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ANALYSIS OF PALLET STORAGE STRUCTURES IN DOWN-AISLE DIRECTION

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Abstract: *The main objective of this paper is to comparatively analyze the mechanical behavior from stability point of view, for the pallet racking systems without vertical bracings, having different stiffness for the beam-end connectors, subjected to vertical and horizontal loads. Two cases of pallet racking systems are analyzed. The type of beam-end connector used to assembly beams with the uprights is different in each case: four-tab connector and five-tab connector. The structures are analyzed by comparing the sway deformation in the down-aisle direction and by comparing the bending moments developed in such structures by taking into account the second order effects. It is shown that the increasing of the rotational stiffness of the beam-end connector leads to the increasing of the critical buckling force.*
Keywords: *stability; storage systems; stiffness; tab connector.*

1. INTRODUCTION

Pallet raking structures are often used in the industry of the storage systems. The main components of these structures are represented by columns, beams, connectors, bracings and baseplates. A typical example is shown in Figure 1. In the last years, the results regarding the bending tests carried-out on the beam-end connectors with tabs were published in some papers [1-3]. There are also published papers on local buckling problems in stub column tests [4].
The main purpose of this paper is to investigate the influence of rotational stiffness of the beam-end connectors (BEC) on the rack stability by taking into account the effects of the second order calculus. This means that the effects of the axial forces are taken into account for calculus of both displacements and bending moments. The connection between uprights and floor connections (FC) also influence the stability of the storage racking structures. These two types of connections (BEC and FC) are usually semi-rigid connections.

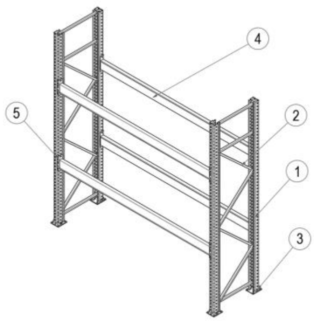
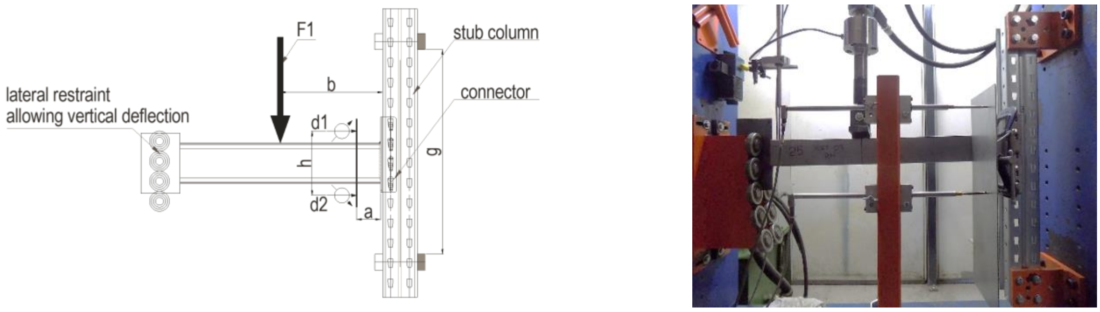


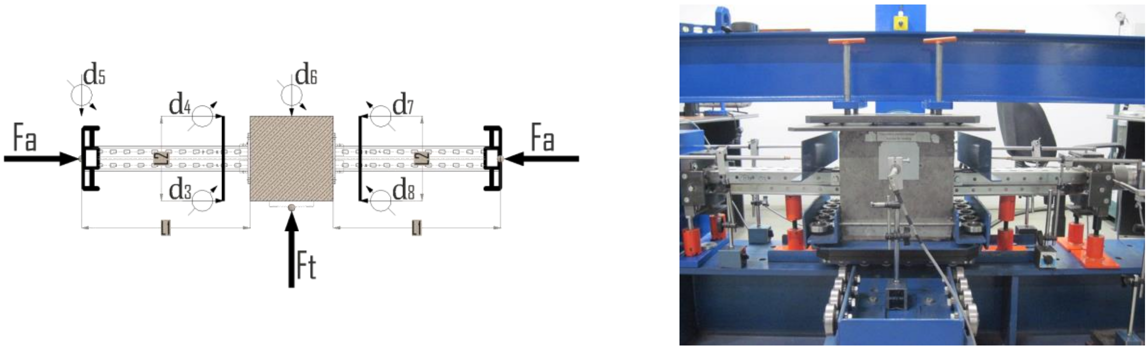
Figure 1: The main elements of a racking system: 1 – upright; 2 – bracing; 3 – baseplate; 4 – beams; 5 – connector.

These types of pallet racking systems have in general many bays and beam levels. The stability becomes a critical factor as the height of the storage racking structures increase and consequently, the second order effects must be considered in the design according to the standard EN 15512 [5].
The rotational stiffness of the beam-end connector and bending moment capacity are currently obtained by testing according to the standard EN 15512 [5] as it is shown in Figure 2. The procedure used to determine the rotational stiffness of the connection is described in detail in another paper published by the authors [1] in function of the force F_1 generated by a hydraulic machine and the rotation of the connector, computed in function of the displacements recorded by the traducers d_1 and d_2 (Fig. 2a). In the same manner, in Figure 3, it is also presented the test setup for determination of the rotational stiffness of FC according to the standard EN 15512 [5].



(a) (b)

Figure 2: Bending test of the beam-end connector: (a) scheme of the test setup; (b) photo of the experiment.



(a) (b)

Figure 3: Set-up of the test used for connection with floor: (a) scheme of loadig; (b) photo of the experiment. F_a – axial load; F_t – transversal load; d_3 - d_8 – displacement transducers.

The main purpose of this paper is to analyze the effects of the rotational stiffness of the beam-end connector on the stability of the racking storage structures and also on the deformation and bending moments developed at the middle of the beams and at the level of the beam-end connector. For this purpose, it is analyzed two kinds of racking storage structures for which the beam-end connector is different: four tab connector and five tab connector.

2. STRUCTURAL MODELS ANALYZED. WORK METHOD.

In this paper, we considered a pallet racking system having height of 12.52 m, 10 bays and eight levels of beams having the span of 2.75 m, loaded as it is shown in Figure 4. All the uprights have the same cross sections and beams are of the same size. The configurations of the two racking structures analyzed are shown in Table 1 and it may note that just the beam-end connector is different.

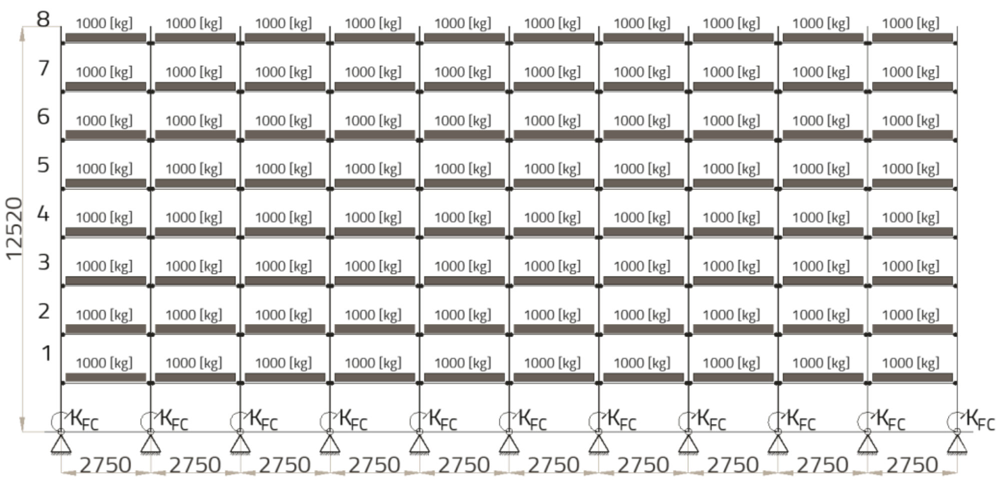


Figure 4: Scheme of loading for the racking storage structures analyzed.

Table 1: Racking configurations

No.	Type of the racking structure	Upright type	Beam type	Beam-upright-connector type	FC type
1	Type A	90/1.50	Box 100	4 Tab	FC 1
2	Type B	90/1.50	Box 100	5 Tab	FC 1

The values of the rotational stiffness corresponding to both four tab and five tab connectors were experimentally obtained and recently published by authors in another works [1, 6]. The values of the rotational stiffness considered in stability analysis are k_{BEC} = 51 kN·m/rad for the four-tab connector and k_{BEC} = 102 kN·m/rad for the five-tab connector [1, 6]. In Figure 5, it is presented the static load scheme of the beam having rotational springs at the both beam ends.

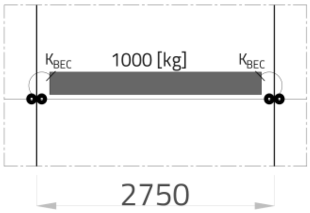


Figure 5: Static load scheme for a beam having rotational springs at the both beam ends.

The paper presents the results obtained from stability analysis by using RFEM software. The analysis of the both racking storage structures shown in Table 1 is made in order to investigate the effects of the rotational stiffness of the BEC and FC connectors on the critical load factor α_{cr}. Moreover, the results regarding the values of the maximum deflections and bending moments are also reported by taking into account the effects of the second order calculus.

3. RESULTS AND DISCUSSIONS

In the first case, the racking storage structure of type A is analyzed. The results show that for this case, the maximum value of the global deformation is 27.4 mm (Figure 6). It was performed also a stability analysis in order to determine the critical load factor α_{cr} for this configuration and the results are shown in Figure 7.

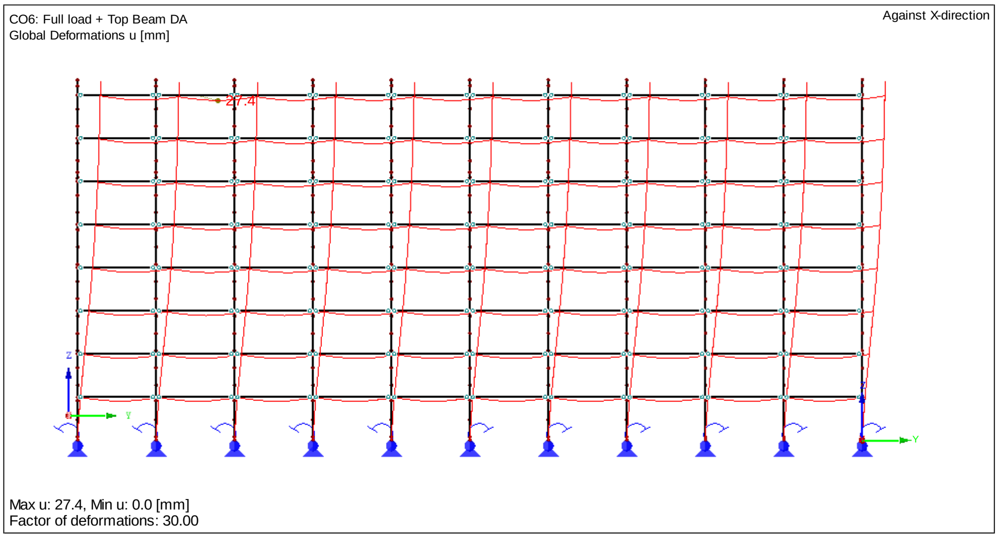


Figure 6: Global deformation for considered load combination. Rack Type A.

In the second case, the racking storage structure of type B is analyzed. The results regarding the global deformation, show that the maximum value is 13.9 mm (Figure 8). The stability analysis reported the critical load factors α_{cr} shown in Figure 9 for the first four modes and the corresponding deformed shapes of the racking structure analyzed.
It may remark that the critical load factors α_{cr} corresponding to the 1st and to the 2nd modes are equal due to the symmetry of the racking storage structures with respect to the two vertical planes in case of the both racking structures analyzed. The same remark may be made for the 3rd mode and for the 4th mode.

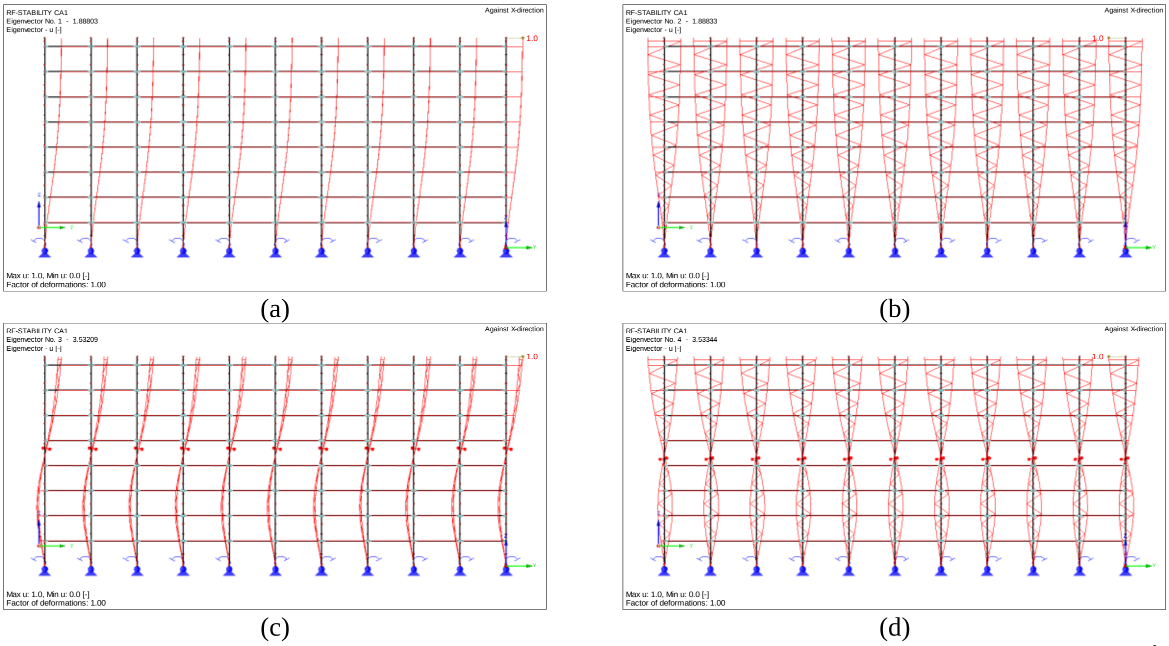


Figure 7: Stability analysis for racking structure of type A: (a) the 1st buckling mode, α_{cr} = 1.89; (b) the 2nd buckling mode, α_{cr} = 1.89; (c) the 3rd buckling mode, α_{cr} = 3.53; (d) the 4th buckling mode α_{cr} = 3.53.

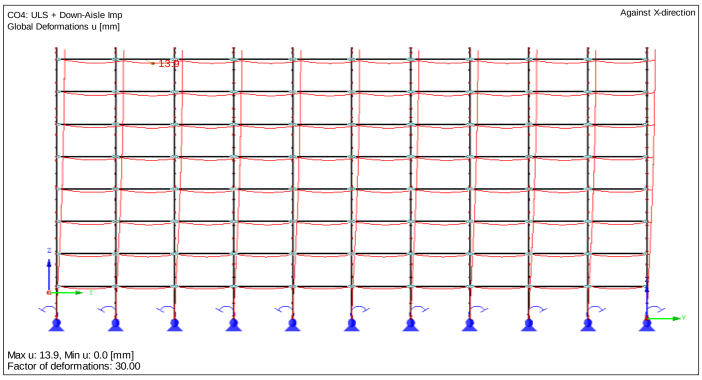


Figure 8: Global deformation for considered load combination. Rack Type B.

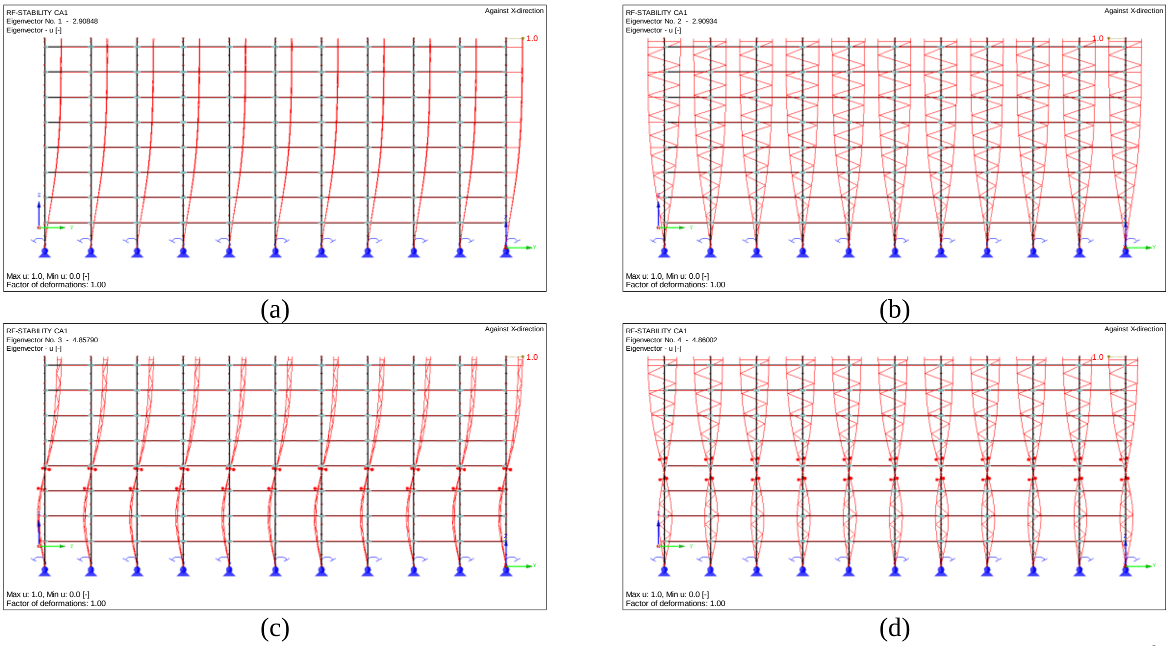


Figure 9: Stability analysis for racking structure of type B: (a) the 1st buckling mode, α_{cr} = 2.91; (b) the 2nd buckling mode, α_{cr} = 2.91; (c) the 3rd buckling mode, α_{cr} = 4.86; (d) the 4th buckling mode, α_{cr} = 4.86.

Other parameters that were compared for the both types of racking storage structures, are the bending moment developed at the middle of each beam and the bending moment developed at beam-end connectors.
Analyzing Figure 10 that shows the bending moment diagram for the racking structure of type A, it may observe that the maximum value of the bending moment developed at the middle of the beam is 2.18 kN·m and the absolute value of the bending moment developed at the beam-end connector is 0.40 kN·m.

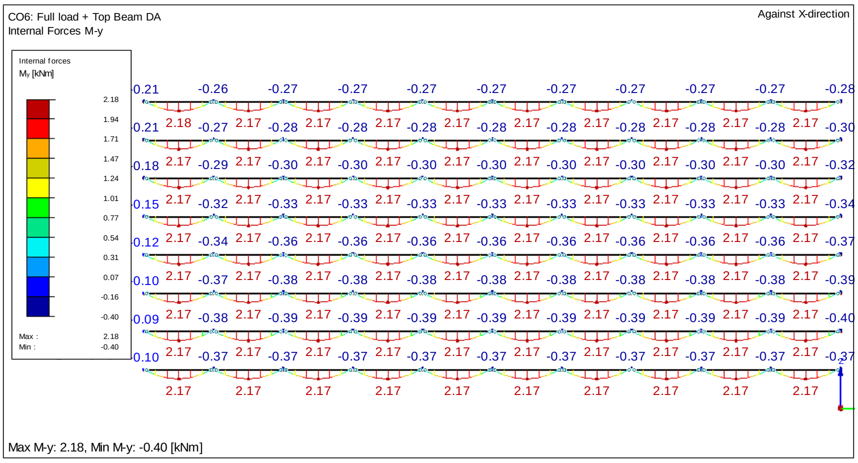


Figure 10: Bending moment diagram for the beams of the racking structure of type A.

In the same manner, Figure 11 shows the bending moment diagram for the racking structure of type B. It may observe that the maximum value of the bending moment developed is 2.01 kN·m at the middle of the beam while the absolute value of the bending moment developed at the beam-end connector is 0.54 kN·m.

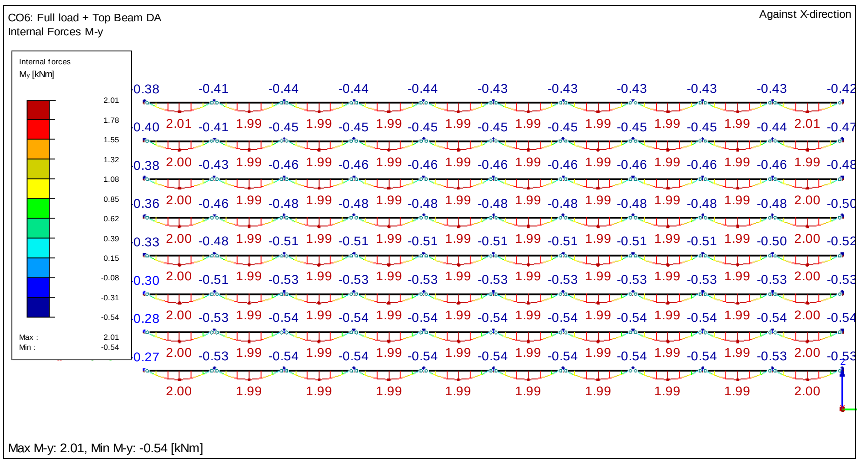


Figure 11: Bending moment diagram for the beams of the racking structure of type B.

The value of the bending moment developed at the base of the upright is also investigated in this analysis. In Figure 12 are presented the bending diagrams for the both racking structures analyzed.

(a) (b)

Figure 12: Bending moments at the bottom of the uprights for both rack types: (a) rack type A (k_{BEC}= 51 kN·m/rad); (b) rack type B (k_{BEC} =102 kN·m/rad).

The rotational stiffness k of the beam-end connectors has a major effect on the stability of the racking storage structures since the beam connections and connections with the floor are just elements that provide stability in down-aisle direction. The comparison between the obtained results is presented in Table 2.

Table 2: Comparison of the results obtained for the both racking structures analyzed

No.	Racking type	BEC rotational stiffness (kN·m/rad)	α_{cr} for buckling mode 1	Global deformation (mm)	Maximum bending moment at the middle of beam (kN·m)	Maximum bending moment at beam-end connectors (kN·m)	Bending moment at the base of the upright (kN·m)
1	Type A	51	1.89	27.4	2.18	0.4	0.42
2	Type B	102	2.91	13.9	2.01	0.54	0.24

Analyzing the results shown in Table 2, it may note that the critical load factor α_{cr} increases as the rotational stiffness of the beam-end connector increases. Global deformation decreases once the racking structure becomes more stable.

3. CONCLUSION

The racking storage structure of type B has a double value for the rotational stiffness (102 kN·m/rad) corresponding to the beam-end connector in comparison with the rotational stiffness of the connection corresponding to the racking storage structure of type A (51 kN·m/rad). It is obvious that racking structure of type B is more stable, the critical load factor is increasing just with 54% with respect to the one corresponding to the racking structure of type A, even if the rotational stiffness is double.
Because in this analysis the second order effects are taking into account, the global deformation decreases from 27.4 mm for the racking structure of type A down to 13.9 mm the racking structure of type B. The bending moments developed at the connection between upright and the baseplates are decreasing with 43 % for the racking structure of type B, because the second order effects are smaller.
Regarding the bending moments, the increasing of the rotational stiffness of BEC leads to the increasing with 35% of the bending moment developed at the level of the beam-end connectors and to the decreasing with 7.8 % of the bending moment developed at the middle of the beam.
The main conclusion after this study is that a higher value of the rotational stiffness of the beam-end connector provides a better stability of the racking storage structures. In this context, the experimentally determination of the rotational stiffness of the beam-end connector is a critical issue, especially for structures with no vertical bracings.

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