ACCOUNTING FOR IMPERFECTIONS AS PER EUROCODE 2 AND EUROCODE 3 IN ETABS 2016 AND SAP2000 V19

I. Overview

Eurocode 2 and Eurocode 3 require frame and member imperfections (global and local) to be accounted for either in the analysis stage or in the design stage.

Accounting global and local imperfections in the analysis stage of a numerical model can be done by either:

- Modeling the global and/or local imperfections explicitly in the model
- Applying horizontal UDL along vertical member length for local imperfection (applicable for EC3 only)
- Applying Equivalent Horizontal Force (EHF) at each story for global imperfection.
- Using the buckling mode shapes as initial geometry (applicable for EC3 only)

Accounting global and/or local imperfections in the analysis stage by modeling the frames and members unstraight or crooked, although can be done, will be impractical and time consuming. Similarly, applying horizontal UDL on vertical members to account for local imperfection is only practical when checking the effect on a single vertical element. These methods will not be discussed here.

In EC2 and EC3, global imperfections can be accounted for in the design stage as ECC (eccentricity) on isolated vertical members. Local imperfections in EC3 are accounted for in the design stage by using the relevant buckling shape factors in member buckling check.

This technical note discusses on how to account for imperfections in ETABS 2016 and SAP2000 v19 models.

II. Accounting for Global Imperfection in Design Stage as ECC

The most convenient way to account for global imperfections is to consider it as an ECC in design of isolated vertical members. This method is available in ETABS 2016 and SAP2000 v19 for EC2 design, but not currently available for EC3 design. This will be included for EC3 design in the future software release/updates.

The inclination value will be calculated as:

$$\theta_i = \theta_0 \alpha_h \alpha_m$$

where

$$\theta_0 = \text{is the basic value given as 0.005 (= 1/200)} ; \text{[Please check your NDP value]}$$

$$\alpha_m = 1$$

$$\alpha_h = 2/\sqrt{l} ; 2/3 \leq \alpha_h \leq 1$$
The eccentricity due to imperfection will be calculated as:

\[ e_i = \theta_i l_0 / 2 \]

The eccentricity \( e \) shall be equal or bigger than code specified minimum eccentricity:

\[ e_{\text{min}} = h / 30 \geq 20 \text{ mm} \]

The resulting geometric imperfection moments, \( M_{i2} \) and \( M_{i3} \), will be added to analysis first order moments in a single direction at a time:

\[ M_{i2} = e_{i2} N_{Ed} \]

\[ M_{i3} = e_{i3} N_{Ed} \]

Setting **Concrete Frame Design Preference** to account for global imperfection in ETABS 2016 and SAP2000 v19 for EC2 column design:

Go to **Design>Concrete Frame Design>View/Revise Preferences...** and specify Theta0 value.
Setting **Shear Wall Design Preference** to account for global imperfection in ETABS 2016 and SAP2000 v19 for EC2 wall design:

Go to **Design>Shear Wall Design>View/Revise Preferences...** and specify Theta0 value.

![Shear Wall Design Preferences for Eurocode 2-2004](image)

### III. Accounting for Global Imperfection in Analysis Stage as EHF

Global imperfection can be accounted for in analysis stage as EHF defined as notional loads in ETABS 2016 and SAP2000 v19.

This is done by defining notional load patterns for all dead load and live load pattern in both x and y directions.

Click on **Define>Load Patterns...**

Add a new notional load pattern for each dead and live load patterns for x and y directions. Specify the Load Ratio as the value of calculated $\theta_i$, or conservatively use 0.0005.
The value of Load Ratio to be used in defining the EHF's is equal to inclination θᵢ from equation below:

\[ θ_i = θ_0 \cdot α_h \cdot α_m \]

where

- \( θ_0 \) = is the basic value given as 0.005 (= 1/200) ; [Please check your NDP value]
- \( α_m \) = number of vertical members contributing to the horizontal force
- \( α_h = 2 + V_l \); \( 2/3 \leq α_h \leq 1 \)
- \( l \) = height of building
If designing for EC2, set the Theta0 value in the concrete frame and shear wall design preferences with very small value (i.e., 0.000001). This is done so that the effect of global imperfection will not be accounted twice. This step is not required if designing for EC3.
The design load combinations should also be updated to include these effects.

Click on **Define>Load Combinations...** and modify/create design load combinations to include the generated EHF load cases with the appropriate load factors. Use positive and negative values for opposing directions.
IV. Accounting for Local Imperfection in Design Stage

ETABS 2016 and SAP2000 v19 automatically accounted for local imperfection effect by the relevant buckling and imperfection factors as per EC3 in the design for buckling resistance of vertical steel members. This is done automatically and no additional input is required.

\[
\frac{N_{Ed}}{N_{Rk}} + k_{yy} \left( \frac{M_{y,Ed} + \Delta M_{y,Ed}}{M_{y,Rk}} \right) + k_{yz} \left( \frac{M_{z,Ed} + \Delta M_{z,Ed}}{M_{z,Rk}} \right) \leq 1 \tag{6.61}
\]

\[
\frac{N_{Ed}}{N_{Rk}} + k_{zy} \left( \frac{M_{y,Ed} + \Delta M_{y,Ed}}{M_{y,Rk}} \right) + k_{zz} \left( \frac{M_{z,Ed} + \Delta M_{z,Ed}}{M_{z,Rk}} \right) \leq 1 \tag{6.62}
\]

The reduction factor, \( \chi \) for the relevant buckling mode is taken as:

\[
\chi = \frac{1}{\Phi + \sqrt{\Phi^2 - \lambda}} \leq 1.0 \tag{EC3 6.3.1.2(1)}
\]

where the factor, \( \Phi \) and the non-dimensional slenderness, \( \lambda \) are taken as:

\[
\Phi = 0.5 \left[ 1 + \alpha \left( \bar{\lambda} - 0.2 \right) + \bar{\lambda}^2 \right] \tag{EC3 6.3.1.2(1)}
\]

\[
\bar{\lambda} = \sqrt{\frac{A_f}{N_{cr}}} \frac{L_{cr}}{i \lambda_1}, \text{ for Class 1, 2 and 3 cross-sections } \tag{EC3 6.3.1.3(1)}
\]

\[
\bar{\lambda} = \sqrt{\frac{A_f f_y}{N_{cr}}} \frac{L_{cr}}{i} \sqrt{\frac{A_{eff}}{A}}, \text{ for Class 4 cross-sections } \tag{EC3 6.3.1.2(1)}
\]

The reduction factor \( \chi_{LT} \) is taken as:

\[
\chi_{LT} = \frac{1}{\Phi_{LT} + \sqrt{\Phi_{LT}^2 - \lambda_{LT}^2}} \leq 1.0 \tag{EC3 6.3.2.2(1)}
\]

where the factor, \( \Phi \), and the non-dimensional slenderness, \( \lambda_{LT} \) are taken as:

\[
\Phi_{LT} = 0.5 \left[ 1 + \alpha_{LT} \left( \bar{\lambda}_{LT} - 0.2 \right) + \bar{\lambda}_{LT}^2 \right] \tag{EC3 6.3.2.2(1)}
\]

\[
\bar{\lambda}_{LT} = \sqrt{\frac{W_{y} f_y}{M_{cr}}} \tag{EC3 6.3.2.2(1)}
\]
ETABS 2015 Steel Frame Design

Eurocode 3-2005 Steel Section Check (Strength Summary)

SAMPLE EC3 CALCULATION SUMMARY

Element Details (Part 1 of 2)

<table>
<thead>
<tr>
<th>Level</th>
<th>Element</th>
<th>Unique Name</th>
<th>Length (mm)</th>
<th>Location (mm)</th>
<th>Combo</th>
<th>Design Type</th>
<th>Element Type</th>
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<tr>
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<td>19</td>
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<td>3596.8</td>
<td>UOS10-1</td>
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Element Details (Part 2 of 2)

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<th>Section</th>
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<td>UKC365X305X97</td>
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Design Parameters

Design Code Parameters

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<tr>
<th>ω_M0</th>
<th>ω_M1</th>
<th>ω_M2</th>
<th>A_t/A_a</th>
<th>LLRF</th>
<th>PLLF</th>
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<tr>
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<td>1.1</td>
<td>1</td>
<td>1</td>
<td>0.76</td>
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<table>
<thead>
<tr>
<th>A (cm²)</th>
<th>I_a (cm⁴)</th>
<th>W_a (cm³)</th>
<th>A_v (cm²)</th>
<th>W_v (cm³)</th>
<th>I_v (cm⁴)</th>
<th>I_h (cm⁴)</th>
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<td>1345</td>
<td>4456</td>
<td>306</td>
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<td>7308</td>
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<table>
<thead>
<tr>
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<th>ε_max (mm)</th>
<th>ε_min (mm)</th>
<th>W_v (cm³)</th>
<th>W_a (cm³)</th>
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Material Properties

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<th>f_u (MPa)</th>
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Stress Check Forces and Moments

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<th>N_a (kN)</th>
<th>M_a (kN-m)</th>
<th>M_a (kN-m)</th>
<th>V_a (kN)</th>
<th>V_a (kN)</th>
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<td>-17</td>
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Using Buckling Mode Shape as Modified Geometry to Account for Global and/or Local Imperfection in Analysis Stage

As per EC3, the assumed shape of global imperfections and local imperfections may also be derived from the elastic buckling mode of a structure in the plane of buckling considered.

The deformed geometry of any Buckling Analysis load case can then be used as modified geometry of the structure to account for global and/or local imperfections.
This method is useful for modelling non-building structures (e.g., domes, etc.) wherein modelling global imperfection as EHF may not be applicable anymore.

This method requires engineering judgment and experience in selecting which buckling load case and mode to use. This may also mean that a single structure will have to be saved in multiple models with different deformed geometry for analysis and design.

After running the buckling analysis load cases, click on **Analyze>Modify Undeformed Geometry...**

Select the buckling load case and one of its mode shape to be used to modify the initial geometry.