENT * #n8  0.000000E+00  0.400000E+03 *----------------------------------------------------------------------*

* NUMBER OF ELEMENTS CREATED * 2 * ELM.NAME  TYPE.OF.ELEMENT  NOD.NAMES * #e13 cbp2  211  #n8 * #e14  qdp2  #n8  221 *----------------------------------------------------------------------*

* NUMBER OF IMPERFECT ELEMENTS * 0 *----------------------------------------------------------------------*

14  0.18104000E+02  0  0.322E-04  3

***************( SUBDIVISION OF ELEMENT #e14 )***************
* NUMBER OF NODES CREATED * 12

252
* NOD.NAME  COORD'S (X,Y) RELATIVE TO END(1) OF SUBDIVIDED ELEMENT *
* #n9  0.0000000E+00  0.3200000E+04 *
*----------------------------------------------------------------------*

*NUMBER OF ELEMENTS CREATED *
* 2 *
* ELM.NAME  TYPE.OF.ELEMENT  NOD.NAMES *
* #e16  cbp2  #n9  #n8  #n9 *
* #e15  gdp2  #n8  #n9 *
*----------------------------------------------------------------------*

*NUMBER OF IMPERFECT ELEMENTS *
* 0 *
*----------------------------------------------------------------------*

*NUMBER OF NODES CREATED *
* 1 *
* NOD.NAME  COORD'S (X,Y) RELATIVE TO END(1) OF SUBDIVIDED ELEMENT *
* #n10  0.0000000E+00  0.4000000E+03 *
*----------------------------------------------------------------------*

*NUMBER OF ELEMENTS CREATED *
* 2 *
* ELM.NAME  TYPE.OF.ELEMENT  NOD.NAMES *
* #e18  cbp2  #n10  #n6 *
* #e17  gdp2  #n1  #n10 *
*----------------------------------------------------------------------*

*NUMBER OF IMPERFECT ELEMENTS *
* 0 *
*----------------------------------------------------------------------*

*NUMBER OF IMPERFECT ELEMENTS *
* 0 *
*----------------------------------------------------------------------*

*NUMBER OF NODES CREATED *
* 1 *
* NOD.NAME  COORD'S (X,Y) RELATIVE TO END(1) OF SUBDIVIDED ELEMENT *
* #n11  0.0000000E+00  0.4000000E+03 *
*----------------------------------------------------------------------*

*NUMBER OF ELEMENTS CREATED *
* 2 *
* ELM.NAME  TYPE.OF.ELEMENT  NOD.NAMES *
* #e19  cbp2  #n7  #n11 *
* #e20  gdp2  #n11  #n2 *
*----------------------------------------------------------------------*

*NUMBER OF IMPERFECT ELEMENTS *
* 0 *
*----------------------------------------------------------------------*

0  0.18108000E+02  0  0.335E-04  3

********************************************************************************

0  0.18112000E+02  0  0.480E-04  3
0  0.18116000E+02  0  0.267E-04  3
16  0.18120000E+02  0  0.205E-04  3
0  0.181240000E+02  0  0.583E-04  2
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***************( SUBDIVISION OF ELEMENT 104 )***************

*NUMBER OF NODES CREATED

* 9

NOD_NAME COORD'S (X,Y) RELATIVE TO END(1) OF SUBDIVIDED ELEMENT

* n12 0.600000E+03 0.000000E+00
* n13 0.120000E+04 0.000000E+00
* n14 0.180000E+04 0.000000E+00
* n15 0.240000E+04 0.000000E+00
* n16 0.300000E+04 0.000000E+00
* n17 0.360000E+04 0.000000E+00
* n18 0.420000E+04 0.000000E+00
* n19 0.480000E+04 0.000000E+00
* n20 0.540000E+04 0.000000E+00

*NUMBER OF ELEMENTS CREATED

* 10

ELM_NAME TYPE.OF.ELEMENT NOD.NAMES

* e21 cbp2 121 n12
* e22 cbp2 n12 n13
* e23 cbp2 n13 n14
* e24 cbp2 n14 n15
* e25 cbp2 n15 n16
* e26 cbp2 n16 n17
*   #e27    cbp2    #n17    #n18  *  
*   #e28    cbp2    #n18    #n19  *  
*   #e29    cbp2    #n19    #n20  *  
*   #e30    cbp2    #n20    221  *  
*----------------------------------------------------------------------*  
*                                                                      *  
*NUMBER OF IMPERFECT ELEMENTS                                           *  
*                   0                                                    *  
************************************************************************  
0       0.34100000E+03    1      0.265E-06         1  
0       0.34200000E+03    1      0.310E-05         0  
0       0.34300000E+03    1      0.311E-05         0  
0       0.34400000E+03    1      0.308E-05         0  
0       0.34500000E+03    1      0.295E-05         0  
0       0.34600000E+03    1      0.290E-05         0  
0       0.34700000E+03    1      0.294E-05         0  
0       0.34800000E+03    1      0.302E-05         0  
0       0.34900000E+03    1      0.303E-05         0  
65       0.35000000E+03    1      0.299E-05         0  
0       0.36000000E+03    0      0.153E-06         1  
66       0.37000000E+03    0      0.289E-03         0  
0       0.38000000E+03    0      0.284E-03         0  
67       0.39000000E+03    0      0.281E-03         0  
0       0.40000000E+03    0      0.311E-06         1  

*****************(  SUBDIVISION OF ELEMENT #e17     )*****************  
*                                                                      *  
*NUMBER OF NODES CREATED                                               *  
*                   0                                                    *  
*----------------------------------------------------------------------*  
*                                                                      *  
*NUMBER OF ELEMENTS CREATED                                            *  
*                   1                                                    *  
* ELM.NAME   TYPE.OF.ELEMENT         NOD.NAMES                         *  
* #e31          cbp2                 #n1       #n10                    *  
*----------------------------------------------------------------------*  
*                                                                      *  
*NUMBER OF IMPERFECT ELEMENTS                                          *  
*                   0                                                    *  
************************************************************************  
0       0.40100000E+03    1      0.149E-07         2  
0       0.40200000E+03    1      0.317E-03         0  

*****************(  SUBDIVISION OF ELEMENT #e20     )*****************  
*                                                                      *  
*NUMBER OF NODES CREATED                                               *  
*                   0                                                    *  
*----------------------------------------------------------------------*  
*                                                                      *  
*NUMBER OF ELEMENTS CREATED                                            *  
*                   1                                                    *  
* ELM.NAME   TYPE.OF.ELEMENT         NOD.NAMES                         *  
* #e32          cbp2                 #n11      #n2                     *  
*----------------------------------------------------------------------*  
*                                                                      *  
*NUMBER OF IMPERFECT ELEMENTS                                          *  
*                   0                                                    *  
************************************************************************  
0       0.40100000E+03    1      0.149E-07         2  
0       0.40200000E+03    1      0.317E-03         0  

256
***( SUBDIVISION OF ELEMENT #e15 )***

*NUMBER OF NODES CREATED
* 1
* NOD.NAME COORD'S (X,Y) RELATIVE TO END(1) OF SUBDIVIDED ELEMENT
* #n21 0.000000E+00 0.280000E+04

*NUMBER OF ELEMENTS CREATED
* 2
* ELM.NAME TYPE.OF.ELEMENT NOD.NAMES
* #e34 cbp2 #n21 #n9
* #e33 qdp2 #n8 #n21

*NUMBER OF IMPERFECT ELEMENTS
* 0

************************************************************************

0 0.42100000E+03 1 0.378E-07 3
0 0.42200000E+03 1 0.342E-04 1
0 0.42300000E+03 1 0.659E-07 1
0 0.42400000E+03 1 0.533E-08 1
0 0.42500000E+03 1 0.528E-08 1
0 0.42600000E+03 1 0.884E-09 1
0 0.42700000E+03 1 0.395E-08 1
0 0.42800000E+03 1 0.672E-08 1
0 0.42900000E+03 1 0.113E-08 1
69 0.43000000E+03 1 0.609E-07 1

***( SUBDIVISION OF ELEMENT #e33 )***

*NUMBER OF NODES CREATED
* 1
* NOD.NAME COORD'S (X,Y) RELATIVE TO END(1) OF SUBDIVIDED ELEMENT
* #n22 0.000000E+00 0.400000E+03

*NUMBER OF ELEMENTS CREATED
* 2
* ELM.NAME TYPE.OF.ELEMENT NOD.NAMES
* #e35 cbp2 #n8 #n22
* #e36 qdp2 #n22 #n21

*NUMBER OF IMPERFECT ELEMENTS
* 0

************************************************************************

0 0.43100000E+03 1 0.130E-03 3
0 0.43200000E+03 1 0.383E-08 1
0.43300000E+03  1  0.133E-08  1
0.43400000E+03  1  0.281E-08  1
0.43500000E+03  1  0.191E-08  1
0.43600000E+03  1  0.203E-08  1
0.43700000E+03  1  0.185E-08  1
0.43800000E+03  1  0.283E-08  1
0.43900000E+03  1  0.467E-03  0
0.44000000E+03  1  0.152E-05  1

****************************( SUBDIVISION OF ELEMENT #e36 )*****************************
* 
*NUMBER OF NODES CREATED
*  1
* NOD_NAME  COORD'S (X,Y) RELATIVE TO END(1) OF SUBDIVIDED ELEMENT
* #n23        0.000000E+00  0.200000E+04
*----------------------------------------------------------------------*
* 
*NUMBER OF ELEMENTS CREATED
*  2
* ELM_NAME  TYPE.OF.ELEMENT  NOD.NAMES
* #e38      cbp2            #n23  #n21
* #e37      qdp2            #n22  #n23
*----------------------------------------------------------------------*
* 
*NUMBER OF IMPERFECT ELEMENTS
*  0
*******************************************************************************
0.44100000E+03  1  0.397E-04  2
0.44200000E+03  1  0.335E-03  0
0.44300000E+03  1  0.354E-03  0
0.44400000E+03  1  0.334E-03  0
0.44500000E+03  1  0.215E-05  2
0.44600000E+03  1  0.458E-08  1
0.44700000E+03  1  0.387E-03  0
0.44800000E+03  1  0.520E-08  1
0.44900000E+03  1  0.233E-05  1
70 0.45000000E+03  1  0.458E-03  0

****************************( SUBDIVISION OF ELEMENT #e37 )*****************************
* 
*NUMBER OF NODES CREATED
*  2
* NOD_NAME  COORD'S (X,Y) RELATIVE TO END(1) OF SUBDIVIDED ELEMENT
* #n24        0.000000E+00  0.400000E+03
* #n25        0.000000E+00  0.160000E+04
*----------------------------------------------------------------------*
* 
*NUMBER OF ELEMENTS CREATED
*  3
* ELM_NAME  TYPE.OF.ELEMENT  NOD.NAMES
* #e39      cbp2            #n22  #n24
* #e41      cbp2            #n25  #n24
* #e40      qdp2            #n24  #n25
*----------------------------------------------------------------------*
* 
*NUMBER OF IMPERFECT ELEMENTS
*  0
*******************************************************************************
0.45010000E+03  2  0.215E-03  1
0  0.45020000E+03  2  0.187E-04  0
0  0.45030000E+03  2  0.925E-07  0
0  0.45040000E+03  2  0.434E-05  0
0  0.45050000E+03  2  0.919E-07  0
0  0.45060000E+03  2  0.911E-07  0
0  0.45070000E+03  2  0.420E-04  0
0  0.45080000E+03  2  0.926E-07  0
0  0.45090000E+03  2  0.919E-07  0
0  0.45100000E+03  2  0.911E-07  0
0  0.45200000E+03  1  0.846E-08  1
0  0.45300000E+03  1  0.118E-04  1
0  0.45400000E+03  1  0.431E-03  1
0  0.45500000E+03  1  0.371E-04  1
0  0.45600000E+03  1  0.477E-04  1
0  0.45700000E+03  1  0.692E-04  1
0  0.45800000E+03  1  0.181E-04  2
0  0.45900000E+03  1  0.133E-03  2
0  0.46000000E+03  1  0.440E-03  1
0  0.46010000E+03  2  0.359E-04  3
0  0.46020000E+03  2  0.134E-04  0
0  0.46030000E+03  2  0.779E-05  0
0  0.46040000E+03  2  0.321E-04  0
0  0.46050000E+03  2  0.131E-04  0
0  0.46060000E+03  2  0.603E-04  0
0  0.46070000E+03  2  0.226E-04  0
0  0.46080000E+03  2  0.163E-04  0
0  0.46090000E+03  2  0.240E-04  0
0  0.46100000E+03  2  0.591E-04  0

*******************************( SUBDIVISION OF ELEMENT #e40 )***********************

* NUMBER OF NODES CREATED
*   1
* NOD.NAME     COORD'S (X,Y) RELATIVE TO END(1) OF SUBDIVIDED ELEMENT
* #n26     0.000000E+00     0.400000E+03

* NUMBER OF ELEMENTS CREATED
*   2
* ELM.NAME     TYPE.OF.ELEMENT     NOD.NAMES
* #e42     cbp2     #n24     #n26
* #e43     qdp2     #n26     #n25

* NUMBER OF IMPERFECT ELEMENTS
*   0

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### Subdivision of Element #e43

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0 0.46410000E+03 2 0.417E-05 2
0 0.46420000E+03 2 0.278E-03 0
0 0.46430000E+03 2 0.177E-03 0
0 0.46440000E+03 2 0.210E-03 0
0 0.46450000E+03 2 0.151E-03 0
0 0.46460000E+03 2 0.123E-03 0
0 0.46470000E+03 2 0.111E-03 0
0 0.46480000E+03 2 0.123E-03 0
0 0.46490000E+03 2 0.119E-03 0
0 0.46500000E+03 2 0.126E-03 0
0 0.46600000E+03 1 0.846E-04 2

### Subdivision of Element #e44

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| NUMBER OF NODES CREATED | 0 |

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<th>ELM.NAME</th>
<th>TYPE.OF.ELEMENT</th>
<th>NOD.NAMES</th>
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<tr>
<td>#e46</td>
<td>cbp2</td>
<td>#n26 #n27</td>
</tr>
</tbody>
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| NUMBER OF IMPERFECT ELEMENTS | 0 |

0 0.46601000E+03 3 0.131E-03 1
0 0.46602000E+03 3 0.357E-04 0
0 0.46603000E+03 3 0.122E-04 0
0 0.46604000E+03 3 0.252E-05 0
0 0.46605000E+03 3 0.347E-05 0
0 0.46606000E+03 3 0.303E-07 0
0 0.46607000E+03 3 0.305E-07 0
0 0.46608000E+03 3 0.160E-05 0
0 0.46609000E+03 3 0.115E-06 0
0 0.46610000E+03 3 0.443E-05 0
0 0.46620000E+03 2 0.458E-03 0
0 0.46630000E+03 2 0.158E-03 0
0 0.46640000E+03 2 0.109E-03 0
0 0.46650000E+03 2 0.410E-04 0

---

260
0  0.46660000E+03  2  0.379E-03  0
0  0.46670000E+03  2  0.180E-04  0
0  0.46680000E+03  2  0.365E-04  0
0  0.46690000E+03  2  0.321E-03  0
0  0.46700000E+03  1  0.774E-04  4
0  0.46900000E+03  1  0.433E-03  2
71  0.47000000E+03  1  0.504E-04  3
0  0.48000000E+03  0  0.473E-04  5
72  0.49000000E+03  0  0.105E-03  2
0  0.50000000E+03  0  0.767E-05  2
73  0.51000000E+03  0  0.289E-05  2
0  0.52000000E+03  0  0.720E-06  2
74  0.53000000E+03  0  0.210E-06  2
0  0.54000000E+03  0  0.773E-07  2
75  0.55000000E+03  0  0.380E-03  1
0  0.56000000E+03  0  0.103E-06  2
76  0.57000000E+03  0  0.742E-04  2
0  0.58000000E+03  0  0.180E-03  1
77  0.59000000E+03  0  0.262E-03  1
0  0.60000000E+03  0  0.963E-07  2
78  0.61000000E+03  0  0.798E-06  2
0  0.62000000E+03  0  0.483E-07  2
79  0.63000000E+03  0  0.241E-07  2
0  0.64000000E+03  0  0.165E-04  3
0  0.64010000E+03  1  0.574E-04  1
0  0.64020000E+03  1  0.274E-04  0
0  0.64030000E+03  1  0.367E-04  0
0  0.64040000E+03  1  0.140E-05  1
0  0.64050000E+03  1  0.246E-03  0
0  0.64060000E+03  1  0.399E-03  1
0  0.64070000E+03  1  0.242E-04  1
0  0.64080000E+03  1  0.150E-05  1
0  0.64090000E+03  1  0.275E-05  1
80  0.64100000E+03  1  0.502E-04  1
0  0.64110000E+03  1  0.293E-03  1
0  0.64120000E+03  1  0.406E-04  1
0  0.64130000E+03  1  0.410E-03  1
0  0.64140000E+03  1  0.265E-03  2
0  0.64150000E+03  1  0.437E-05  3
0  0.64160000E+03  1  0.217E-05  4
0  0.64161000E+03  2  0.495E-03  3
0  0.64162000E+03  2  0.500E-04  2
0  0.64163000E+03  2  0.807E-04  2
0  0.64164000E+03  2  0.416E-04  2
0  0.64165000E+03  2  0.555E-04  2
0  0.64166000E+3  2  0.386E-03  1
0  0.64167000E+3  2  0.288E-04  2
0  0.64168000E+3  2  0.111E-07  3
0  0.64169000E+3  2  0.387E-04  1
0  0.64170000E+3  2  0.147E-03  1
0  0.64171000E+3  2  0.355E-04  3

************* *( SUBDIVISION OF ELEMENT 304 )**************

* NUMBER OF NODES CREATED
* 1
* NOD_NAME     COORD'S (X,Y) RELATIVE TO END(1) OF SUBDIVIDED ELEMENT
* #n28       0.0000000E+00  0.4000000E+03

* 261
*NUMBER OF ELEMENTS CREATED
* 2
* ELM.NAME TYPE.OF.ELEMENT NOD.NAMES
* #e47 cbp2 301 #n28
* #e48 qdp2 #n28 311
*----------------------------------------------------------------------*

*NUMBER OF IMPERFECT ELEMENTS
* 0
***********************************************************************

0  0.64172000E+03  2  0.317E-03  3

******************( SUBDIVISION OF ELEMENT #e48 )******************
*
*NUMBER OF NODES CREATED
* 1
* NOD.NAME COORD’S (X,Y) RELATIVE TO END(1) OF SUBDIVIDED ELEMENT
* #n29 0.000000E+00 0.320000E+04
*----------------------------------------------------------------------*

*NUMBER OF ELEMENTS CREATED
* 2
* ELM.NAME TYPE.OF.ELEMENT NOD.NAMES
* #e50 cbp2 #n29 311
* #e49 qdp2 #n28 #n29
*----------------------------------------------------------------------*

*NUMBER OF IMPERFECT ELEMENTS
* 0
***********************************************************************

0  0.64173000E+03  2  0.392E-07  4

******************( SUBDIVISION OF ELEMENT #e49 )******************
*
*NUMBER OF NODES CREATED
* 1
* NOD.NAME COORD’S (X,Y) RELATIVE TO END(1) OF SUBDIVIDED ELEMENT
* #n30 0.000000E+00 0.400000E+03
*----------------------------------------------------------------------*

*NUMBER OF ELEMENTS CREATED
* 2
* ELM.NAME TYPE.OF.ELEMENT NOD.NAMES
* #e51 cbp2 #n28 #n30
* #e52 qdp2 #n30 #n29
*----------------------------------------------------------------------*

*NUMBER OF IMPERFECT ELEMENTS
* 0
***********************************************************************

******************( SUBDIVISION OF ELEMENT 305 )******************
*
*NUMBER OF NODES CREATED
* 1
* NOD.NAME COORD’S (X,Y) RELATIVE TO END(1) OF SUBDIVIDED ELEMENT
* #n31 0.000000E+00 0.360000E+04
*----------------------------------------------------------------------*
*NUMBER OF ELEMENTS CREATED
* 2
* ELM.NAME TYPE.OF.DR. NOD.NAMES
* #e54 cbp2 #n31 321
* #e53 qdp2 311 #n31

*NUMBER OF IMPERFECT ELEMENTS
* 0

0 0.64174000E+03 2 0.101E-06 4

********************( SUBDIVISION OF ELEMENT #e53 )********************

*NUMBER OF NODES CREATED
* 1
* NOD.NAME COORD'S (X,Y) RELATIVE TO END(1) OF SUBDIVIDED ELEMENT
* #n32 0.000000E+00 0.320000E+04

*NUMBER OF ELEMENTS CREATED
* 2
* ELM.NAME TYPE.OF.ELEMENT NOD.NAMES
* #e56 cbp2 #n32 #n31
* #e55 qdp2 311 #n32

*NUMBER OF IMPERFECT ELEMENTS
* 0

0 0.64175000E+03 2 0.172E-06 4

********************( SUBDIVISION OF ELEMENT #e55 )********************

*NUMBER OF NODES CREATED
* 1
* NOD.NAME COORD'S (X,Y) RELATIVE TO END(1) OF SUBDIVIDED ELEMENT
* #n33 0.000000E+00 0.240000E+04

*NUMBER OF ELEMENTS CREATED
* 2
* ELM.NAME TYPE.OF.ELEMENT NOD.NAMES
* #e58 cbp2 #n33 #n29
* #e57 qdp2 #n30 #n33

*NUMBER OF IMPERFECT ELEMENTS
* 0

0 0.64176000E+03 2 0.243E-06 4
0 0.64177000E+03 2 0.436E-03 1
0 0.64178000E+03 2 0.723E-05 2

********************( SUBDIVISION OF ELEMENT #e55 )********************

*NUMBER OF NODES CREATED
* 1
* NOD.NAME COORD'S (X,Y) RELATIVE TO END(1) OF SUBDIVIDED ELEMENT
* #n34 0.000000E+00 0.280000E+04
*----------------------------------------------------------------------*
* NUMBER OF ELEMENTS CREATED
* 2
* ELM.NAME TYPE.OF.ELEMENT NOD.NAMES
* #e60 cbp2 #n34 #n32
* #e59 qdp2 311 #n34
*----------------------------------------------------------------------*
* NUMBER OF IMPERFECT ELEMENTS
* 0
***********************************************************************
 0 0.64179000E+03 2 0.127E-03 4
 0 0.64180000E+03 2 0.319E-04 2
 0 0.64181000E+03 2 0.396E-03 4
***********************************************************************
***************( SUBDIVISION OF ELEMENT #e57 )***************
* NUMBER OF NODES CREATED
* 2
* NOD.NAME COORD'S (X,Y) RELATIVE TO END(1) OF SUBDIVIDED ELEMENT
* #n35 0.000000E+00 0.400000E+03
* #n36 0.000000E+00 0.200000E+04
*----------------------------------------------------------------------*
* NUMBER OF ELEMENTS CREATED
* 3
* ELM.NAME TYPE.OF.ELEMENT NOD.NAMES
* #e61 cbp2 #n30 #n35
* #e63 cbp2 #n36 #n33
* #e62 qdp2 #n35 #n36
*----------------------------------------------------------------------*
* NUMBER OF IMPERFECT ELEMENTS
* 0
***********************************************************************
 0 0.64182000E+03 2 0.122E-08 6
 81 0.64182000E+03 4 0.191E+00 10
***********************************************************************
9.7 Apexes

(a) Indicates the kind of analysis required.

(b) Introduces the characteristics of the materials: the name, the material model, and the properties, which are different for each material model (Chapter 3).

(c) Introduces the type of section, the name, material and the dimensions.

(d) Defines the groups. There you define the element type, the group name and the name give to the section.

(e) Defines the coordinates of the structural nodes.

(f) Defines the global coordinates of the structural nodes (non.structural.nodes).

(g) Defined the nodal restraints. The f-command indicates the name of the first nodes which has restraints, and the r-command is refereed to the increment of this and how many times it has to increment the nod.name.

(h) Defines the connectivity of elements in a mesh configuration. First is indicated the group name. At the f-command is the name of the element and the extreme nodes of it and at the r-command is defined the increment of the nod.name, the extreme nodes and when it has to stop.

(i) Indicates the kind of load and the direction of each one.

(j) This module, phases, is used to trace the load deflection curve for the proportional loading.

(k) This module specifies the iterative strategy applied during a load or time step.

(l) Defines the tolerance at the iterative calculating process, and the reference value in calculating the convergence.

(m) Specifies the frequency of numerical output.

(n) This module specifies levels within elements of specific types (*).

(o) This module specifies the conditions which govern the termination of the automatic control phrase under a proportional static loading regime (**).

(p) This modules defines subdivision patterns utilised in automatic mesh refinement.

(q) This module specifies piecewise linear load curves for dynamic or time history loading.

(r) This module specifies the time scheme for dynamic analysis and its parameters (***)

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This module defines of intervals at which structural equilibrium is established (****) .