SEISMIC BEHAVIOUR OF THE PALLET RACKS ASSEMBLY

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SUMMARY: The research consists in the simulation of a pallet rack assembly subjected to seismic loads. Since 2012 in Europe all the rules regarding the seismic checks have been updated and are much stricter. These norms are also mandatory even in countries that are not declared dangerous seismic areas. In this context, the shelves of a robotic application must be well dimensioned and made of durable materials.

KEYWORDS: pallet rack, seismic behavior, FEM.

1. Introduction

An assembly of pallet storage racks was employed to determine the seismic behavior, to calculate the maximum displacements during the earthquake, and to check the structural strength. The paper also illustrates how to process the earthquake spectrum for correct stress input. The difficulty of the problem was the lack of noteworthy earthquake spectra available in the studied seismic zone. Under these conditions several analyses were performed in the following variants:

a) Two rack loading arrangements: fully loaded and loaded only on the highest level at full load capacity

b) Three types of dynamic analysis: static, modal, frequency response

c) Processing of a major earthquake spectrum.

The combination of these variants resulted in different runs. The main results are presented and analyzed.

2. Preparation of the computational model

The industrial shelf model employed was first modeled in Catia V5 (Fig.1). Then this assembly was remodeled and simplified with beams in ANSYS - Design Modeler (Fig.2), to which a cross-section for each structural element was assigned (rectangular - crossbars, solid rectangular - "X" bars for stabilization, "C" profile - support posts). The reason for geometric defeaturing is that the discretization can be easily generated and the computation is much faster.

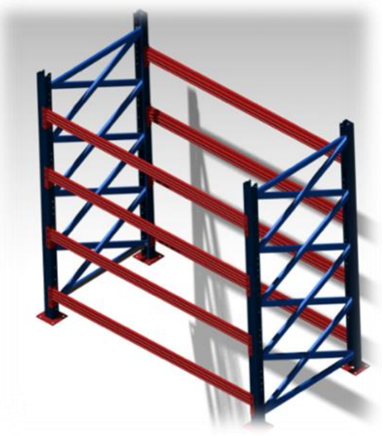


Fig.1

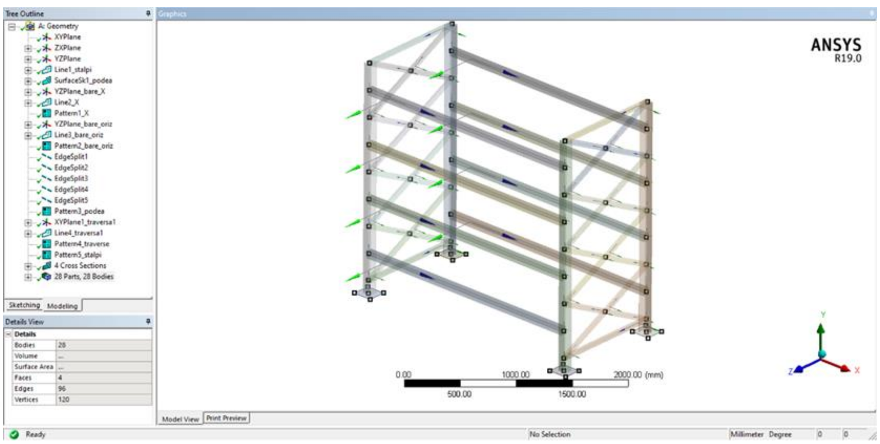


Fig.2

In order to perform a reliable simulation, it is essential to properly define the materials of the components. As such, the material employed was structural steel (Fig. 3):

Outline of Schematic B2, C2, D2: Engineering Data

	A	B	C	D	E
1	Contents of Engineering Data			Source	Description
2	Material				
3	Structural Steel			General_Materials.xml	Fatigue Data at zero mean stress comes from 1998 ASME BPV Code, Section 8, Div 2, Table 5-110.1
*	Click here to add a new material				

Properties of Outline Row 3: Structural Steel

	A	B	C
1	Property	Value	Unit
2	Material Field Variables	Table	
3	Density	7850	kg m^-3
4	Isotropic Secant Coefficient of Thermal Expansion		
6	Isotropic Elasticity		
7	Derive from	Young's Modulus and Poisson's Ratio	
8	Young's Modulus	2E+05	MPa
9	Poisson's Ratio	0.3	
10	Bulk Modulus	1.6667E+11	Pa
11	Shear Modulus	7.6923E+10	Pa
12	Alternating Stress Mean Stress	Tabular	
16	Strain-Life Parameters		
24	Tensile Yield Strength	250	MPa
25	Compressive Yield Strength	250	MPa
26	Tensile Ultimate Strength	460	MPa
27	Compressive Ultimate Strength	0	Pa

Fig.3

3. Initial static structural analysis

A structural analysis was completed to check if the assembly can withstand the weight of 8 pallets, each weighing max. 1500 kg. On each of the 4 shelves there are 2 EUR3 pallets (LxW): 1000 x 1200 mm.

The structure is fixed to the floor by 4 "Fixed Support" surfaces. Forces are applied evenly along the length of the cross beam with "Line pressure" (6000 N/m).

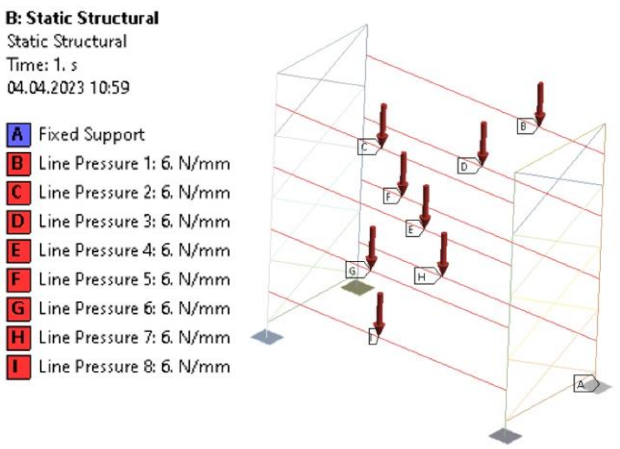


Fig.4

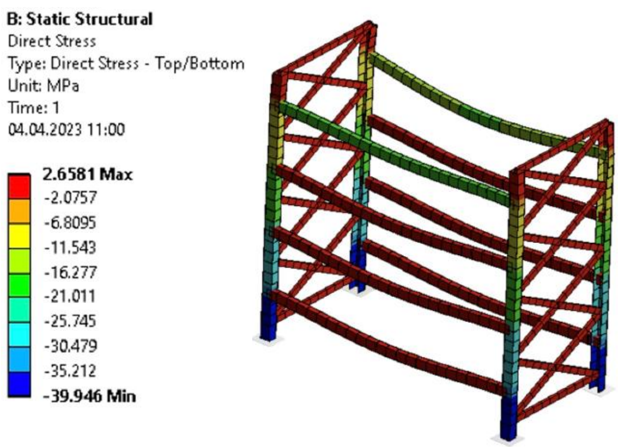


Fig.5

Static structural analysis results:

- Maximum direct stress is |-39.95| MPa = 40 MPa;
- Maximum displacements on the Y-axis (vertical) are 9.83 mm, on the X-axis are 1.91 mm and on the Z-axis are 7.65 mm. The displacements are significant even if the stresses are in the linear elastic range.

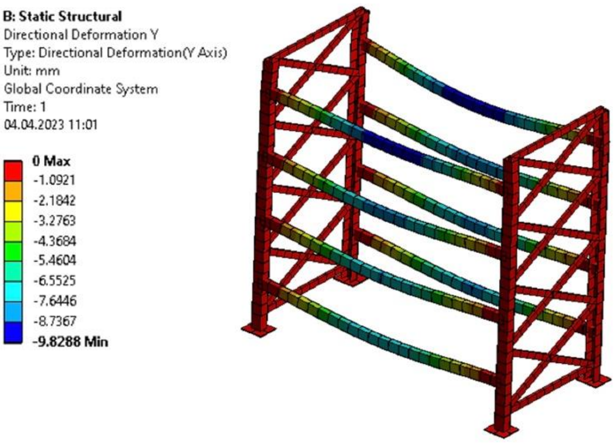


Fig.6

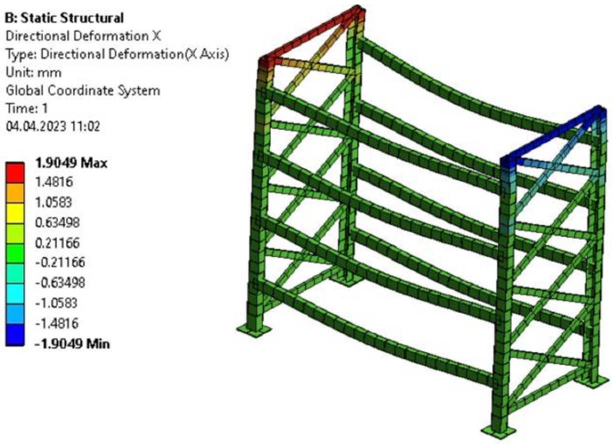


Fig.7

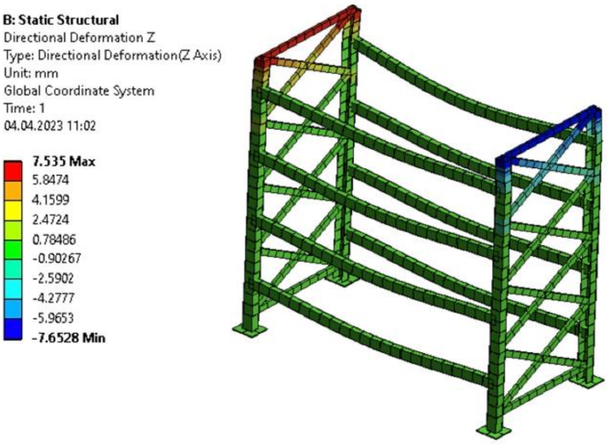


Fig.8

The system of equations solved during this computation:

$$\{F\} = [K] \cdot \{u\} \tag{1}$$

$$\{\varepsilon\} = [B] \cdot \{u\} \tag{2}$$

$$\{\sigma\} = [B] \cdot \{u\} \tag{3}$$

In ANSYS the solution of equation (1) is done by the Wavefront Method [1]. This means that the number of equations that are active at a given time.

$$F_k = \sum_{j=1}^{L} k_j \cdot u_j \tag{4}$$

Where k - is the equation number, j - the column, and L - the total number of equations.

The computation time depends on the square of the average value of the wavefront. Each resolving node is removed from the matrix by the Gauss elimination method. The stiffness matrix expands or contracts after the first or last occurrence of a node on an element. [2]

4. Modal analysis

Modal analysis was employed to determine the dynamic characteristics of structures, namely: natural frequencies and natural mode shapes. In the case of modal analysis, the mathematical formulation of the problem is:

$$[M]\{\ddot{u}\} + [C]\{\dot{u}\} + [K]\{u\} = \{0\} \tag{5}$$

Where [M] is the inertial matrix, [C] is the damping matrix [K] is the stiffness matrix. {F(t)} - the vector of external forces is {0}in this case. The matrices [C] and [M] are obtained by assembling the corresponding stiffness matrix of each finite element.

Modal analysis was done for 20 vibration modes to include a modal mass of 93% (Table 2), taking into account that a seismic computation wil be also performed. Five dominant mode shapes (1, 7, 14, 16, 20) were observed, in which the pallet rack swings in the X and Z directions (Fig.9 and 10), which may influence the response spectrum analysis.

The free vibration were checked for both cases. The frequencies between 10 - 73 Hz for case 2 (the shelf is loaded only on the highest level) are on a wider spectrum than case 1 with frequencies between 12 - 63 Hz (the shelf is fully loaded). The differences can be seen in Table 1. For this reason, the analysis was continued with the most unfavorable case 2.

Table .1

Modes	Case 1	Case 2
	Case 1(Hz)	Case 2(Hz)
1	12.374	10.573
2	20.883	18.082
3	27.581	28.206
4	28.844	29.342
5	30.968	30.703
6	32.256	31.815
7	34.593	32.721
8	36.96	36.749
9	39.056	38.335
10	40.225	38.788
11	42.112	42.143
12	44.574	44.103
13	46.219	45.388
14	46.371	46.381
15	52.38	52.422
16	56.899	61.68
17	57.096	65.093
18	57.367	65.978
19	57.6	66.571
20	62.871	72.803

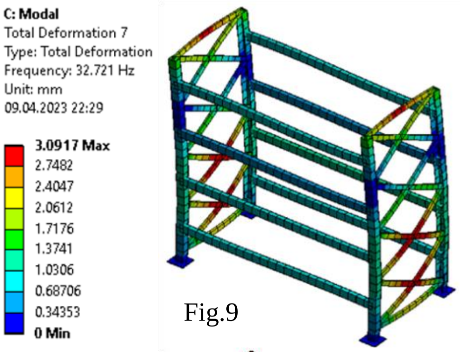


Fig.9

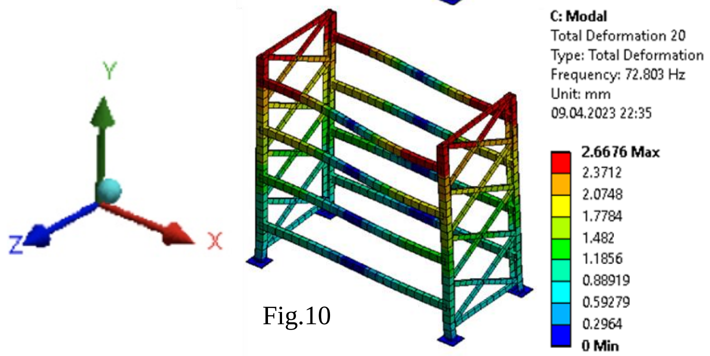


Fig.10

Table nr.2

***** PARTICIPATION FACTOR CALCULATION ***** X DIRECTION

MODE	FREQUENCY	PERIOD	PARTIC.FACTOR	RATIO	EFFECTIVE MASS	CUMULATIVE MASS FRACTION	RATIO EFF.MASS TO TOTAL MASS
1	10.5727	0.94584E-01	0.51371	1.000000	0.263900	0.798697	0.738633
2	18.0821	0.55303E-01	0.44111E-02	0.008587	0.194582E-04	0.798756	0.544617E-04
3	28.2064	0.35453E-01	0.0000	0.000000	0.00000	0.798756	0.00000
4	29.3422	0.34081E-01	0.0000	0.000000	0.00000	0.798756	0.00000
5	30.7035	0.32570E-01	0.0000	0.000000	0.00000	0.798756	0.00000
6	31.8153	0.31431E-01	0.0000	0.000000	0.00000	0.798756	0.00000
7	32.7208	0.30562E-01	0.23443	0.456344	0.549572E-01	0.965084	0.153820
8	36.7488	0.27212E-01	0.0000	0.000000	0.00000	0.965084	0.00000
9	38.3350	0.26086E-01	0.0000	0.000000	0.00000	0.965084	0.00000
10	38.7876	0.25781E-01	0.0000	0.000000	0.00000	0.965084	0.00000
11	42.1431	0.23729E-01	0.0000	0.000000	0.00000	0.965084	0.00000
12	44.1033	0.22674E-01	0.0000	0.000000	0.00000	0.965084	0.00000
13	45.3883	0.22032E-01	0.0000	0.000000	0.00000	0.965084	0.00000
14	46.3812	0.21560E-01	0.91526E-01	0.178165	0.837694E-02	0.990437	0.234463E-01
15	52.4217	0.19076E-01	0.0000	0.000000	0.00000	0.990437	0.00000
16	61.6801	0.16213E-01	-0.38316E-01	0.074587	0.146815E-02	0.994880	0.410922E-02
17	65.0925	0.15363E-01	0.39687E-03	0.000773	0.157502E-06	0.994881	0.440835E-06
18	65.9785	0.15156E-01	-0.41127E-01	0.080058	0.169140E-02	1.00000	0.473408E-02
19	66.5715	0.15021E-01	0.0000	0.000000	0.00000	1.00000	0.00000
20	72.8026	0.13736E-01	-0.39548E-04	0.000077	0.156406E-08	1.00000	0.437767E-08
sum					0.330413		0.924798

5. Characteristics of the earthquake employed as input data

The data used for the analyses was taken from records regarding a surface earthquake that occurred on September 20, 1999 in Taiwan. The magnitude of the earthquake was 7.7 with duration of 59 seconds. The acceleration spectrum in fig.11 includes the stresses on the X, Y, and Z axes, chosen according to the P and S wave directions of the earthquake, namely: V, N, and E. [4] [5].

The damping value was chosen 2% for all spectrums.

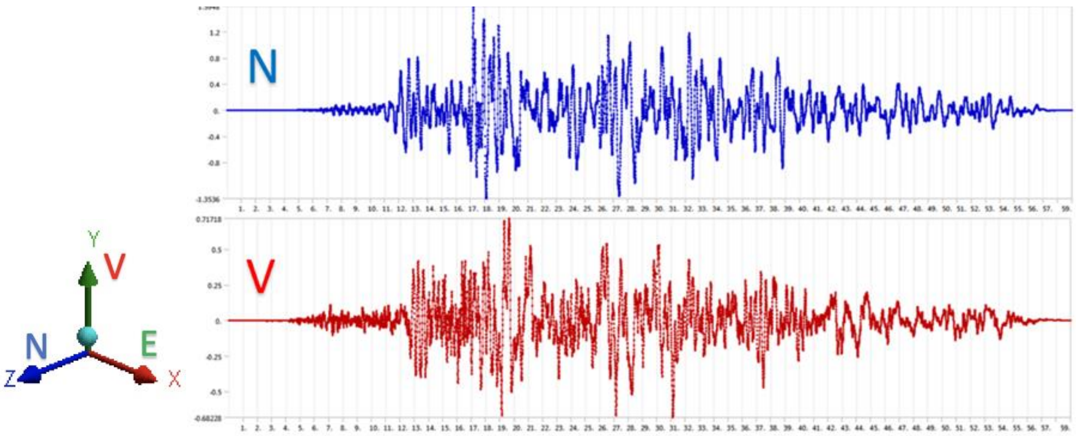


Fig.11 [5]

6. Response spectrum

The response spectrum evaluates the stress and displacements that occur in the assembly during the earthquake. It is useful in the design stage of the assembly due to its computational efficiency and "worst case" approach. An analysis of each vibration mode was performed to find the maximum, then the responses were combined to get the total result. This analysis employs the vibrational characteristics o the structure.

The following results were obtained:

- The cumulative maximum total deflections in case 1 do not exceed 3.1 mm (Fig. 12).

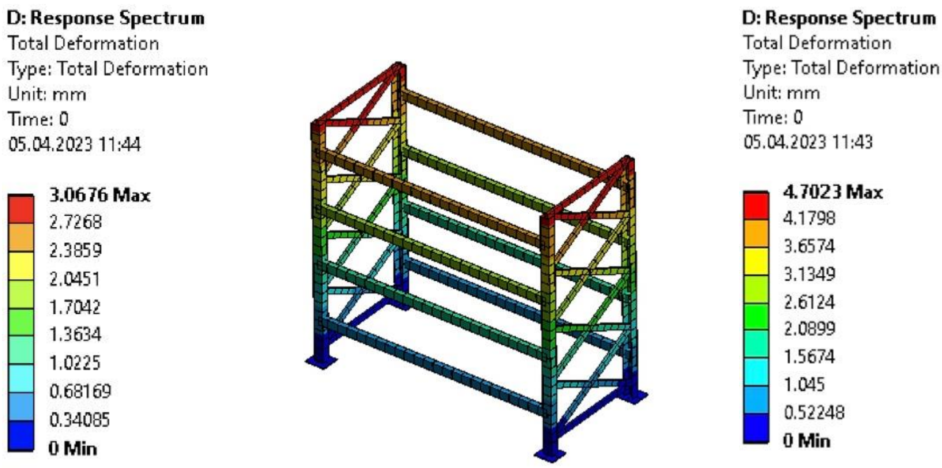


Fig. 12

- For the most severe test in case 2, this cumulative distance did not exceed 5 mm (Fig. 13).

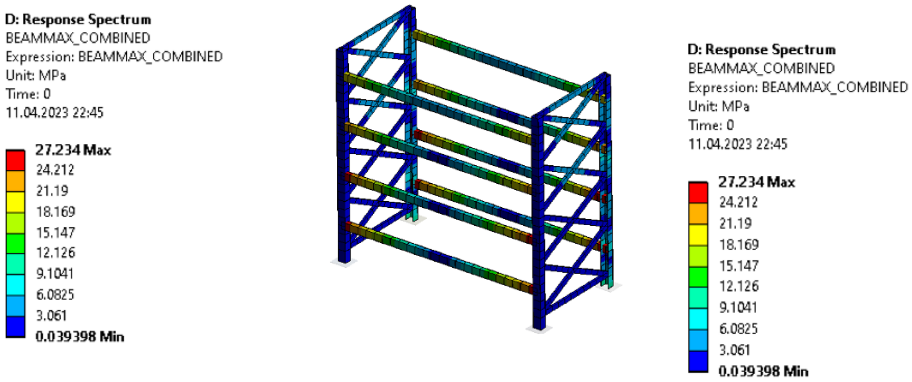
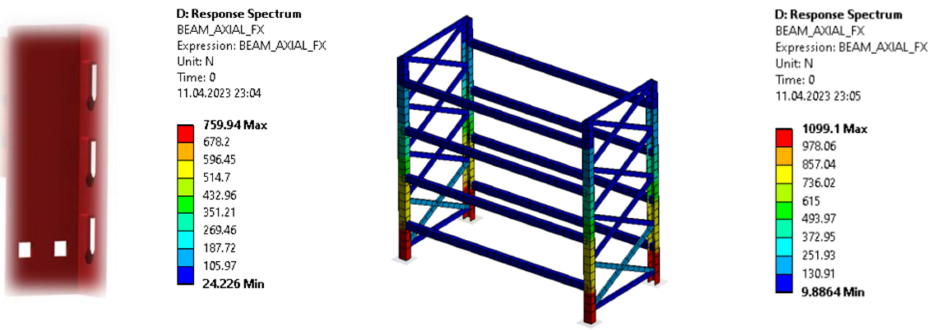


Fig. 13

- The axial forces of the beams were also processed to verify the assembly joints for case 1, 2 (Fig. 14).



(6)

Fig. 14

7. Conclusion

The results demonstrated that all the simulations carried out proved important displacements, but do not influence the structural integrity of the assembly. Also, the calculated maximum stress does not register unsafe levels. On the other hand, special attention was paid to the joints in order to check their shear resistance. No problems were found. This was clearly due to the appropriate X structural shape of the rack formed by the reinforcement bars. The assembly can be used both in the industrial field: in factories, warehouses, etc., but also in the public field: in shops, supermarkets.

8. Bibliography

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