ON THE PLASTIC JOINTS FOR A PLANE STRUCTURE

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Abstract: *The paper presents some considerations about the formation of the plastic joints in a plane structure using a method for calculating the elastic and plastic energy stored. Then it is determinated the order of appearance of the plastic joints.*
Keywords : *structure, plastic joint, energy, dynamic load*

1. INTRODUCTION

Using a method developed in the book [2] and the paper [3], Tofan and Ulea proposed in [4], [6] and [8] MathCAD representations of the bus bodywork section and in [5] a MathCAD model for the roll over test of a bus bodywork section. In [7] Ulea and Itu used FEM in order to analyse a staticaly roll over test of a bus bodywork.
In [9] Ulea presents a method to calculate the energy stored in plastic joints. First step is a static FEM analysis in order to arange the structure nodes after von Mises stresses. It is possible to define a coeficient k in order to calculate the necessary additional force to obtain a new plastic joint. In this way apears new plastic joints till the whole dynamic energy will be used.
In order to verify the method, a new FEM model was made, considering only the nodes and the elements of the frontal plane of the bus bodywork section from [7].
In the resulting gravity centre (node 464) was applied a static force of F = 6274 N. The force is tangent to the gravity centre roll over trajectory. The relation between the force applied point and the structure nodes 395, 396, 397, 431, 432 and 433 was made using rigid elements.

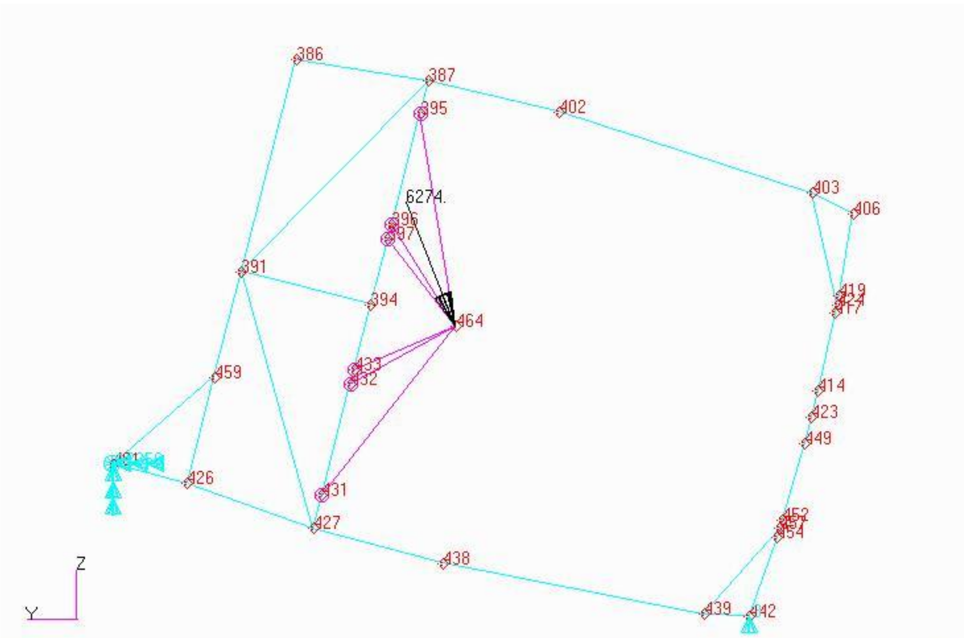

Figure 1: Loading and constraints

The load is calculated in order to have the same gravity centre displacement of 26,1 mm as the space model loaded by 15647 N. The node of the tilting axis have all degrees of freedom blocked, excepting the rotation around this axis. The distance between this node and the impact plane is 800 mm.

În figure 1 are presented the nodes, the loading and constraints of the plane model.

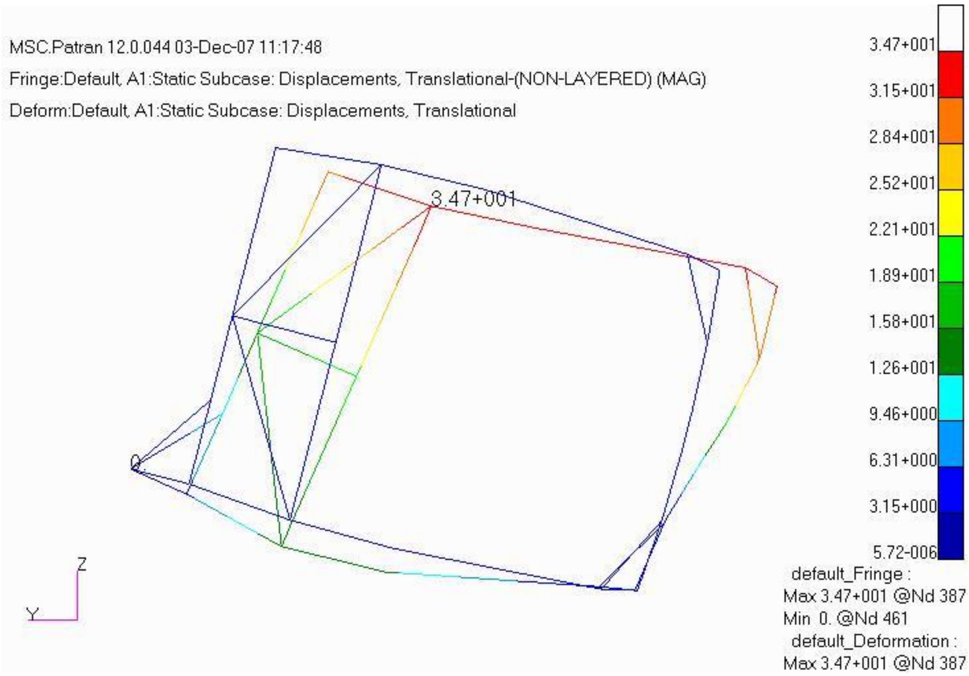

Figure 2: Total displacements

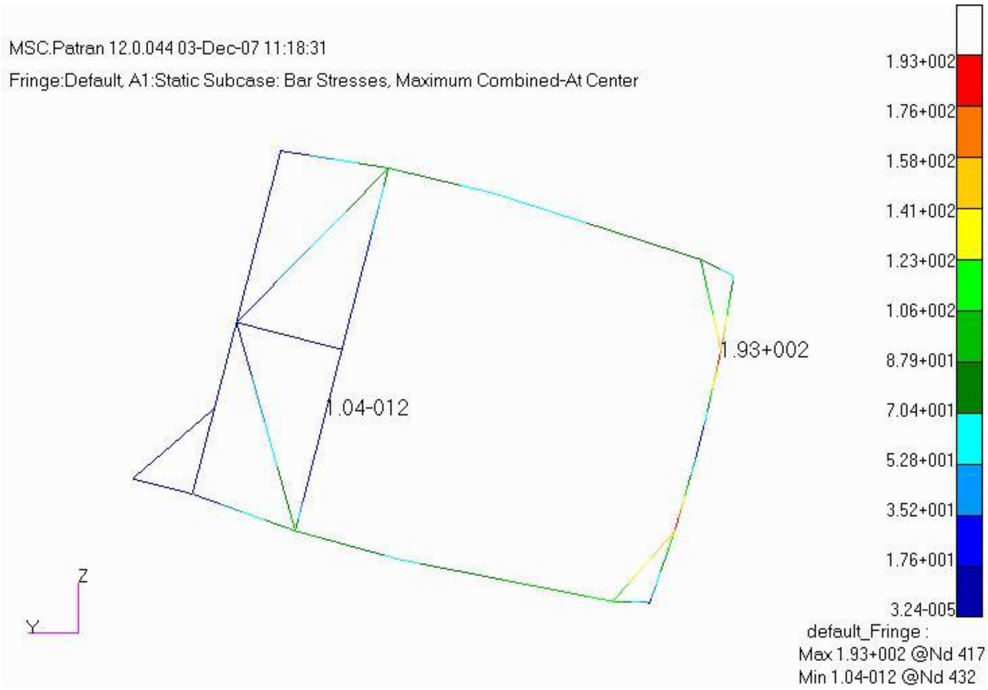

Figure 3: Von Mises stresses

In figure 2 are presented the total node displacements and in figure 3 the von Mises stresses.
In [9] we calculate the ratio k between the plastic bending moment M_{ip} and the elastic bending moment in a node cross section M_{ie} with the relation:

$$k = \frac{M_{ip}}{M_{ie}} = \frac{2\sigma_c S_z}{\sigma_{ech} W_z} \tag{1}$$

where σ_{ech} is the von Mises stress, W_z the section modulus corresponding to the type of rectangular tube used, σ_c the yield limit for the material, and S_z is the static moment of the half-section.

For each node having a given cross section, a further load ΔF_0 should be added to produce a plastic joint:

$$\Delta F_0 = (k-1)F \qquad (2)$$

In the table 1 are presented some results of the FEM calculations: number of nodes, von Mises stress, type of truss and k ratio.

Table 1: The most loaded nodes

Node	**387**	**403**	**417**	**419**	**424**
σ_{ech} [MPa]	92,47	83,18	193,47	165,83	148,52
Type	80x40x4	80x40x4	40x40x3	40x40x3	40x40x3
k	3,57	3,97	1,7525	2,04	2,28
Node	**427**	**439**	**452**	**454**	**457**
σ_{ech} [MPa]	95,25	110,94	193,3	116,72	157,59
Type	80x40x4	80x40x4	40x40x3	40x40x3	40x40x3
k	3,47	2,98	1,7541	2,9	2,15

In the nodes 417 and 452 is the smallest value of ratio k = 1,75.
In order to obtain plastic joints in these nodes it is necessary an additional force given by the relation (2) $\Delta F = 0{,}7525\ F = 4705$ N.

2. FIRST PLASTIC JOINTS

The nodes 417 and 452 are transformed into internal joints. The node 417 became the nodes 465 and 466 and the node 452 became the nodes 467 and 468. In the node 464 is applied the additional force $\Delta F_1 = 4705$ N.
In figure 4 are presented the constraints, the load and the nodes of the new plane model.

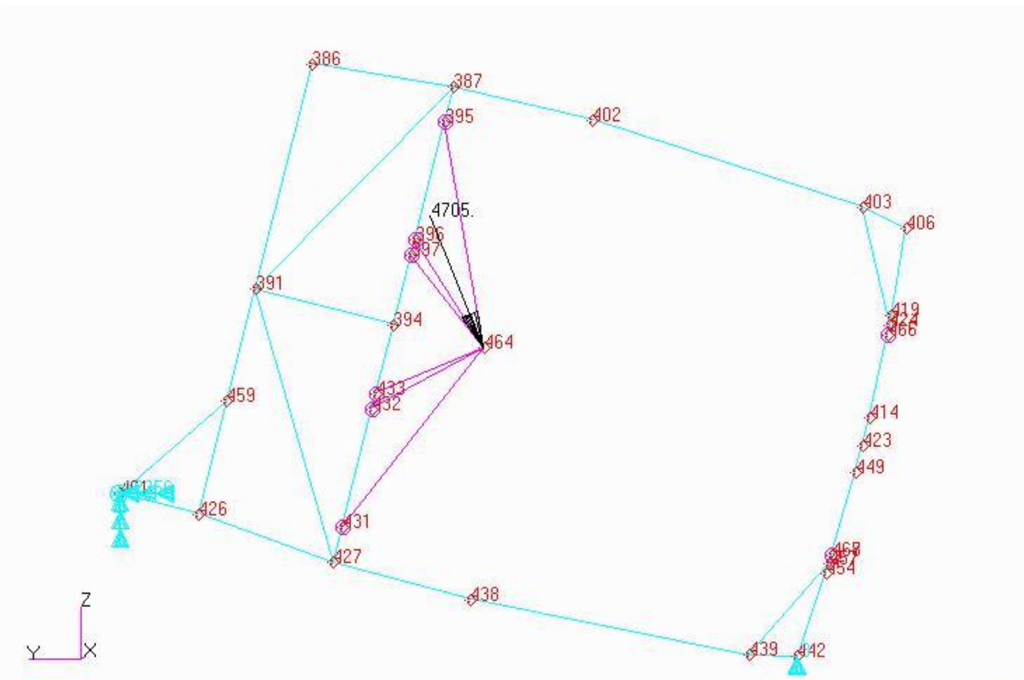

Figure 4: Two internal joints FEM model

In the table 2 are presented the most loaded nodes, where σ_{ech} is the von Mises stress in this step, $\sigma_{ech\ a}$ is the sum of the stresses in previous steps and SUM is the sum of the stresses for all steps.
In the node 438 appear the smallest ratio k = 1,28.
In order to obtain plastic joint in this node it is necessary an additional force $\Delta F_2 = 0{,}28\ F = 1757$ N.

Table 2: The most loaded nodes

Node	387	395	402	403	419	424
σ_{ech} [MPa]	147,27	78,40	189,42	24,13	1,13	1,91
$\sigma_{ech\ a}$ [MPa]	92,47	60,3	59,77	83,18	165,83	148,52
Sum [MPa]	239,74	138,7	249,19	107,31	166,96	150,43
Type	80x40x4	60x40x4	80x40x4	80x40x4	40x40x3	40x40x3
k	1,38	2,42	1,33	3,08	2,03	2,25
Node	**427**	**431**	**438**	**439**	**454**	**457**
σ_{ech} [MPa]	147,82	59,06	191,46	19,18	1,91	0,59
$\sigma_{ech\ a}$ [MPa]	95,25	35,52	66,23	110,94	116,72	157,59
Sum [MPa]	243,07	94,58	257,63	130,12	118,63	158,18
Type	80x40x4	60x40x4	80x40x4	80x40x4	40x40x3	40x40x3
k	1,36	3,55	1,28	2,54	2,86	2,15

3. NEXT PLASTIC JOINT

The node 438 became an internal joint. This node is transformed into the nodes 469 and 470.
A force ΔF_2 = 1757 N is applied in the node 464.
In figure 5 is presented the new FEM model.

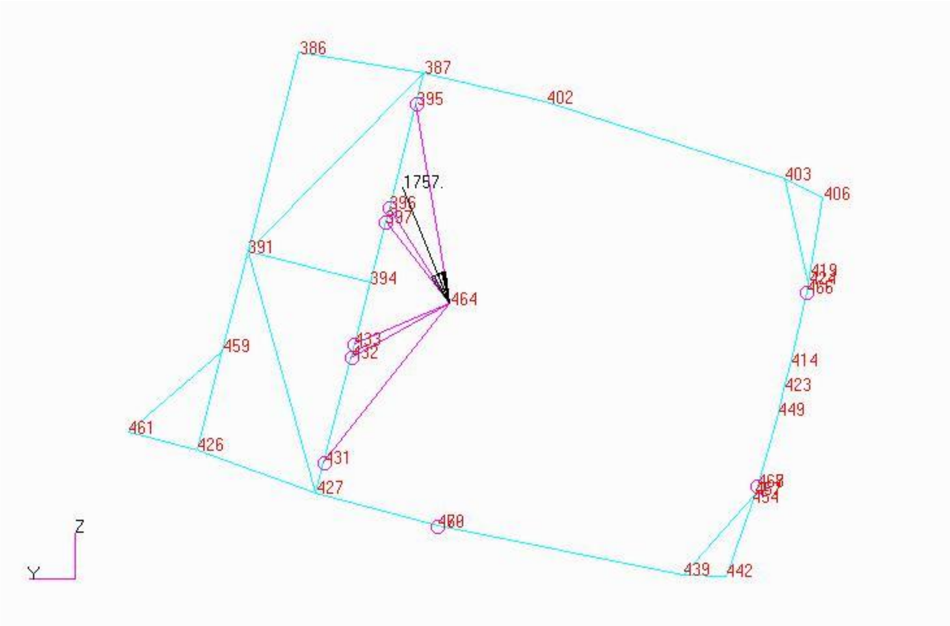

Figure 5: Three internal joints FEM model

In figure 6 is presented the deformed structure.
The most loaded nodes are presented in the table 3.
One can notice that at the transformation of node 438 in plastic joint, by stress redistribution, apear new plastic joints in this order, node 402, k = 0,84 and node 387, k = 0,94.
By transformation of the nodes 402 and 387 in plastic joints, the stucture becomes a mechanism.

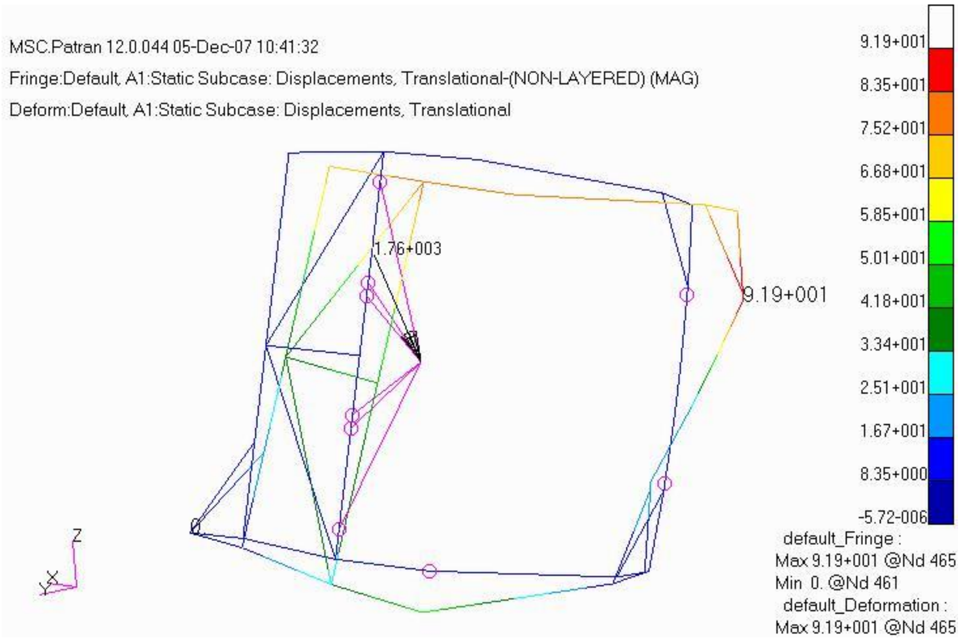

Figure 6 Total displacements

Table 3: The most loaded nodes

Node	**387**	**395**	**402**	**403**	**419**
σ_{ech} [MPa]	110,84	50,50	142,49	18,15	0,85
$\sigma_{ech\ a}$ [MPa]	239,74	138,7	249,19	107,31	166,96
Sum [MPa]	350,58	189,2	391,68	125,46	167,81
Type	80x40x4	60x40x4	80x40x4	80x40x4	40x40x3
k	0,94	1,78	0,84	2,63	2,02
Node	**424**	**427**	**439**	**454**	**457**
σ_{ech} [MPa]	1,00	0,62	1,86	2,29	0,96
$\sigma_{ech\ a}$ [MPa]	150,43	243,07	130,12	118,63	158,18
Sum [MPa]	151,43	243,69	131,98	120,92	159,14
Type	40x40x3	80x40x4	80x40x4	40x40x3	40x40x3
k	2,24	1,36	2,5	2,8	2,13

In the table 4 is presented the elastic energy in the structure elements, for this load step.

Table 4: Energy

Element	**Energy [Nmm]**	**Element**	**Energy [Nmm]**	**Element**	**Energy [Nmm]**	**Element**	**Energy [Nmm]**
224	1861,649	250	55,47011	305	48,72835	362	1,229644
227	141,787	280	3,989767	315	0,649021	363	1,388194
235	14,07391	282	1,307715	342	3,27956	370	2,795454
237	2037,844	286	6,256627	344	1,306576	371	2,794769
240	74,71154	293	920,4795	355	44,37156	375	3,827252
246	29941,12	294	3,442995	356	5,241808	**Total**	51230,93
247	16042,85	302	8,933885	357	1,397127		

4. CONCLUSION

The method developped in the paper [9] permits to describe the formation of plastic joints in a structure.
Because the k ratio for the two elements became subunit number, it is necessary to consider also the stored energy in the plastic zones, according to the relations from [9].
By transformation of the nodes 402 and 387 in plastic joints, the stucture becomes a mechanism.
So the plane model it is useful to verify the method, but this model is not adequate for a real spatial structure.

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