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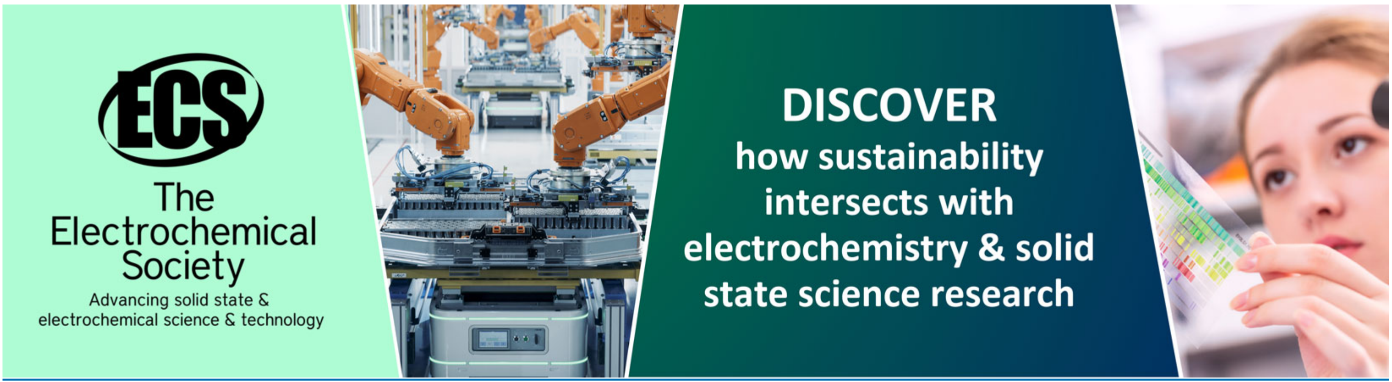

Innovative solutions to make travel more comfortable

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Abstract. Traveling in various vehicles and means of transport (ambulance, airplane, …) can be characterized by sudden accelerations, decelerations and vibrations/perturbations. All these loads are transferred to the passenger, making the journey uncomfortable. The study for the improvement of comfort in such situations was the subject of a collaboration between the authors of the present document. The designed solutions are reported in a patent application published with the number WO2023111937A1.

1. Introduction

Passenger comfort is an important aspect in designing vehicles and means of transport. It is essential, for instance, to improve the comfort of patients and medical staff present in an ambulance. The primary approach to ensure a comfortable travel is to minimize the transmission of loads to the people present in the compartment since the transportation can include sudden accelerations, decelerations, vibrations and changes of direction due to the emergency situation. Similar considerations can be made for airplane transportation, where perturbations affect passenger comfort. It is for this reason that people continuously search for solutions that improve passenger comfort by decreasing the transfer of such loads during transportation.

A method for reducing the vibrations transferred to the people in an ambulance is described in CN109124903A [1]. According to this invention, four rods are positioned crosswise, with one end connected to one of the vertices in the lower region of the cabin and the other end to a pressurized element. The system created by the rods and the pressure produced by cylinders mounted on the bottom region of the vehicle enable the damping of any vertical movements of the cabin.

Document KR100855613B1 [2] presents a system to improve the comfort for a patient on a stretcher only during the phases of loading and unloading from the ambulance. The rear height of the vehicle is adjusted with an air spring, which is placed between the frame and a leaf spring attached to the bottom portion of the vehicle chassis.

A system for reducing the pitching and rolling of a cab mounted on a vehicle chassis is described in JP2001301651A [3]. The solution involves the presence of a connecting element inclined with respect to the horizontal direction, which connects the front part of the cabin to the vehicle frame. An air spring is also interposed between the cabin and the inclined element. The rear suspension system comprises two inclined air springs positioned between the cab and the chassis.

JPS6218374A [4] refers to a truck cab suspension system with a structure which adjusts the stiffness of an elastic element interposed between the cab and the vehicle chassis based on the external factors which can reduce the travel comfort. There are a cab support element and an arch element which connects the two side members of the vehicle chassis in the rear area of the cab. The front suspension system involves an element connected by hinges to two brackets fixed respectively to the vehicle frame and to the cab support element. A compressed coil spring and shock absorber are located between the cab and the element connected by hinges. The rear suspension system consists of a shock absorber and a coil spring compressed between a bracket attached to the arch element and another component. Both shock absorbers are composed of an electromagnetic actuator that adjusts the damping. Each actuator is controlled by a unit which manages the operating parameters based on external data evaluated by special sensors.

Document EP2886377A1 [5] presents a solution for maintaining the cab of a truck or tractor horizontal when parked on uneven areas. The front axle supports the frame with springs. Each spring is associated with a shock absorber which absorbs the shocks suffered by the chassis when the vehicle is in motion. There is also a front stabilizer bar that reduces rotation of the vehicle upper body during movement. The cabin is suspended by vertically arranged coil springs, while the lateral rotation of the cabin is controlled by a stabilizer only during movement.

US2014319876A1 [6] shows a suspension system capable of damping the shocks suffered by the driver cab of a vehicle. The solution described comprises a spring-shock absorber unit and a hydraulic system consisting of two double-acting cylinders positioned respectively on the right and left side of the cab. Each cylinder has one chamber at the top and one chamber at the bottom, for a total of two chambers per cylinder. The two cylinders are then cross-connected with respect to the described chambers. To limit the transverse oscillations of the vehicle, the solution also includes two transverse shock absorbers, connected to two cross-bridge structures.

A suspension system for the driver cab of a vehicle and, in particular, of an agricultural machine is presented in document WO2018203124A1 [7]. One of the solutions presented has a counter-frame on which the cabin is mounted. The suspension system consists of a front unit fixed to a bracket mounted on the counter-frame and a rear unit fixed to the vehicle chassis. There are two transverse elements and two longitudinal elements which keep the cabin in position avoiding lateral movements and provide torsional resistance to the structure.

Document MXPA02004380A [8] reports a suspension for a truck driver cab that reduces the twisting forces transmitted to the frame. Two air springs are positioned below the rear sill of the truck and two inclined shock absorbers are placed between the air springs.

Improving the passenger comfort was the objective of a collaboration among the authors of the present document. The designed solutions are reported in a patent application published with the number WO2023111937A1 [9]. The proposed solutions consist of an alternative suspension system and a vehicle comprising such a suspension system. The suspension system can be used on different types of vehicles.

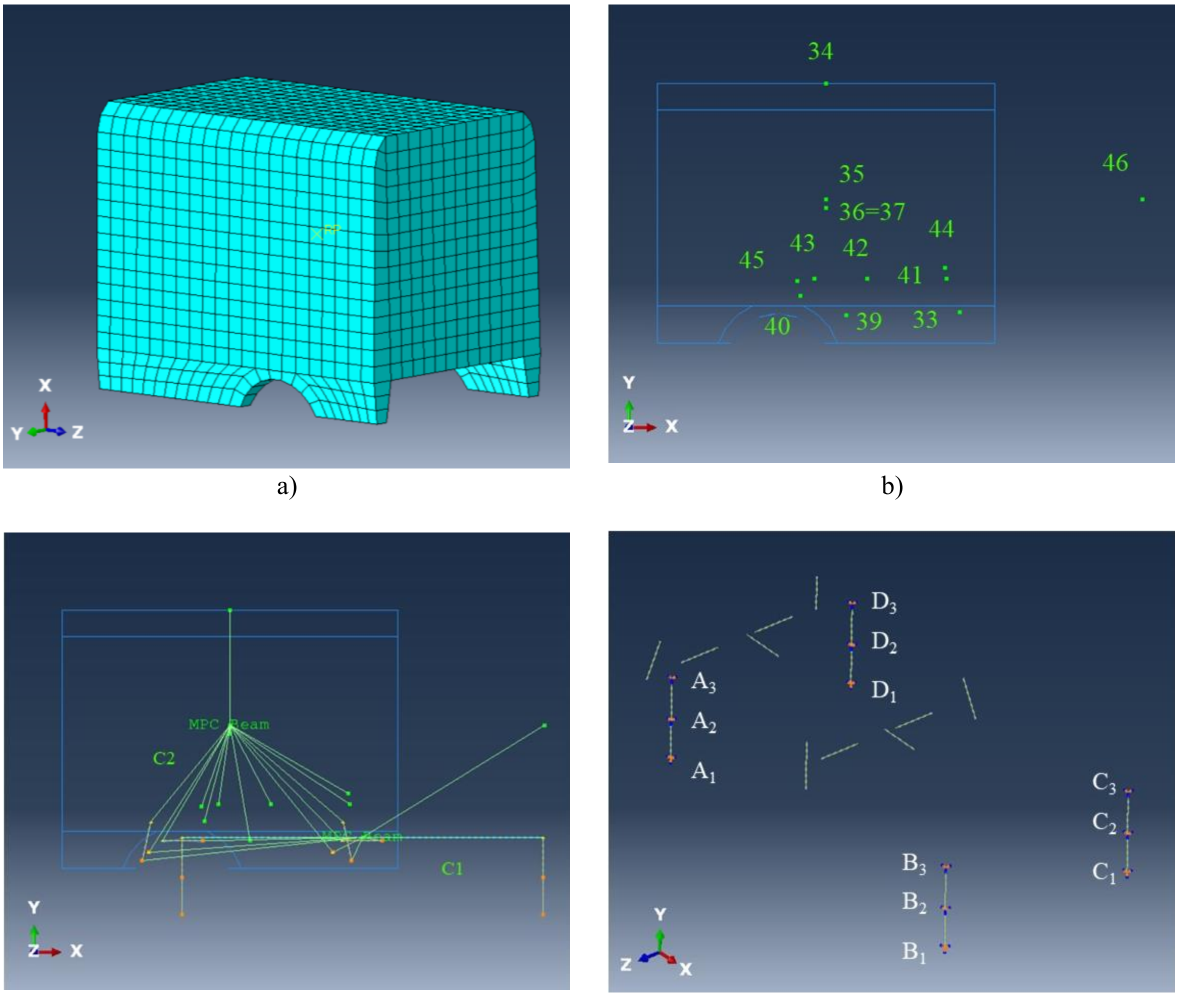
2. Finite element analyses

The Abaqus finite element code [10] was used to conduct preliminary simulations for the conception of different solutions to improve passenger comfort in vehicles and means of transport. The case study analyzed is the improvement of the comfort in an ambulance compartment. An implicit integration scheme was used instead of the explicit one, commonly adopted for impact simulation [11-14], since this is not the objective of the study.

The model created for the analysis of the dynamic behavior of the ambulance compartment is shown in Figure 1. 2D rigid elements were used to model the ambulance compartment (Figure 1a), whose inertial properties were assigned to the centroid. Concentrated masses were used to model the presence of the equipment and human beings in the compartment, of the cabin and of the vehicle frame according to Figure 1b and Table 1.

A multi-point constraint type beam (C1 in Figure 1c) was used to constrain the movement of the primary suspension (suspension of the vehicle) to the frame centroid, the centroid of the cabin and the secondary suspension (suspension to improve comfort). Another multi-point constraint type beam (C2 in Figure 1c) was used to constrain the movement of the compartment centroid and the equipment inside to the movement of the secondary suspension. The tires of the vehicle were modelled using four connector elements (A_1A_2, B_1B_2, C_1C_2 and D_1D_2 in Figure 1d) with an axial stiffness of 250000 N/m per single element. Each shock absorber of the primary suspension was modelled with a connector element (A_2A_3, B_2B_3, C_2C_3 and D_2D_3 in Figure 1d) having an axial stiffness of 50000 N/m and an axial damping coefficient of 5123.5 Ns/m. Each shock absorber of the secondary suspension (other elements in Figure 1d) was modelled with a connector element having an axial stiffness of 160000 N/m and an axial damping coefficient of 4000 Ns/m.

In the first simulation step, a gravity load in the vertical direction (y) was applied to the whole model for 10 s in order to reach the static equilibrium condition of the system due to its own weight. Subsequently, a further gravity load was applied in the three directions x, y and z for 50 ms. In the final simulation step, a gravity load in the vertical direction was applied for 10 s in order to reach again the static equilibrium condition of the system after its perturbation. In all the simulation steps the nodes A_1, B_1, C_1 and D_1 were fixed while only the vertical movement of the nodes A_2, B_2, C_2, D_2, A_3, B_3, C_3 and D_3 was allowed.



a) b)

c) d)

Figure 1. Finite element model: a) compartment; b) concentrated masses; c) rigid connections; d) connectors for modelling tires, primary and secondary suspensions.

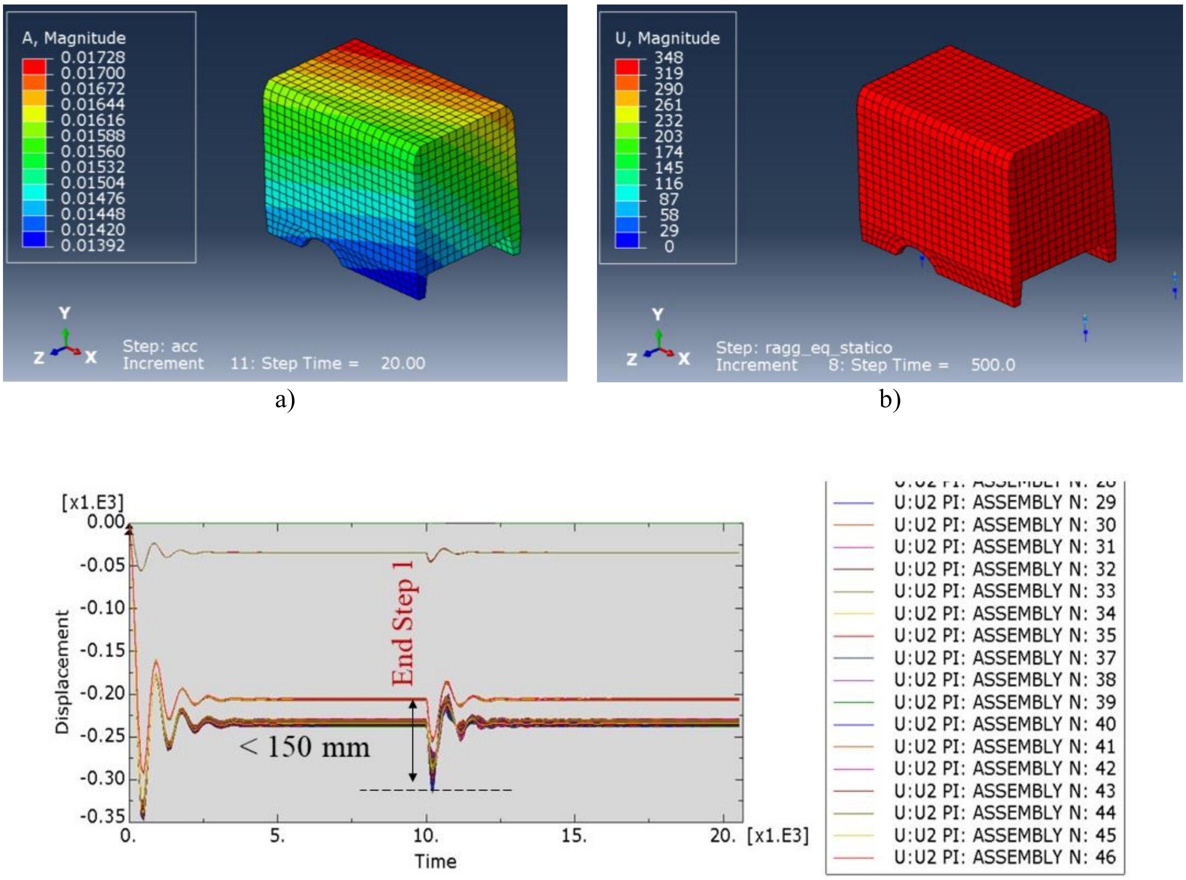
Table 1. Concentrated masses.

Point	Description	Mass (kg)	Notes
40	Stretcher support	89	
41	Seat 1 (+ 1 person)	140	
42	Seat 2 (+ 1 person)	140	
43	Seat 3 (+ 1 person)	140	
44	Support	5	
36,37	Furniture + cables + ventilation system	170 (85x2)	Distributed in the two side walls Positioned in the center of gravity of the walls
34	Air conditioning system	40	Positioned in the center of gravity of the ceiling
45	Stretcher (+ 1 person and equipment)	215	
39	Secondary suspension	250	
35	Compartment	411	Placed in the centroid Moments of inertia with respect to the x, y and z axes: 2110 kgm^2
46	Cabin	1000	
33	Frame	900	Moments of inertia with respect to the x, y and z axes: 2850 kgm^2

In this document the analysis focuses on accelerations and displacements, Table 2 and Figure 2. Accelerations are related to travel comfort [15,16]. Displacements were measured to verify that the compartment and the other vehicle components do not move much and do not collide with each other or with objects eventually present on the road. The minimum and maximum values of the acceleration along the travel direction (x), the vertical direction (y), the transversal direction (z) and in magnitude are shown in Table 2. These values do not consider the first simulation step for reaching the static equilibrium condition, which is not related to travel comfort, and refer only to the ambulance compartment. The minimum values in the x and z directions are equal in magnitude to the increment in gravity load applied in the three directions in the simulation step which provides the perturbation load. The maximum acceleration obtained in the compartment is 17.28 m/s^2 in magnitude (Figure 2a), equal to slightly less than double the acceleration of gravity. The minimum and maximum displacements of the whole model along the x, y and z directions and in magnitude are shown in Table 2. The maximum displacement in magnitude is 348 mm (Figure 2b). However, these values of displacements take into account the achievement of the static equilibrium condition, obtained at the end of the first simulation step. The maximum actual displacements resulting from the implemented perturbation, i.e. the relative displacements, were approximately estimated as the maximum difference between the displacements obtained after the beginning of the second simulation step and the displacements at the end of the first simulation step for reaching the equilibrium condition, as shown in Figure 2c for the displacement in the y direction. Combining the maximum relative displacements in the three directions x, y and z, the maximum relative displacement in magnitude is certainly less than 160 mm. The maximum displacement values obtained, both absolute and relative, are small compared to the dimensions of the ambulance and therefore can be considered acceptable.

Table 2. Results of the finite element analysis.

Direction	Min. acc. (m/s^2)	Max. acc. (m/s^2)	Min. displ. (mm)	Max. displ. (mm)	Max. rel. displ. (mm)
x	-9.81	5.76	-33	17	<50
y	-12.73	7.60	-348	0	<150
z	-9.81	8.65	-32	25	<40
Magn.		17.28		348	<160



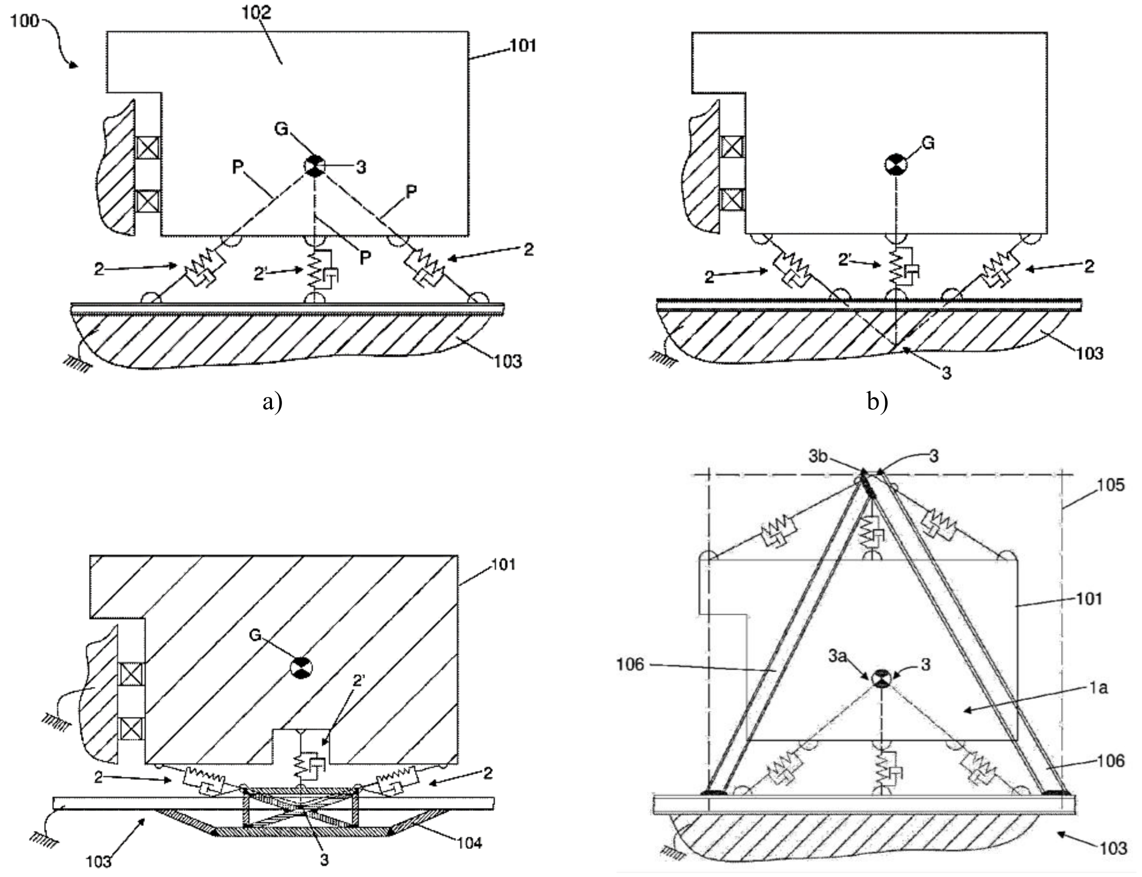
a) b)

c)

Figure 2. Finite element results: a) acceleration (magnitude) field when the maximum value is achieved (mm/ms^2); b) displacement (magnitude) field when the maximum value is achieved (mm); c) estimate of the relative displacement in the y direction (time in ms, displacement in mm).

3. Patent application WO2023111937A1

The different solutions identified to improve passenger comfort are reported in the patent application published with the number WO2023111937A1 [9], Figure 3.



a) b)

c) d)

Figure 3. Possible solutions to improve passenger comfort: a) straight pyramid; b) overturned pyramid; c) with counter-frame; d) suspended compartment [9].

Figure 3a shows a suspension setup that could be mounted in a vehicle 100, between the compartment 101 and the vehicle frame 103. The presented configuration contains several suspensions, indicated with number 2 in the figure, composed of at least one elastic element and/or a damping element. The suspensions are arranged forming a straight pyramidal configuration. The system may also include one or more supplementary suspensions, located transversely to the pyramidal configuration.

The solution presented in Figure 3b is similar to that presented in Figure 3a but the suspension system is arranged according to an overturned pyramidal configuration.

Figure 3c shows a configuration in which the vehicle frame 103 incorporates a counter-frame 104, capable of optimizing the distribution of loads in the vehicle frame. The counter-frame acts as an extension of the suspension system for the compartment 101. It is suitably sized and has bending and torsional stiffness. This influences the dynamic and shock-absorbing behavior of the vehicle. As a result, in this particular solution, there is a sequence of suspension elements: a vehicle suspension system, a suspension system associated with the existence of the counter-frame and one or more suspension systems arranged according to one of the pyramidal configurations of Figures 3a and b.

According to the solution presented in Figure 3d, the vehicle incorporates a second body 105, which contains the compartment 101. The casing 105 is fixed to the vehicle frame 103, or to the counter-frame. An additional suspension system, similar to the one described above, is present in the vehicle, between the casings 105 and 101. The two suspension systems are positioned on opposite sides of the compartment 101, one above and the other below. The purpose of this design solution is to have a suspended compartment. One or more inclined beams 106 may be present and converge at the common vertex of the suspension system located above the compartment to increase the stiffness of the casing 105. In Figure 3d, the suspension systems are arranged in a straight pyramid configuration, but variations with one or both of the suspension systems assuming the overturned pyramid arrangement are admissible. The solution presented in Figure 3d can also include the presence of a counter-frame, with defined torsional-bending stiffness.

4. Conclusions

Passengers of vehicles and means of transport, such as ambulance and airplane, may be subjected to sudden accelerations, decelerations and vibrations/perturbations which make travel uncomfortable. Possible solutions designed to improve passenger comfort are reported in a patent application published with the number WO2023111937A1 and can be described according to four schemes: (i) straight pyramid, (ii) overturned pyramid, (iii) vehicle with a counter-frame, (iv) suspended compartment. Future studies could involve theoretical and experimental approaches as well as further numerical analyses in order to deepen the behavior of the conceived systems as done in [17-19] for other mechanical problems.

References

[1] Ran J 2019 Patent CN109124903A
[2] Kang S H 2008 Patent KR100855613B1
[3] Hiramatsu M and Momiyama F 2001 Patent JP2001301651A
[4] Ozawa T, Noguchi M, Okawa T and Kutsukake Y 1987 Patent JPS6218374A
[5] Vreede R J 2015 Patent EP2886377A1
[6] Schauer M, Eismann J, Helm E, Quaing M and Bublies H 2014 Patent US2014319876A1
[7] Soldan D J and Jenning J M 2018 Patent WO2018203124A1
[8] Taylor M A 2004 Patent MXPA02004380A
[9] Baragetti S, Monticelli L and Arcieri E V 2023 Patent WO2023111937A1
[10] ABAQUS, ABAQUS Documentation, Dassault Systèmes, Providence, RI, USA, 2017
[11] Arcieri E V, Baragetti S, Fustinoni M, Lanzini S and Papalia R 2018 *Procedia Struct. Integr.* **8** 212
[12] Arcieri E V, Baragetti S and Božić Ž 2021 *Procedia Struct. Integr.* **31** 22
[13] Baragetti S and Arcieri E V 2019 *Procedia Struct. Integr.* **24** 91
[14] Baragetti S and Arcieri E V 2020 *Eng. Fail. Anal.* **113** 104564
[15] UNI, UNI ISO 2631-1:2014
[16] BS, BS 6841:1987
[17] Baragetti S 2006 *Meccanica* **41** 443
[18] Baragetti S, Guagliano M and Vergani L 2000 *Int. J. Mater. Prod. Technol.* **15** 91
[19] Baragetti S and Tordini F 2007 *Int. J. Fatigue* **29** 1832