Qualification of *Constrained_Lagrange_In_Solid command for steel/concrete interface modeling

L. MOUTOUSSAMY [1,2], G. HERVE[1], F. BARBIER[1]
[1] Tractebel Engineering France,
[2] University Pierre and Marie Curie, Master SdI MMS MS2
February 2, 2011

Absract

Modeling reinforced concrete is an important requirement for civil engineering calculation. Particularly, engineers need to have information about both rebar and concrete. The need for modeling them separately comes obviously to allow local and global analysis of a reinforced concrete structure.

This paper focuses on the validation of modeling of reinforced concrete with the CSCM material and Constrained Lagrange In Solid to tie the rebar. The interest for this method is the possibility to mesh separately concrete and rebar and to avoid overmeshing caused by the concordance between concrete and rebar nodes. This coupling is commonly used to model Eurocodode 2 compatible reinforced concrete.

In order to validate the method, a comparison between analytical and numerical results is presented for simple civil engineering frames (beam and portal frame). This first study is made with a pseudo-dynamic loading. First, a four points bending test is presented for different case of steel rate in order to validate that momentum in a section is correctly represented when the concrete is at the maximum damage rate. Then, in a second step, a bending test on a common framework is presented to confirm that the momentum is correctly transmitted in articulation. A particular attention is accorded to the formation of plastic hinges.

INTRODUCTION

The modeling of reinforced concrete structures is performed nowadays in LS-Dyna following different commonly assumed methodologies, like:
- Multilayer shell methodologies,
- Homogenization of reinforced concrete layer for rebar layers and concrete both modeled with solid elements
- Concrete solid elements with truss beam modeling rebar, with perfect bond due to node merging,
- Concrete solid elements with truss beam modeling rebar, with *CONSTRAINED_LAGRANGE_IN_SOLID* keyword used to model perfectly the concrete bond.

The two last methodologies provide quite the same drawbacks considering a perfect concrete bond. Yet it has the advantage to fulfill the EC2 assumptions of equality of strains between concrete and rebar at their interface.

The advantage of the last way of carrying out the modeling is to decouple both actions of pre-processing. Indeed, as we do not need to share nodes, it is possible to bring a good modeling of the rebar distribution and geometry decorelated from the concrete modeling.

This way of performing the modeling has been formally exposed in Y. Murray's report (Murray, June 2006). However, the report didn't provide any evaluation of this reinforcement modeling.

The purpose of this study is not to compare the method to the others but to bring some element of assessment of the reinforced concrete modeling we are dealing with.

This task has been achieved taking into account the European standard of EC2. Y. Murray is providing robust proves of the capability of this method in the frame of LS-Dyna's predilection field of transient dynamics. Multiple simulations has been made to validate the method in the dynamic field (for instance, OECD IRIS benchmark, Y. Murray's report) using experimental data for assessment (for example, crack pattern, displacement, projectile velocity are used parameters for an impact simulation).

The aim of this paper is to assess the method in the quasi static field by comparing to very well documented example relying on EC2 calculations of beams and portico frames considering varying reinforcement ratios. The goal was to figure out the usual behavior of under-reinforced, just reinforced and normally reinforced structures.

The choice of *MAT_CSCM_CONCRETE* has been made considering its capability of handling the very essential behavior of the concrete in several cases and that is deeply linked to the CEB code model which robustness has been assessed. The choice of *MAT_PLASTIC_KINEMATIC* constitutive equation was relying on the facts that, first, due the simple formulation of the truss beam elements it was quite sufficient, secondly, that is was very easy to assume the characteristics provided by the technical code EC2.

I. FOUR POINTS BENDING TEST

In this part, a four point bending test is presented. Different reinforced concrete beams to verify that the alliance of *CONSTRAINED_LAGANGE_IN_SOLID* with *MAT_CSCM_CONCRETE* and *MAT_PLASTIC_KINEMATIC* was able to represent a simple behavior with crack opening.

Three different steel rates were studied, depending on EC2 rules. An under rated, just rated and "classically" rated beam were tested to check the three waited behavior of the structure.

A. Specimens

The tested specimens are 5m length, 0.50m height and 0.25m width reinforced concrete beam on simple support.

The concrete is modeled with Constant Stress Solid elements and CSCM Concrete material. The characteristics are:

- Minimum characteristic compressive strength : f_{ck} = 52,5 MPa
- Mean value of axial tensile strength : f_{ctm} = 3,2 MPa
- Young's modulus : E = 31.8 GPa

The steel is modeled with resultant Beam element (type 3) with EC2 characteristics which are:

- Young's modulus : E = 200 GPa
- Yield strength : f_{yk} = 500 MPa

The cover is fixed to 0.05m according to EC2 rules.

Two different mesh sizes were tested, to insure that a coarse mesh can be enough to model simple phenomena.
The "coarse mesh" has a mesh size of nearly 0.1m for concrete (480 elements for the whole beam) and 0.125m for rebar (88 elements). The "medium mesh" has a mesh size of nearly 0.04m (8640 concrete elements and 230 rebar elements).

Different steel rates in bending (see table below) were tested in order to verify that the three behaviors are correctly represented. Resistance to shear force is insured by HA14 rebar to avoid that shear doesn't ruin the structure before yyielding in bending reinforcements.

	Section (cm²)	Rebar type	Ratio
Under-reinforced	0,57	2 HA6	0,05%
Minimum-reinforced	1,57	2 HA10	0,13%
Classically-reinforced	9,82	2 HA25	0,79%

The under and just-reinforcement rates are calculated from EC2.

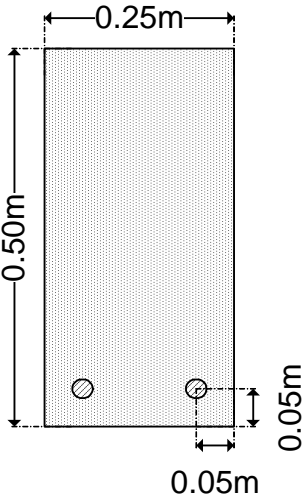The following figures represent the different meshing and the rebar repartition
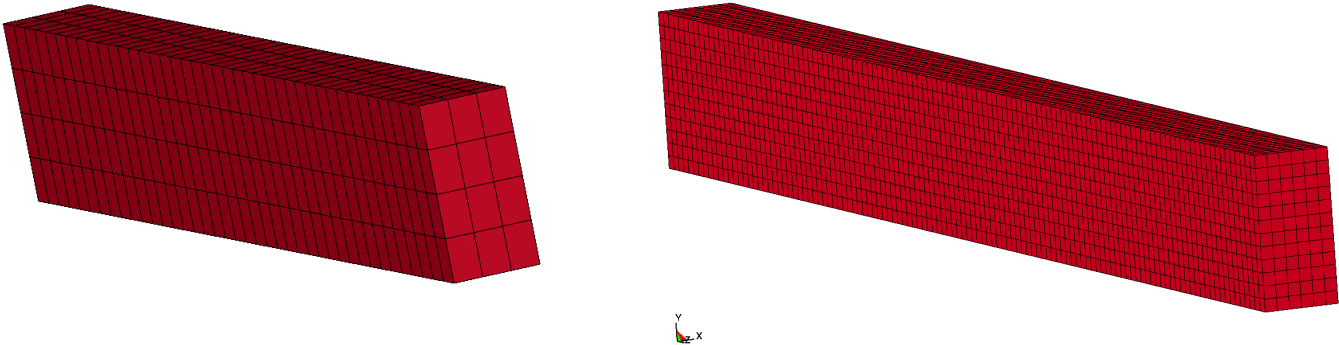

Figure 1 - Beam section

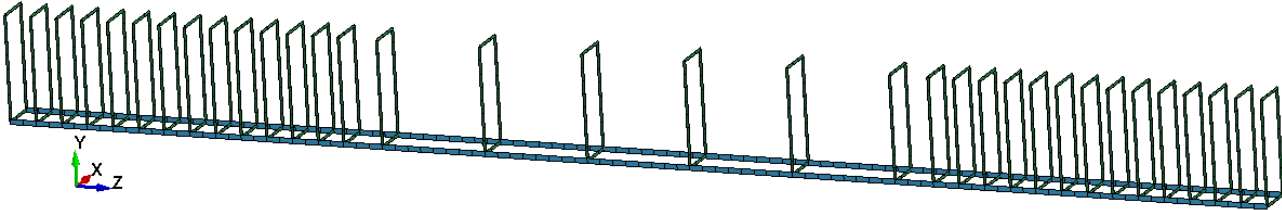**Figure 2 – Coarse mesh (left) and medium mesh (right)**

Figure 3 – Rebar repartition

B. Results

1. Preliminary results

The exposed results concern resultant forces. Before detailing numerical results, a short presentation of the theoretical system is developed. In the studied configuration, the main characteristics are:

$$L' = 1\text{m} \qquad ; \qquad v = 0,50\text{m} \qquad ; \qquad I = 260416 \text{ cm}^4$$

$$M = PL' \quad \Rightarrow \quad \sigma_{inf} = \frac{Mv}{2I} = \frac{PL'v}{2I} = \sigma_{trac} \quad \Rightarrow \quad P = \frac{2I\sigma_{trac}}{L'v}$$

We obtain P = 67kN at the cracking point.

We also need the resultant force at yielding point which is calculated with EC2 rules:

Rebar	P_{plast} (kN)
HA6	25
HA10	68
HA25	394

2. Numerical results

The resultant/deflection curves are presented to expose the obtained behavior in the simulations.
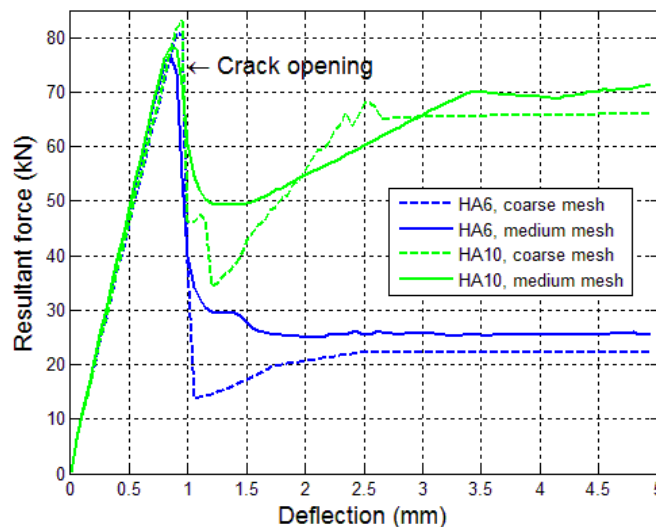

Figure 4 - Resultant forces for under and minimum rated beams

This first graph allows us to conclude that the global behavior is correctly represented for the two first cases of reinforcement ratio.

The crack opening happens at higher values than the calculated one, but we supposed that limit conditions were not correctly represented in the model (unstead of blocking a node line, a "real" support should have been modeled). So resultant force at crack opening point is 3 to 17% more important than the theoretical one (which is correct according the wrong modeling of limit conditions).

The values for yielding point are correct, we find values close by 2 to 10% to the theoretical value.

The most important test is the "classical" bending reinforcement ratio because it is the most representative of real structures.
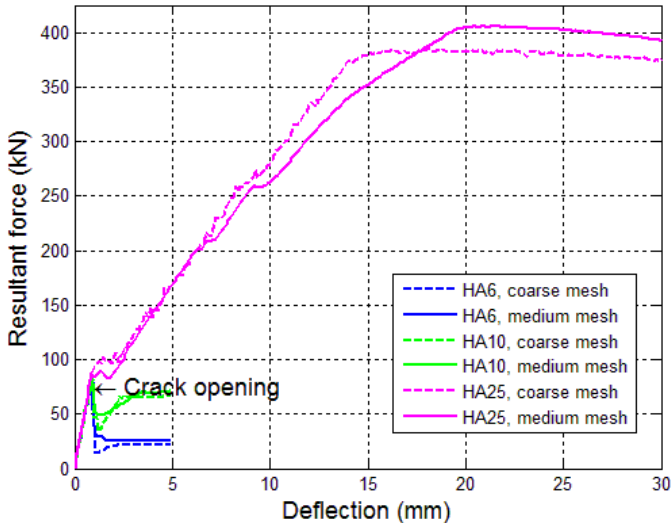

Figure 5 - Resultant forces for all tested beams

It is clear that crack opening happens at the same point than other tests and that yielding point happens at a correct value (3% from theoretical value).
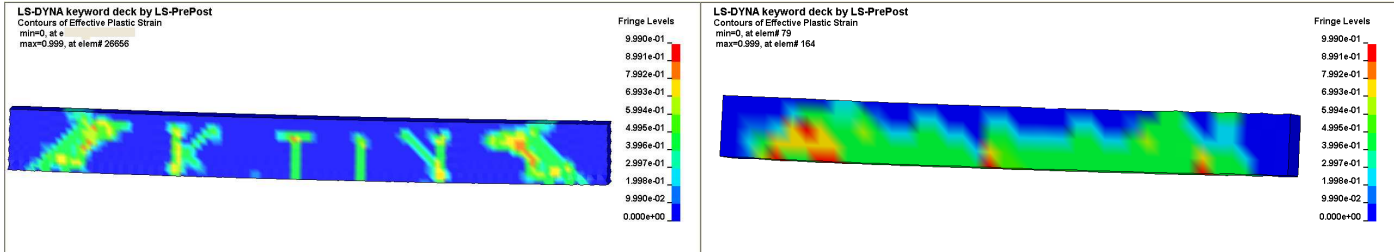
3. Crack pattern

Figure 6 – Crack pattern in the « classically » reinforced beam for the medium mesh (left) and the coarse mesh (right)

We can see on figure 7 that crack opening is correctly modeled by the plastic strain (damage) variable for the concrete elements: the central crack (bending cracks) appears first (their pattern assess the pure bending in the middle part of the girder), and the 45° cracks (shear crack) appears when before rebar yielding and prove that ruin happens because of shear forces.

C. Preliminary conclusion

The obtained results assess that simple static behavior of reinforced concrete is correctly modeled with CLIS+CSM+PLASTIC_KINEMATIC.
Moreover, the results with coarse meshing are correct and close to results obtained with a smaller meshing. A four element heighted beam is enough to modeled simple bended element.

II. BENDED PORTICO FRAME

In these tests, the aim was to study the transmission of momentum in cracked section. For this purpose, we used a portico frame to check that multiple crack opening were correctly modeled and represented in the structure global behavior.

A. Specimens

The material characteristics are the same than the precedent test. We decided to simulate only a coarse mesh, which is enough to represent bending (according to our first study), and the elements dimensions are also the same than in the first study.

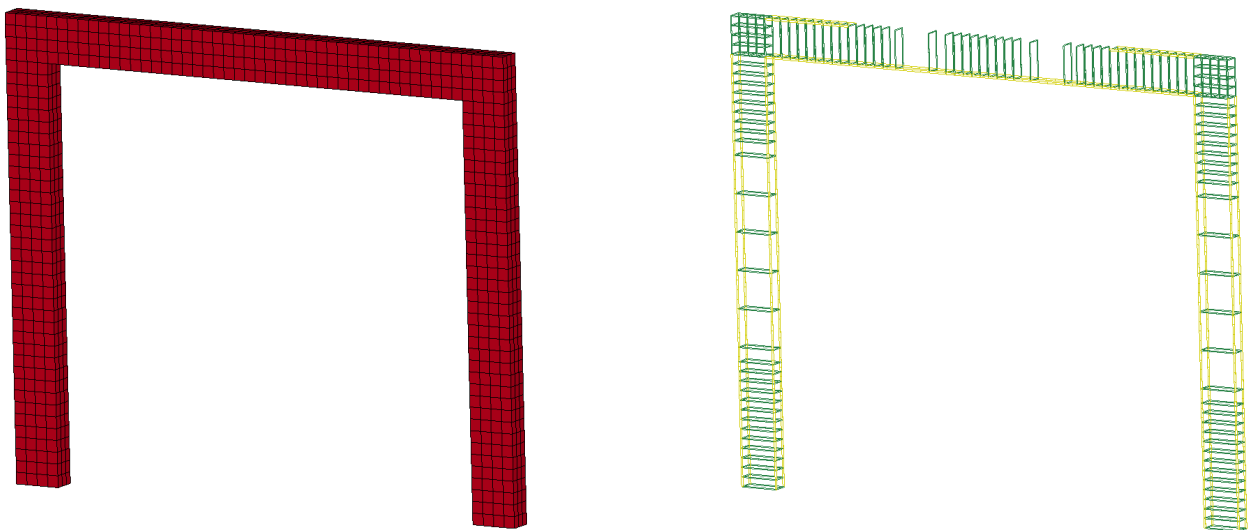The meshing and the rebar are represented on the following figure:

Figure 7 - Concrete meshing (left) and rebar (right)

The column height is 5m and the rail length is 11m. The section is the same than before (0.5mx0.25m)

The steel ratio is also simplified with only two cases: under rated and "classically" rated according to:

	Column steel ratio	Rail steel ratio
Under-reinforced (HA6)	0,01%	0,005%
Classically-reinforced (HA25)	3,14%	1,57%

B. Results

1. Preliminary results

The presented results concern momentum in middle-rail section. Before presenting numerical results, a short presentation of the theoretical system is presented.
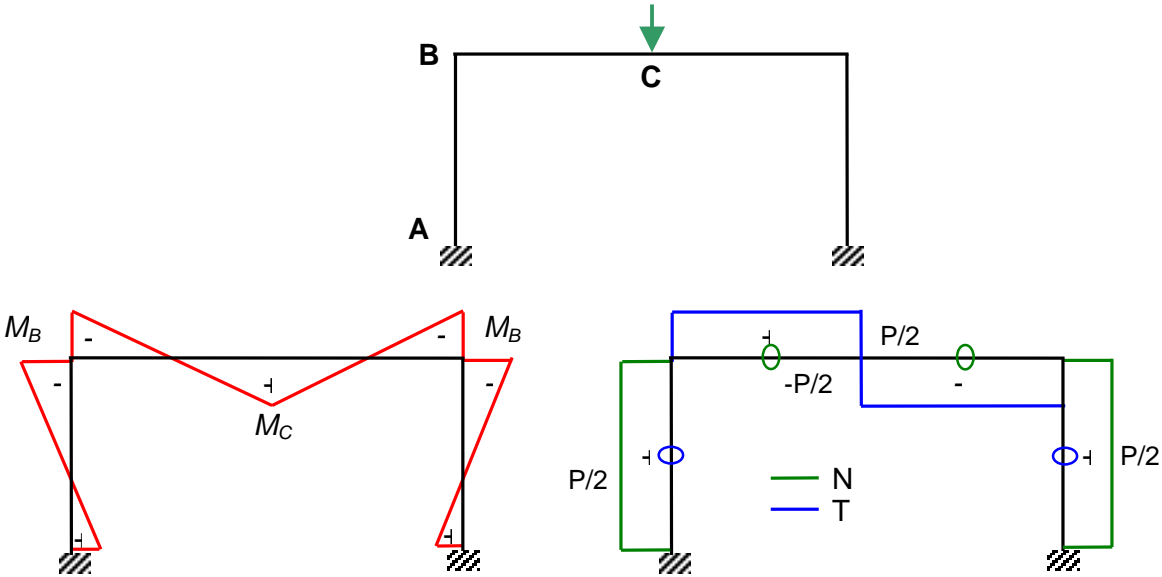

Figure 8 - Load on the structure and diagrams of normal forces, shear forces and bending moments

For the crack opening, the ultime bending momentum found with EC2 calculation is
M = 44kN.m and for rebar yielding point, momentum is different according to steel ratio:

	M_u (kN.m)
Under-reinforced (HA6)	12.5
Classically-reinforced (HA25)	197

2. Numerical results

In this part of the study, the interpreted results are momentum/deflection curve in order to validate that momentum are well transmitted in the structure.
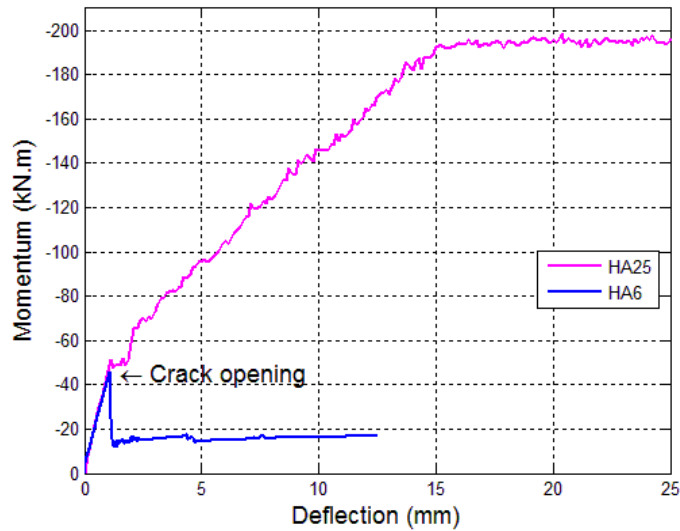

Figure 9 - Momentum curve in the middle-rail section

The precedent figure assess that crack opening in bended section is correctly modeled: the numerical results are close to theoretical values.

We observe a 1% difference for crack opening momentum with the under-rated case, and 4.4% for the normal case. A difference of 1% is observed for yielding momentum in the normal case and a 20% deviation for the under-rated case.

This last difference is very important, but it can easily be explained by the fact that the compressed section is to small to be represented by the meshing, so the stress distribution is out-of-true. This is not significant because the section is not representative of common reinforced concrete structure because of the low steel rate (0.005% steel ratio in the section).
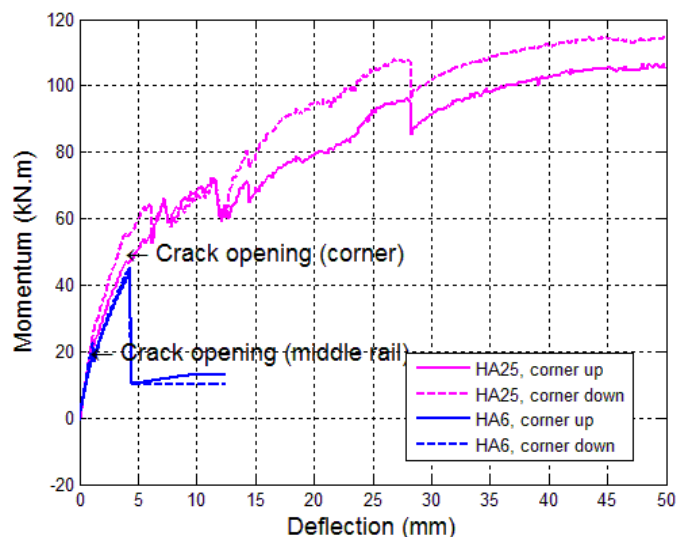

Figure 11 - Momentum in the corner sections

This last figure represents the momentum in the sections around the corner. We observe that before crack opening, momentum is perfectly transmitted in the structure, which is very important to respect EC2 hypothesis.

We can also observe that after the crack opening in the corner, a small difference appears due to the fact that the two sections do not crack at the same time (the stress transfer is not instantaneous, so the rail corner section cracks first) but the difference is not significant.

The values of momentum at crack opening are quite perfect (between 0 and 3% difference.. compared to EC2 results).

3. Crack pattern

We also see that crack opening still correctly represented by plastic strain, with all the plastic hinges formation (corner, base, rail):
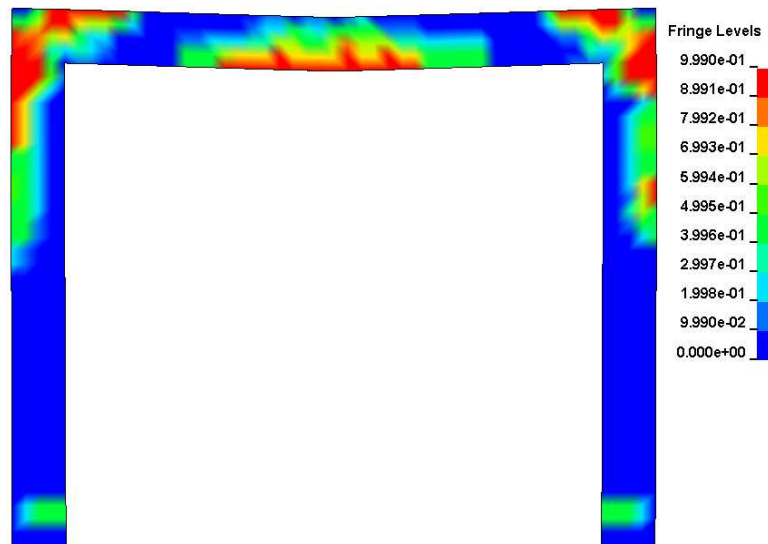

Figure 12 - Crack pattern at the end of simulation in the normal case (deflection is not amplified)

C. Preliminary conclusion

This second simulations campaign allows us to conclude that CLIS coupled to CSCM and Plastic Kinematic material is adapted to model reinforced concrete in static cases : momentum are correctly obtained, the transfer in junction is correctly modeled.

CONCLUSION

One must assume that the goals exposed in introduction have been reached. Indeed the first analysis carried out assuming a simply supported beam, has exposed:
- mesh sensitivity,
- capability to model the crack behavior,
- good values of resultant forces,

The second analysis carried out on the portico frame structure, provided:

- good position of the plastic hinges,
- good values of plastic momentum,
- good transmission of the momentum

These relevant elements are bringing robust proves of the good capability of this modeling of reinforced concrete structures.
The industrial application is also significant, because of its possibility to split modeling operations.
The main drawback of this kind of modeling is the large amount of degrees of freedom brought by the beam modeling of the reinforcement.
From this point of view multilayer methods are more efficient. Yet this kind of approach doesn't bring the opportunity of identifying precisely the weakest design elements of the full reinforcement modeling using beams.

REFERENCES

- Fuentès, A. (1980). *Le Béton armé après fissuration : état de service, état limite ultime, ductilité, mécanisme de rupture des structures hyperstatiques.* Broché.

- Murray, Y. A. Abu-Odeh and R. Bligh (June 2006). *Evaluation of Concrete Material Model 159, Report No. FHWA-HRT-05-063, Federal Highway Administration.*

- Murray, Y. (2007). *Users Manual for LS-DYNA Concrete Material Model 159,Report No. FHWA-HRT-05-062, Federal Highway Administration.*

- Moutoussamy, L. (2010). Qualification d'une méthode souple de modélisation de l'interface acier/béton, Masters Thesis, University Pierre and Marie Curie, Paris

- Rouzaud, C. (2010). *Simulation d'essais de tir de projectiles sur des dalles en béton armé*, Masters Thesis, EPF, Sceaux