Nonlinear analysis – Assignment 6

**Problem 1:**

The modelization of the frame is done accordingly to assignment 5, with an introduced bi-linear behavior in the columns. The beam is modelized as an elastic element with two zero-length elements at its extremities with tri-linear constitutive laws, as shown in figure 1.

Figure 1: Beam zero-length elements constitutive laws

The constitutive law for the columns is modelized with:

, the hardening ratio

Figure 2: Column constitutive law

**Column elements discretization**

In order to capture the inelastic behavior of the steel columns, composed of HEA450 cross section, the cross section is discretized into a set number of fibers.

As it is assumed that the column will be stressed not only in the axial direction, but also in bending and in shear, it appears that a minimum of 3 elements in each direction is required. In order to mitigate the computation time, it is decided to discretize the section into 9 fibers as a first approach. The discretization is the following (unit : [mm]) :

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The columns are implemented in OpenSees as displacement-based beam column elements with Steel01 material, and discretized cross section as defined.

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Figure 3: Elements defined in OpenSeesNavigator for the steel MRF

The column elements are modelized with 5 integration points.

Displacement controlled incrementation is applied on the frame, at the node corresponding to the top left corner of the frame.

A total displacement of 600 mm is applied, with 1mm increments.

The final deformed shape is obtained:

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Figure 4: Deformed shape, total displacement incrementation

**Beam strength degradation**

The beam strength degradation is observed on the moment-displacement curve of the zero-length elements of the beam. Element 4 correspond to the left one, and 5 to the right one.

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Figure 5: Moment-displacement curve of the zero-length elements. Force in Nmm, dsp in mm.

The right connection is the first to degrade, for a horizontal roof displacement of 110mm. In order to observe the effect of the columns discretization and bi-linear material modelization, the obtained results are compared with the one from assignment 5. In this assignment, the columns were considered as simple linear-elastic elements.

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Figure 6: Moment-displacement curve of the zero-length elements, linear-elastic columns. Force in Nmm, dsp in mm.

With a linear-elastic modelization, the strength degradation first appears for a roof displacement of 105 mm.

Therefore, the implementation of the strength hardening behavior in the column and of the fiber discretization results in an increase of the beam computed strength, relative to the displacement.

If the columns were experiencing only elastic deformation, the observed displacement at the zero-elements strength degradation should be the same as in assignment 5. Therefore, we can assume that plastic deformation is computed in the column elements, allowing larger deformations before that the strength peak of the connections is reached.

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Figure 7: Moment-displacement curve of the columns elements. Force in N, dsp in mm.

It is indeed observed in the moment-displacement curve of the columns. For a roof displacement of 26mm, a first change in the slope of the curve is observed, followed by multiple others. These changes in slope are due to the discretization of the cross-section. When a fiber reaches the yielding stress, it plastify (i.e. enter the hardening state), resulting in a change of the slope.

As the columns plastify before the strength degradation of the connection, the hypothesis formulated before is confirmed.

It is observed that the quasi-totality of the fiber plastify for a roof displacement of around 70 mm.

**Storey shear strength of the steel beam**

The story shear strength of the steel beam reduce to zero when the moments computed in two connection elements are reduced to 0. From figure 5, it is observed that the moment in the left connection reaches 0 for a roof horizontal displacement of 386 mm.

**Problem 2:**