VERIFICATION OF STRESS BY FEM ANALYSIS / MECHANICAL TESTING OF AGRICULTURAL MOBILE AGGREGATES COUPLING DEVICES
/
VERIFICAREA SOLICITĂRILOR PRIN ANALIZA MEF / TESTAREA MECANICĂ A DISPOZITIVELOR DE CUPLARE ALE AGREGATELOR AGRICOLE MOBILE

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ABSTRACT
The coupling devices must be checked for the resistance they provide during the movement of a mobile aggregate (tractor + trailer or agricultural machine), which can be done by a finite element analysis (SOLIDWORKS Simulation, CATIA, ANSYS, etc.) or by testing in service or, the fastest, in simulated and accelerated mode on special installations. The paper presents the results obtained by finite element analysis of a 55 HP tractor draught bar (after meshing the model), determining the most stressed points and the maximum risk areas where breaks will occur, respectively after performing the tests in static and dynamic mode (in case of fatigue) on the simulated and accelerated test installation to determine if deformations or breaking result from stresses.

REZUMAT
Dispozitivele de cuplare trebuie verificate din punct de vedere al rezistenţei pe care o asigură în timpul deplasării unui agregat mobil (tractor + remorcă sau maşină agricolă), verificare ce se poate realiza printr-o analiză cu element finit (SOLIDWORKS Simulare, CATIA, ANSYS, etc.) sau prin testări în exploatare sau, cel mai rapid, în regim simulat şi accelerat pe instalaţii speciale. Lucrarea prezintă rezultatele obţinute prin analiza cu element finit a unei bare de tracţiune a unui tractor de 55 CP (după discretizarea modelului), determinându-se punctele solicitate cel mai puternic şi zonele de risc maxim unde vor apărea rupturile, respectiv după testarea în regim static şi dinamic (la oboseală) pe instalaţia de încercări în regim simulat şi accelerat, pentru a determina dacă în urma solicitărilor apar deformaţii sau rupturi.

INTRODUCTION
The coupling devices for tractor - agricultural machine / trailer unit are designed in different types, depending on the towing / towing mass, the type of machine / towed gear, the angle under which it engages, etc. Analysis of the operation of coupling devices for agricultural aggregates (tractor-agricultural machinery) aims to identify the optimal coupling and to determine the optimal operation, in the case of normal and / or critical stresses, by simulated and accelerated tests, respectively in exploitation on uneven soils, to identify its critical areas (Finite Element Analysis - FEM) (*Biriş, 1999; Blumenfeld, 1995*).

The optimization of the coupling can be achieved taking into account the results of this analysis, which will lead to optimal operation and increase of the service life, under safety conditions for the operator, but especially for the participants to the traffic.

Tractors, trailers and their couplings (draught / coupling devices) must comply with certain technical and mechanical requirements for the safety of public road transport in Romania and to be allowed into circulation (*Ormenişan, 2014*).

When developing new types of coupling systems for tractors, trailers and agricultural machinery all technical conditions must comply with the European standards in order to increase the degree of interchangeability and safety in circulation. This is one of the main reasons for studying these devices, having in view due the multiple accidents caused by inadequate coupling systems (on tractors or farm tractors, respectively between tractors and farm tractors), which are not carried out in compliance with certain specifications about traffic safety (*Andrei et al., 2006; Zatocilová et al., 2014*).

Particularly for the coupling systems of tractors and trailer trucks intended for operation in the agricultural or forestry sector, the condition which implies that they must be carried out and meet the same rules is based on the need to couple between them all machinery of the same type existing on the European and Romanian market and, on the other hand, to the fact that these coupling systems have safety features in operation and mostly during road traffic.

For most machinery and equipment used in agriculture and forestry there is a freedom of expression in terms of their development (constructive, functional, etc.) *(Maican E. et al., 2018)*. Nevertheless, for the coupling systems, which are the elements that contribute to the safety in operation and circulation, severe conditions are demanded by internal and European manufacturing regulations, functional parameters, mounting conditions etc., which all the mentioned factors must comply with (*Stoica, 2001*).

In Romania, like in other European countries, road traffic in particular changes on a year-to-year basis and from country to country, depending on the increase of the motoring index, the state of the road network, the level of economic development of the country in general and in particular of the car transport (*Iordache, 2011*).

Despite the variety of measures taken to organize and improve road traffic, road safety is still far from being satisfactory, with a large number of road accidents resulting in serious material damage and even more, in losses of life. Although their participation to public traffic is occasional, the agricultural and forestry transport (represented by tractor–trailer systems or agricultural machinery) has an important role in these accidents (*Bodea, 2008*).

Most of these accidents are due to unsuitable general technical conditions or failures in the safety components of the involved agricultural or forestry machinery, including the coupling systems. Another important factor that can lead to incidents and road accidents is the fact that some tractors and agricultural machinery are not provided with the appropriate coupling systems (*Cândea et al., 2008*).

MATERIALS AND METHODS

The experimental research for FEM analysis of the draught bar was carried out in the *SOLIDWORKS Simulation* (Fig.1) and testing of a coupling device resistance from the U650M tractor was carried out on a draught bar (Fig. 2), which was tested in static and dynamic regime on a Hidropuls-type installation (Fig. 3).

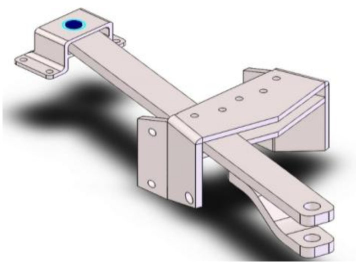


Fig. 1 - Model: Rel-1.0 used for the analysis

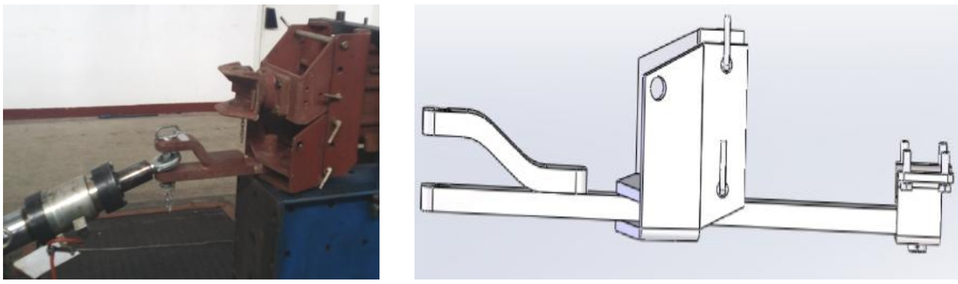


Fig. 2 – Draught bar mounted for the experiments

Verification of the coupling devices (static and dynamic) is achieved on specialized installation for testing in simulated and accelerated regime, type Hidropuls (Fig. 3), where they are mounted in the same position in which they are used during operation. Determination of forces and stresses in the coupling devices must take into account the shape, dimensions and technical conditions imposed on their aggregation devices, for each type of coupling system being provided in the legislation (directives, regulations, standards etc.), the conditions which they must meet and respect.

Fig. 3 – Testing installation in simulated and accelerated regime, Hidropuls type

RESULTS

Nonlinear static analysis of draught bar – *longitudinal stress*

Type of analysis: *Nonlinear- Static*

Table 1

Reaction forces

Selection mode	M.U.	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	-250	6.31357e-007	-2.8424e-005	250

Table 2

Moment of reaction

Selection mode	M.U.	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	0

Table 3

Obtained results

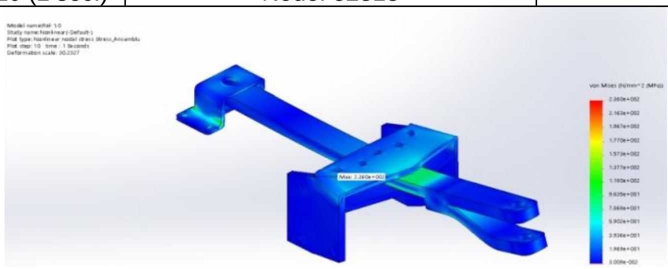
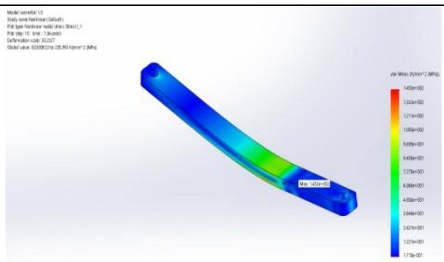
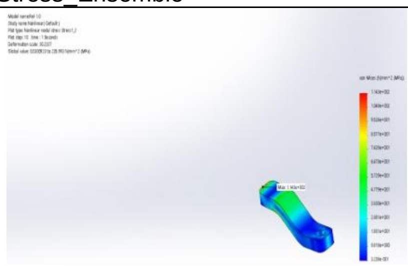
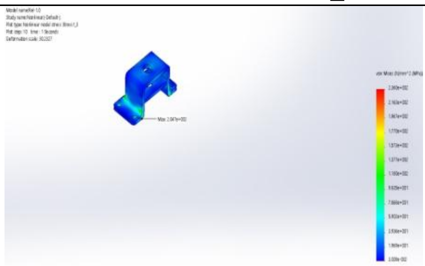
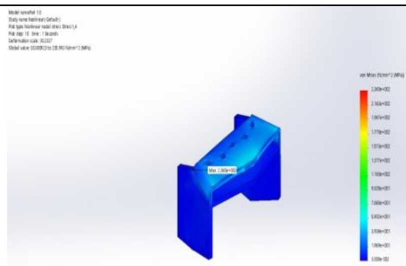
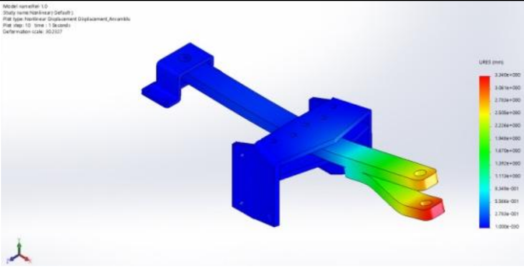
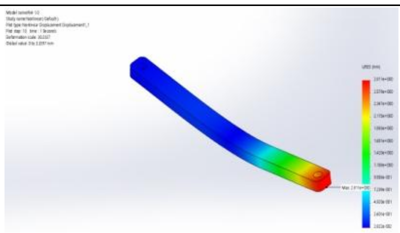
Name	**Type**	**Min**	**Max**
Stress	VON: von Mises stress at step no.: 10 (1 sec.)	3.009e-002N/mm^2 (MPa) Node: 52818	2.360e+002N/mm^2 (MPa) Node: 48787
 Rel-1.0-Nonlinear-Stress-Stress_Ensemble			
 Rel-1.0-Nonlinear-Stress-Stress 1_1		 Rel-1.0-Nonlinear-Stress-Stress 1_2	
 Rel-1.0-Nonlinear-Stress-Stress 1_3		 Rel-1.0-Nonlinear-Stress-Stress 1_4	

Table 3 (continuation)

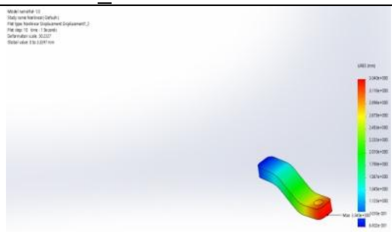
Name	Type	Min	Max
Displacement	URES: Displacement resultant at step no.: 10 (1 sec.)	0.000e+000mm Node: 12293	3.340e+000mm Node: 8276



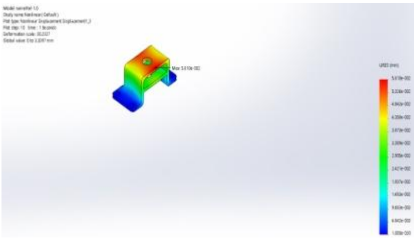
Rel-1.0-Nonlinear-Displacement-Displacement_Ensemble



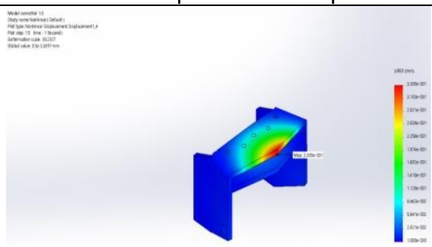
Rel-1.0-Nonlinear-Displacement-Displacement 1_1



Rel-1.0-Nonlinear-Displacement-Displacement 1_2

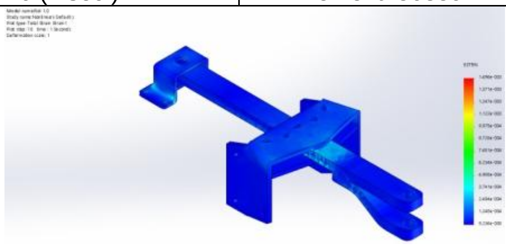


Rel-1.0-Nonlinear-Displacement-Displacement 1_3



Rel-1.0-Nonlinear-Displacement-Displacement 1_4

Name	Type	Min	Max
Strain	ESTRN: Equivalent stress at step no.: 10 (1 sec.)	9.236e-008 Element: 56359	1.496e-003 Element: 24502



Rel-1.0-Nonlinear-Strain-Strain1

Nonlinear static analysis of draught bar - *Nonlinear stress in curve*

Table 4

Reaction forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	-242.994	6.87689e-006	-58.7709	250

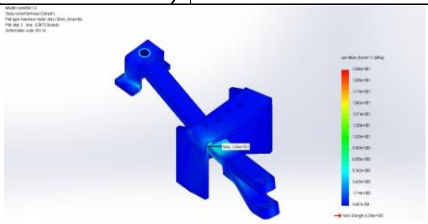
Reaction Moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	0

Table 5

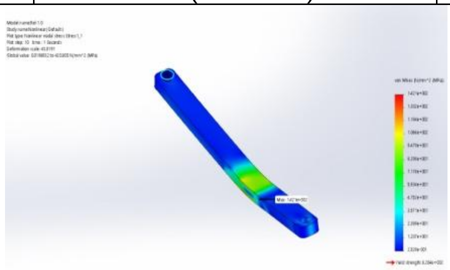
Study Results

Name	Type	Min	Max
Stress_Ensemble	VON: von Mises Stress at Step no: 3 (0.0475 seconds)	8.867e-004 N/mm^2 (MPa) Node: 49337	2.056e+001 N/ mm^2 (MPa) Node: 62193

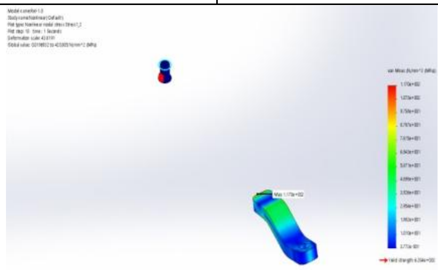


Rel-1.0-Nonlinear-Stress-Stress_Ensemble

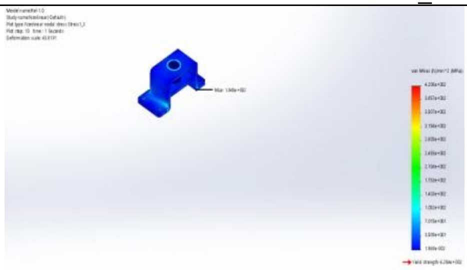
Name	Type	Min	Max
Stress	VON: von Mises Stress at Step no: 10 (1 seconds)	1.969e-002 N/ mm^2 (MPa) Node: 49337	4.208e+002 N/ mm^2 (MPa) Node: 62193



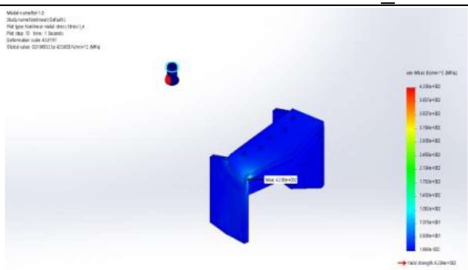
Rel-1.0-Nonlinear-Stress-Stress1_1



Rel-1.0-Nonlinear-Stress-Stress1_2

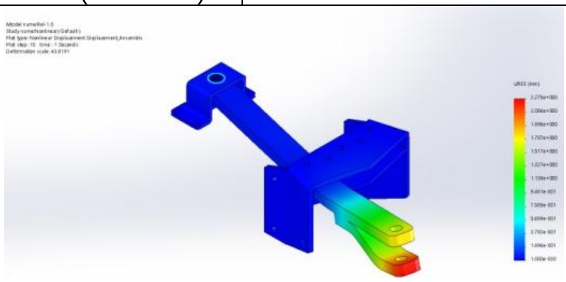


Rel-1.0-Nonlinear-Stress-Stress1_3

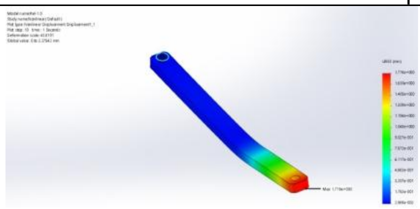


Rel-1.0-Nonlinear-Stress-Stress1_4

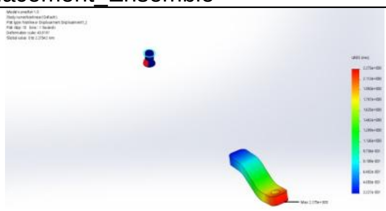
Name	Type	Min	Max
Displacement	URES: Resultant Displacement at Step no: 10 (1 seconds)	0.000e+000mm Node: 12176	2.275e+000mm Node: 8211



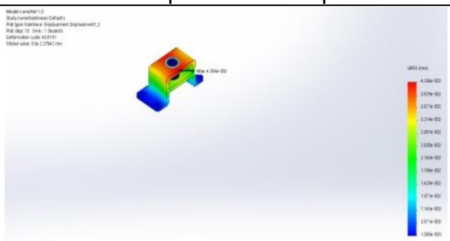
Rel-1.0-Nonlinear-Displacement-Displacement_Ensemble



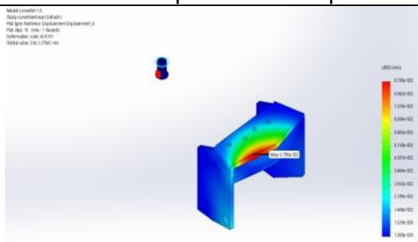
Rel-1.0-Nonlinear-Displacement-Displacement 1_1



Rel-1.0-Nonlinear-Displacement-Displacement 1_2



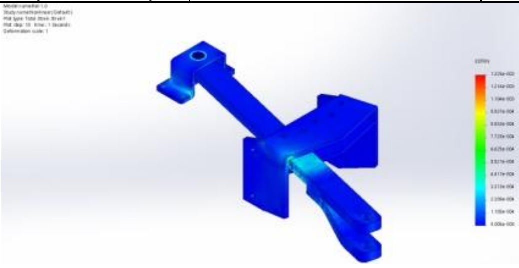
Rel-1.0-Nonlinear-Displacement-Displacement 1_3



Rel-1.0-Nonlinear-Displacement-Displacement 1_4

Table 5 (continuation)

Name	Type	Min	Max
Strain	ESTRN: Equivalent Strain at Step no: 10 (1 seconds)	9.005e-008 Element: 26676	1.325e-003 Element: 30722



Rel-1.0-Nonlinear-Strain-Strain1

Data processing - static tests

Static tests were carried out at INMA Bucharest on a specialized installation (Hidropuls), with the towing device and any tractor coupling component attached to a rigid structure by means of the same components used for mounting on the tractor body (Fig. 4).

Fig. 4 - Mounting on the Hidropuls installation for the static test of the draught bar

Equipment for measuring and control used to record loads and applied moments must be of high precision: applied loads ± 50 daN; moments ± 0.01 mm.

During the test, the deformation of the coupling device must not exceed 10% of the maximum elastic deformation observed. Verification was performed after removal of the load and return to the initial load of 500 daN.

MT = 1450 kg = 1422.45 daN;   MR = 1500 kg = 1471.50 daN;
D = 25 kN = 2500 daN;   S = 7 kN = 700 daN.

where:

MT - total permissible tractor mass, from a technical point of view;
MR - total permissible mass of the towed vehicle, from a technical point of view;
D - mathematically determined force (the components of the horizontal force on the longitudinal axis of the vehicle);
S - static load of the draught bar (component of the vertical forces on the road).

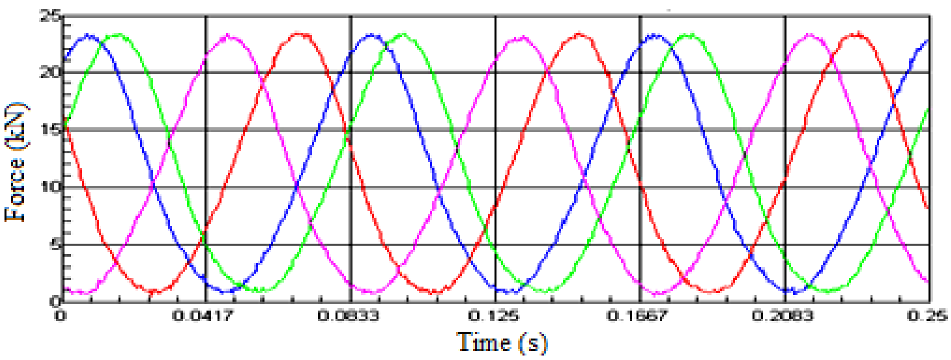


Fig. 5 - Force-time diagram for the static test of the draught bar on the Hidropuls installation

Data processing - dynamic tests

In dynamic tests, the resistance of the mechanical coupling system (draught bar) was established by alternating traction at a specialized stand (Hidropuls installation).

This dynamic method describes the fatigue test which applies to the entire draught bar, respectively, when the draught bar, equipped with all the components required for installation, is mounted and tested on the Hidropuls.

Alternate forces have been applied sinusoidally, from the longest possible distance (by alternate towing and / or lifting), to a load cycle determined by the material involved, during which no cracks or wear must occur.

The horizontal force components on the longitudinal axis of the vehicle, and the components of the vertical force, formed the basis of the load to be subjected to the test. However, the components of horizontal force at right angles to the longitudinal axis of the vehicle, as well as the moments are of secondary importance, therefore they have not been considered.

The horizontal force components on the longitudinal axis of the vehicle are expressed by a mathematically determined force, *D*.

$$D = g \cdot (M_T \cdot M_R) / (M_T + M_R) \quad (1)$$

The technically acceptable load masses specified by the manufacturer on this traction unit are: M_T = 1450 kg = 1422.45 daN; M_R = 1500 kg = 1471.50 daN; D = 25 kN = 2500 daN; S = 7 kN = 700 daN.

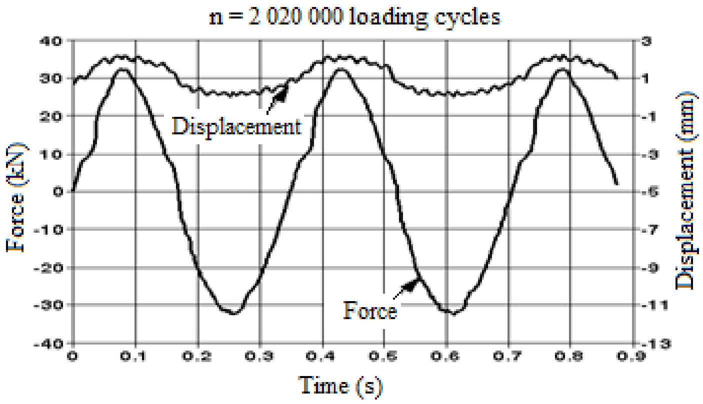


Fig. 6 - Diagram force-time and movement-time (in the horizontal direction)

CONCLUSIONS

For non-linear static analysis of the draught bar - longitudinal stress, the highest stresses occur in the hinge area of the bar between the two fixation elements at the engine chassis, respectively in the coupling bolt between the tractor and the trailer, which is why they must be optimized in the sense of choosing a quality material, with a good coefficient of elasticity that will allow taking over some shocks that occur in the case of passing over pits, etc. and which can cause shearing of the bolt or articulation elements.

For non-linear stresses in the curve, the highest stresses occur as in the case of longitudinal stresses, in the hinge areas of the bar at the engine chassis, respectively in the coupling bolt between tractor and trailer, but they are larger in the first coupling bolt in the fixation element to the chassis and the front and rear parts of the bar (against the bolt), which implies a reinforcement (optimization) of this area.

Data obtained and processed after the testing in static and dynamic regime show that the draught bar did not break when more than 2000000 cycles (2020000 cycles) of stress - in dynamic regime were applied, with a maximum displacement at a horizontal plane of ± 1.12 mm which corresponded to a force of ± 32.27 kN and a maximum displacement at the vertical plane of ± 0.48 mm which corresponded to a force of ± 10.19 kN, respectively at a force equal to 1.5 times the permitted towable mass in the case of static load, without any visible deformation, rupture or other visible damage.

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