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ALTERNATIVE DESIGN FOR A SEMI – TRAILER TANK VEHICLE

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RESEARCH ARTICLE

ABSTRACT: The assessment of the design parameters of a semi-trailer tank vehicle is crucial and it is related to the three motions, namely longitudinal (driving and braking), lateral (guidance and steering), and vertical (suspension and damping). Since semi-trailer tanks are mainly used for the transportation of dangerous goods, European Standards specify the minimum requirements for their construction and handling. In the present study, different semi – trailer tank designs with the same overall length are investigated using the finite element (FE) software ANSYS® v.18.0 and the calculation method provided in European Directives. The design parameters under consideration consist on the geometry of cross section and the section of the tank, the number of compartments and the payloads and the materials used. Different computational models of a semi - trailer tank vehicle have been set up in order to investigate the influence of each of the above mentioned design parameters. Their boundary values as well as the suitable computation for structural integrity and handling are defined through the corresponding Standards and the restrictions posed by the manufacturing procedures of such a semi – trailer tank. The outcomes of this study provide, among others, a useful insight for tank manufacturers.

KEY WORDS: semi-trailer tank vehicle, structural design, handling, European Directives, Finite Element Method

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ALTERNATIVNO PROJEKTOVANJE POLUPRIKOLICE CISTERNE

REZIME: Ocena projektnih parametara poluprikolice cisterne je od presudnog značaja i odnosi se na kretanja u tri pravca: podužni (vožnja i kočenje), bočni (vođenje i upravljanje) i vertikalni (oslanjanje i prigušenje). Pošto se poluprikolice cisterne koriste za transport opasnih materija, evropski standardi propisuju minimalne zahteve za njihovu konstrukciju i rukovanje. U ovoj studiji su analizirana su različita rešenja poluprikolice cisterne iste ukupne dužine, korišćenjem metode konačnih elemenata u programskom paketu ANSYS® v.18.0 kao i metoda proračuna definisanim evropskim direktivama. Razmatrani projektni parametri su: geometrija poprečnog preseka i preseka rezervoara, broja pregrada i mase i primenjeni materijali. Formirani su različiti proračunski modeli poluprikolice cisterne kako bi se istražio uticaj svakog gore pomenutog projektnog parametra. Granične vrednosti, odgovarajuće za proračun integriteta konstrukcije i manipulisanje, definisani su odgovarajućim standardima i ograničenjima uslovljenim procesom proizvodnje poluprikolice cisterne. Rezultati ovog istraživanja, između ostalog, pružaju korisne informacije proizvođačima cisterni.

KLJUČNE REČI: poluprikolica cisterna, projektovanje strukture, upravljanje, evropske direktive, metod konačnih elemenata

ALTERNATIVE DESIGN FOR A SEMI – TRAILER TANK VEHICLE

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1. INTRODUCTION

The typical way of transportation for liquid and granular material by road is with the use of tank vehicles. Common liquid materials transported by road are fuels which are dangerous goods. Liquid fuels belong in Class 3 of flammable liquids for which the main danger is this of fire. The safety regulations for vehicles carrying dangerous goods are outlined by the "European Agreement concerning the International Carriage of Dangerous Goods by Road" (ADR) and specifically "Part 6 - Requirements for the construction and testing of packagings, intermediate bulk containers (IBCs), large packagings and tanks" (ADR, 2017). In the aforementioned text the basic requirements for design, construction, testing, inspection, re-testing, qualification and maintenance of such tanks are thoroughly described.

Tanks, in general, can be divided into categories according to their construction material and their maximum working pressure. If the tank is metallic and its working pressure is not exceeding 0.5 bar its design and construction is at the same time related to the European Standard EN 13094 (EN13094, 2015). According to both previously mentioned Standards the cross-section of tank can be cyclical, elliptical or box-shaped. Furthermore, their section can be rectangular, wedge-shaped or cone-shaped and they can be compartmented or not. In Annex A of the EN13094 it is stated that there are four different methods for the verification of the design of such a tank, namely, (a) dynamic testing, (b) finite element stress analysis, (c) reference design, (d) calculation method or a combination of them. In order for (a) or (c) to be performed the construction of the tank is a prerequisite, while both (b) and (d) can be performed right after the preliminary design of the tank, prior to its construction, leaving space for the construction of an optimized design (Koulocheris, 2017). In ADR different categories of tanks are mentioned such as fixed tanks, also referred as tank-vehicles, demountable tanks, tank containers and portable tanks. A tank – vehicle can be a motor vehicle, an articulated vehicle, a trailer or a semi-trailer. Semi–trailers are trailers without front axle. Most European trailers have three axles with single-tire hubs totaling 6 wheels. A large proportion of the semi-trailer weight is supported by the tractor unit.

According to Eurostat (Eurostat, 2017), 77.6% of the total tonne-kilometres transported in 2015 have been transported with semi-trailers and road tractors. A common type of semi-trailer is the semi-trailer tank vehicle which is mainly used for hauling liquids such as gasoline and alcohol, or various types of gases. They are similar in principle to intermodal trailers but with a different frame intended to be attached to a liquid or gas tank. The maximum dimensions and weights for international traffic, with respect to road safety reasons and to avoid damaging roads, bridges and tunnels are set with Directive (EU) 2015/719. According to this Directive two-axle motor vehicles with three-axle semi-trailers transporting tanks or swap bodies of a length of up to 13.7 m should be allowed in intermodal transport operations up to a total authorized weight of 42 tonnes.

In this paper guidelines for an alternative design for a semi-trailer tank vehicle are provided. With this respect different computational models of semi-trailer tank vehicles developed in the Vehicles Laboratory of the National Technical University of Athens are investigated. Each semi-trailer tank vehicle geometrical model consists of the shell walls, the front and rear end, different number of partitions or surge plates and top openings. The tank is mounted on the vehicle with six supports. The front two supports are mounted on one support plate which connects with the motor vehicle through a fifth wheel coupling while the rest four of them are connected to a support plate each and are mounted on the semi-trailer. The distance between the two front supports is restricted due to the geometry of the section of the tank while the distance between the rest of the supports is restricted by the axles of the semi-trailer thus it is the same for all semi-trailer tank vehicles. With the use of the Finite Element (FE) method the influence of the cross sectional geometry, the construction material and the compartmentalization of the tank, to the semi-trailer tank vehicle performance is investigated. For the implementation of the FE method ANSYS® v. 18.0 finite element (FE) software has been utilized. In total sixteen (16) FE models have been set up and evaluated in the loading cases provided by the Standard EN13904, for the evaluation of the structural integrity of the tank vehicles. The outcomes of this study offer a useful insight for tank manufacturers.

2. FINITE ELEMENT MODELS & DESIGN PARAMETERS

In Figure 1 the side view of a typical semi-trailer tank vehicle is provided.

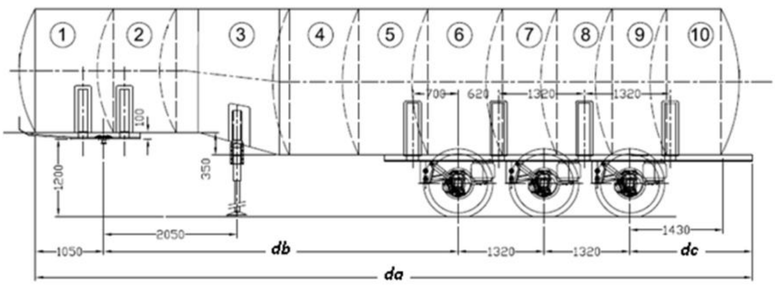


Figure 1. Semi-trailer tank vehicle

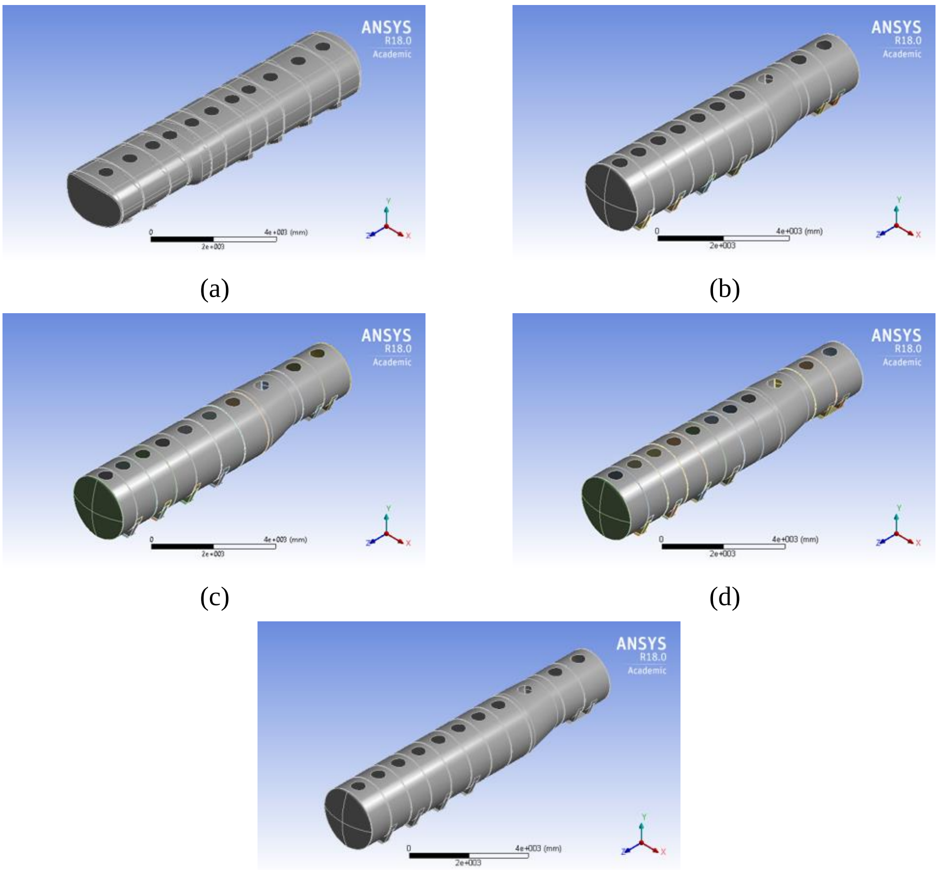
In order to investigate the influence of different design parameters in semi-trailer tank vehicles, the geometrical 3D models of five (5) main semi-trailer tank vehicle configurations have been constructed. Their geometrical characteristics are provided in Table 1.

Table 1. Geometrical characteristics of the main semitrailer tank vehicle configurations

Configuration	Cross Sectional Geometry	Overall Length (mm)	Overall Width (mm)		Number of Compartments
			Front	Back	
1a	Box-shaped	11340	2470/1538	2470/1768	11
2a	Circular	11380	1900	2250	11
3a	Circular	10280	1900	2250	10
4a	Circular	11201	1900	2250	10
5a	Circular	12030	1900	2250	11

In all configurations the different parts of the semi-trailer tank vehicle are considered to be in fully bonded contact simulating welded connections. Thus, the shell walls of the each compartment (Ki) are in contact with the front end/partition (Di) and the shell walls of the final compartment are in contact with both the front partition and the rear end of the tank.

All shell walls are in contact to each other while the top openings are in contact with the corresponding shell walls. Finally, the tank shell walls are mounted to the semi-trailer with six supports (Si) and their corresponding support plates (SPi). The first two supports (S1 & S2), which are in contact with SP1, are in contact with the shell walls of the smaller dimensions (in front of the wedge shaped part of the tank section) while the rest of the supports (S3 to S6) are in contact with the shell walls of the larger dimensions (behind the wedge shaped part of the tank section). The rear supports in all cases have a distance of 1320 mm between them, which is equal to the distance of the axles of the semi-trailer tank vehicle and are placed between them as it is obvious in Figure 1. For every tank there is a combination of the dimensions da, db and dc (Figure 1) in order for the semi-trailer tank vehicle to host the designed tank. In Figure 2 the geometrical models of the main semi-trailer tank vehicle configurations are presented.



(a) (b) (c) (d) (e)

Figure 2. Geometrical models of the main semi-trailer tank vehicle configurations

In Table 2 information on the construction material, the tare weight and the payload of each configuration is reviewed. The payload of all semi-trailer tank vehicles has been calculated considering the tanks filled with water up to their highest point.

Table 2. Material, tare weight and payload of the FEA models

Configuration	Material	Tare Weight (N)	Payload (N)
1a	Al	2360	39500
2a	Al	1980	40000
3a	Al	1820	36000
4a	Al	2040	39500
5a	Al	1930	42500

Using these semi-trailer tank vehicle configurations as a starting point, new setups are generated in order to evaluate the influence of different design parameters and a comparative analysis has been performed for all the FEA analyses. The design variables under consideration consist on the geometrical and material characteristics of the tank and the number of compartments. All the design parameters along with their explored values are presented in Table 3. In Table 3 also the initial configuration used for the corresponding setups is mentioned.

Table 3. Design parameters under consideration and FEA models

Design Parameter	Value	Main Configuration
Geometry of cross section	Box shaped	Config1
	Circular	Config2
Construction Material	St	Config1 & Config2
	Al	
Number of compartments for the same overall length (Setups)	10, 8, 7	Config3
	11, 10, 8	Config4
	10, 8, 6, 4, 3, 2	Config5

In Figure 3 the partitions for the configurations of different cross sections are presented. In order to construct the partitions of different geometry, different manufacturing methods are engaged. Hence, the box-shaped partitions are manufactured through moulding, while the circular ones with press forging.

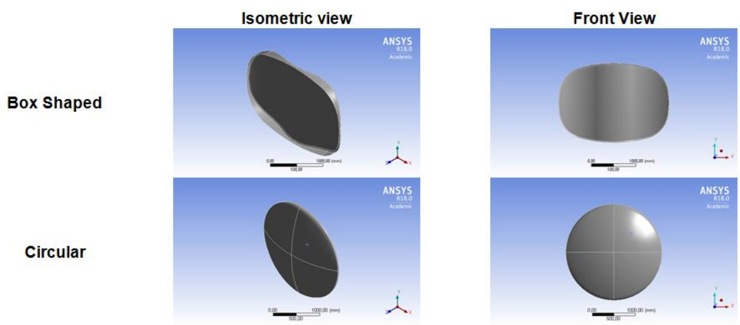


Figure 3. Crossectional geometry of the ends and partitions

In Table 4 the physical and mechanical properties of aluminium alloy (Al) and structural steel (St) are presented.

Table 4. Physical and mechanical properties of aluminium alloy and structural steel

Property	Material	
	Al (EN14286, 2008)	St
Density (kg/m^3)	2660	7850
Elastic modulus (MPa)	70300	210000
Poisson' s ratio	0.3	0.3
Tensile strength (MPa)	125	250
Ultimate strength (MPa)	275	360
Maximum Allowable stress (MPa) (EN13094, 2015)	93.75	176.25

The separation of configurations 3, 4 and 5 in compartments lead to different setups generated either from changing the number and position of the partitions or by replacing the closed geometry of the partitions with an open one, of the surge plates. Surge plates are non-hermetically closed partitions intended to reduce the effect of surge mounted at the right angles to the direction of travel. Surge plates have the same geometry with partitions but have holes on their surface in order to allow the flow of the transported liquid. The area of the surge plate shall be at least 70% of the cross-sectional area of the tank (ADR, 2017) and the openings are created according to EN13094 (EN13094). In Figure 4 the geometrical model of a partition and a surge plate are presented.

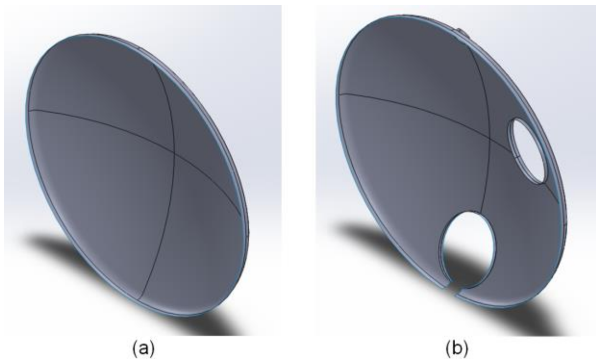


Figure 4. 3D model of (a) a partition and (b) a surge plate

In Figure 5, the side view of configurations 3a and 4a is presented with respect to the position of the axles of the semi-trailer. The position of the axles is represented by the three perpendicular centrelines. Support S3 is placed in such a way with respect to the axles of the semi-trailer that its mid plane is located 700 mm from the first axle.

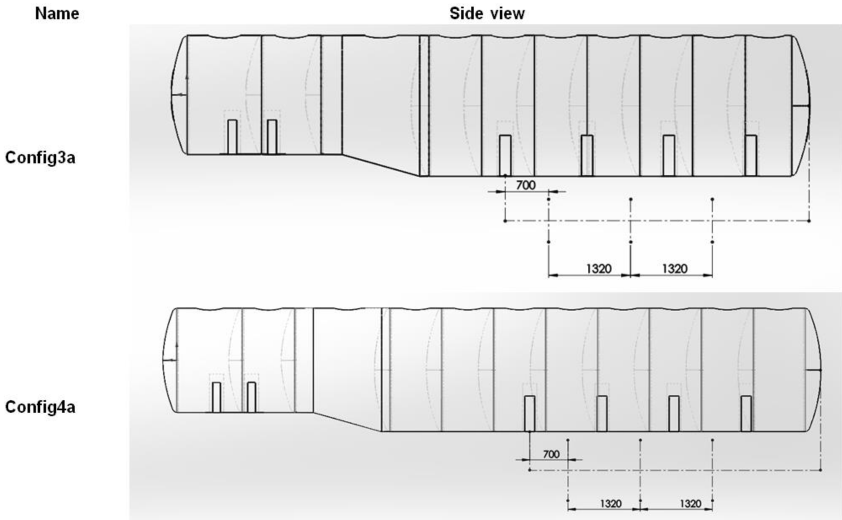
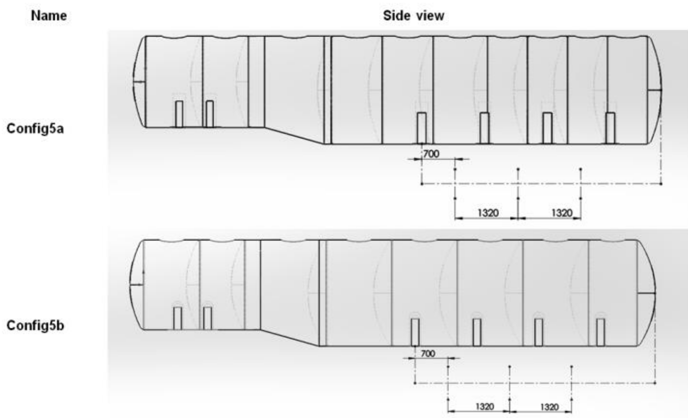


Figure 5. Side view of Configuration 3 and 4

For each configuration two setups have been generated without changing the location of the partitions, but with just replacing them with surge plates. In more details, while in Configuration 3a all partitions are closed, in configuration 3b partition number 5 and 7 are replaced with surge plates leading to a tank of 8 compartments, while in configuration 3c partitions number 4, 6 and 8 are replaced with surge plates leading to a tank of 7 compartments. As far as configuration 4a is concerned all its partitions are closed and the tank consists of 11 compartments. In configuration 4b partition 8 is replaced with surge plates leading to a semitrailer tank of 10 compartments, while in configuration 4c partitions number 5, 7 and 9 are replaced with surge plates leading to a tank of 8 compartments. In Figure 6 the alternative set-ups of configuration 5 are also presented with respect to the position of the axles. In configurations 5d, 5e and 5f the positioning of the partitions does not change, but specific partitions are replaced with surge plates. In the rest of the setups both the placement and the number of partitions varies.



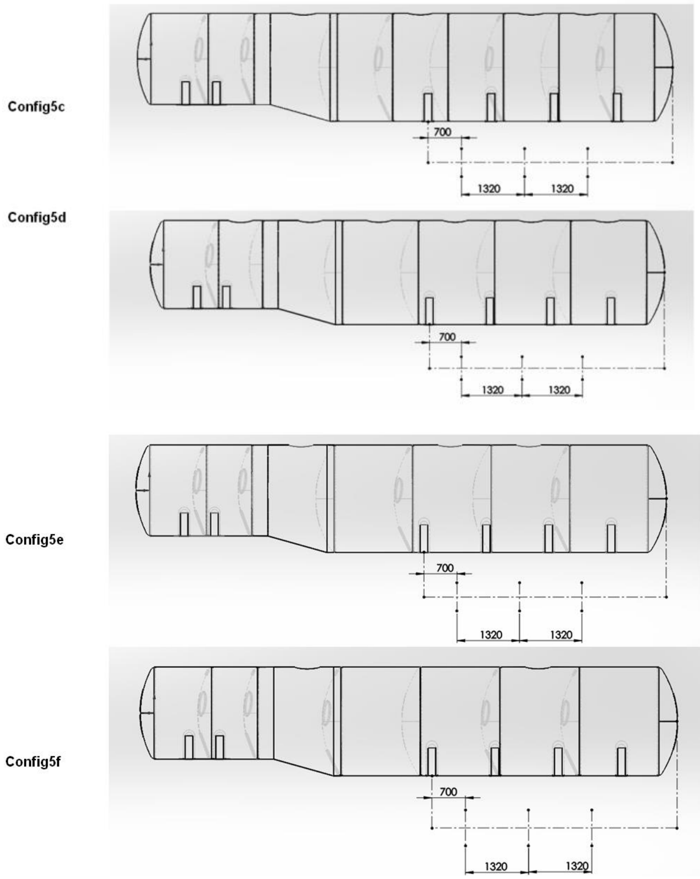


Figure 6. Different set-ups of Configuration 5

In more details in configurations 5a and 5b all partitions are closed and they consist of 10 and 8 compartments, respectively. Configuration 5c has 5 surge plates and 5 partitions and consists of 4 compartments. In configuration 5d, only the second partition is replaced with a surge plate and it consists of 6 compartments. In configuration 5e additionally partitions number 3, 5 and 7 are replaced with surge plates and it consists of 3 compartments, while configuration 5f consists of 2 compartments having only the 5th partition closed. In order investigate the influence of the aforementioned design parameters and evaluate each design, the loading conditions described in the Standard EN13094 are going to be implemented in each FE model. According to this Standard, the shell walls, the shell ends, the partitions (or surge plates) and their attachments are designed to withstand the stresses developed due to the (a) dynamic, (b) pressure and (c) partial vacuum conditions. According to these conditions, the following loading cases (LC) are implemented.

1. Acceleration of 2g acting on the maximum design mass in the direction of the travel
2. Acceleration of 1g acting on the maximum design mass at right angles of the travel
3. Acceleration of 1g acting on the maximum design mass vertically, upwards
4. Acceleration of 2g acting on the maximum design mass vertically downwards

5. The maximum of
   a. the pressure created by a column of water equal to twice the depth of the tank multiplied by the density of the relative density of the denser substance
   b. the pressure created by a column of water equal to twice the depth of the tank
   c. 1.3 times the working pressure
6. Test pressure equal to 1.3x (Pts+Pta)
7. Vacuum condition of 3 kPa below atmospheric pressure.

Pts is the pressure of the breathing devices which is equal to 0.012 MPa in all configurations and setup, while Pta varies among configurations and it is equal to the pressure corresponding to the maximum design mass. LC 1 – 4 simulate the dynamic conditions and should be applied along with the pressure of the breather device. LC 5 – 6 simulate the pressure conditions, while LC 7 simulates the partial vacuum conditions. LC 6 is applied considering the payload of each compartment separately, while the rest LC 1 – 5 and 7 are applied to the semi-trailer tank vehicle considering its total payload. In all LCs the SP were considered fully fixed, simulating welded connections to the semi-trailer frame.

3. RESULTS

In total, 16 FE models have been constructed. In Table 5 the number of the FE and the nodes of the FE models of the five main configurations along with the average quality of the mesh for each configuration is presented. A convergence study has been performed for all FE models in order to define the mesh and the same mesh has been used in all setups.

Table 5. Mesh characteristics for the FE models of all configurations

Configuration	Number of FE	Number of Nodes	Average Quality
1a	56341	59362	0.93
2a	13587	14828	0.82
3a	13706	14977	0.82
4a	14623	15949	0.81
5a	15751	17297	0.82

The mesh in all configurations consists of SHELL181 surface FE and CONTA174 and TARGE170 surface contact FE. The criterion for meshing is uniformity, with maximum edge length of 50 mm. SHELL181 is a FE used to model thin to moderately thick shell structures, such as pressure vessels and tanks (Ansys, 2017, Das, 2105 & Koulocheris, 2016). It consists of 4-nodes with six degrees of freedom at each node, three translational and three rotational ones. The results of the FE models in terms of maximum stress values and stress contours are presented in this section. The FE models consist of the 5 main configurations (denoted with the corresponding number of their configuration and the letter “a”) with the geometrical characteristics presented in Table 1 and the mesh characteristics presented in Table 3. All main configurations are considered to be constructed out of aluminium alloy. For configurations 1 and 2 a new set up has been created with structural steel as construction material (denoted with the corresponding number of their configuration and the letters “st”. Finally, new setups have been developed for configurations 3, 4 and 5 changing the compartmentalization of the semi-trailer tank vehicles.

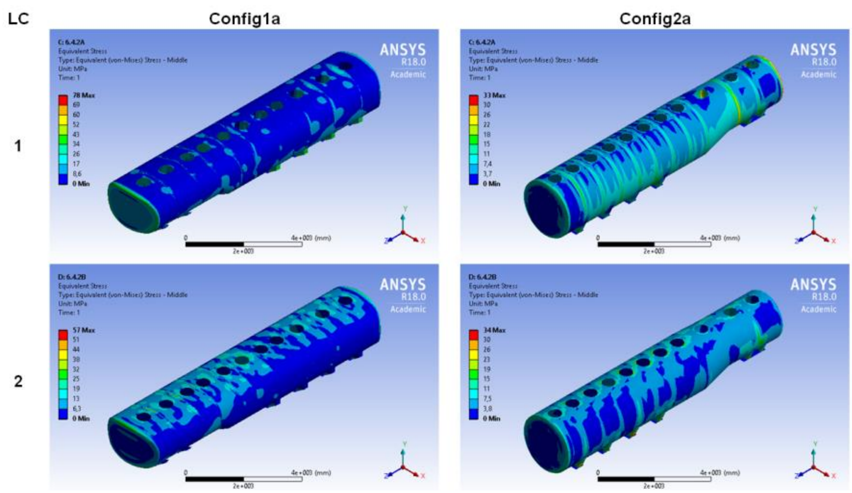
3.1 Main configurations

At the beginning the results of the 5 main configurations are going to be presented. The stress results of all the LCs are going to be presented in groups. Initially, the results of the LCs simulating the dynamic conditions are going to be presented. In Table 6 the maximum value of equivalent Von Mises stress (SEQV) in MPa for each of the LC1-4 is presented, along with the component where it was observed.

Table 6. Maximum value of equivalent Von Mises stress per FE model for LCs 1-4

Configuration	LC1		LC2		LC3		LC4	
	SEQV (MPa)	Component	SEQV (MPa)	Component	SEQV (MPa)	Component	SEQV (MPa)	Component
1a	80	S1	55	D4	60	D2	82	D4
2a	34	D1	34	S4	25	K10	34	S3
3a	36	D1	27	S4	34	K10	28	S3
4a	34	D1	40	S2	26	K4	38	S3
5a	38	D1	28	S4	14	K10	24	S4

In Figure 7 the equivalent Von Mises stress contours for LC1-4 for the tank are presented for configurations 1a and 2a. The contours of these two configurations are presented in comparison since they have different cross-section geometry but almost equal total length and payload.



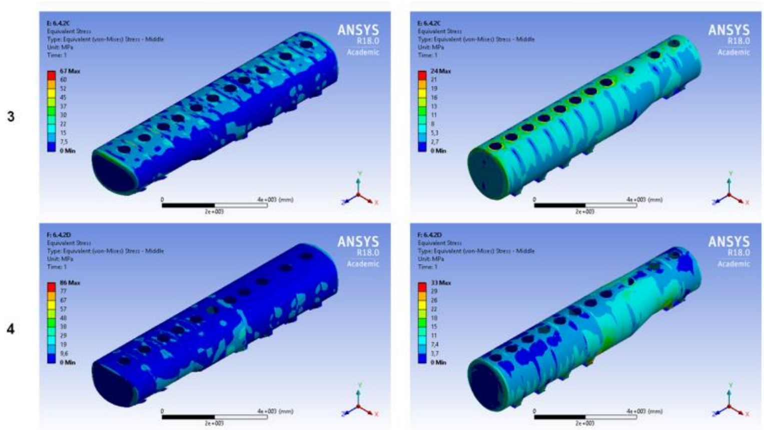


Figure 7. Equivalent Von Mises stress contours for LC1-4 for configurations 1 and 2

Furthermore, the maximum value of SEQV, in MPa, obtained from LC 5 and 7, which are the pressure conditions and the vacuum condition, accordingly, are presented in Table 7, along with the component where it appears.

Table 7. Maximum value of equivalent Von Mises stress per FE model for LC 5 & 7

Configuration	LC5		LC7	
	SEQV (MPa)	Component	SEQV (MPa)	Component
1a	76	D2	8	D2
2a	57	D12	4	D12
3a	54	D11	4	D11
4a	54	D12	4	D12
5a	51	D11	4	D11

In Figure 8 the equivalent Von Mises stress contours for LC5 & 7 for the tank are presented for configurations 1a and 2a.

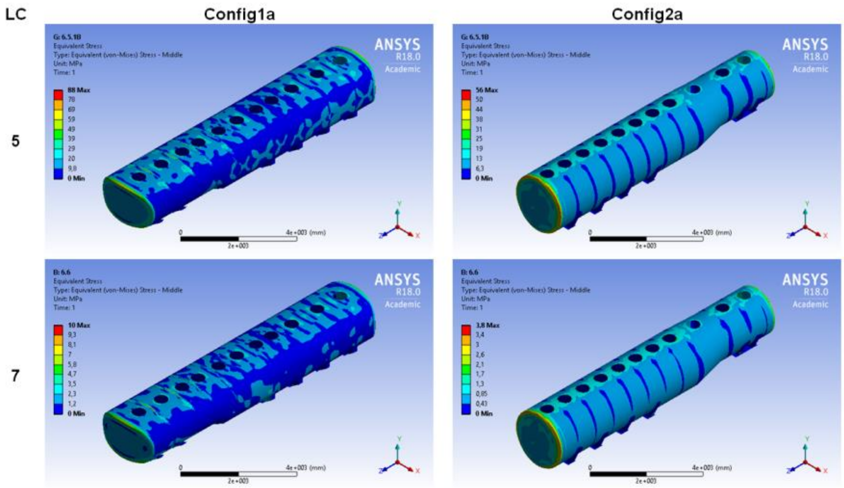


Figure 8. Equivalent Von Mises stress contours for LC5 & 7 for configurations 1 and 2

Finally, in Table 8, the results of the LC 6 which simulates the pressure conditions per compartment are presented. Table 8 contains the number of the compartment whose pressurization lead to the maximum value of SEQV, in MPa, and the component where it appeared.

Table 8. Maximum Von Mises stress per FE model

Configuration	LC6		
	Compartment	SEQV (Mpa)	Component
1a	2	83	D3
2a	11	58	D11
3a	9	57	D10
4a	11	55	D12
5a	10	63	D11

In Figure 9 the equivalent Von Mises stress contours for LC6 for the tank are presented for configurations 1a and 2a.

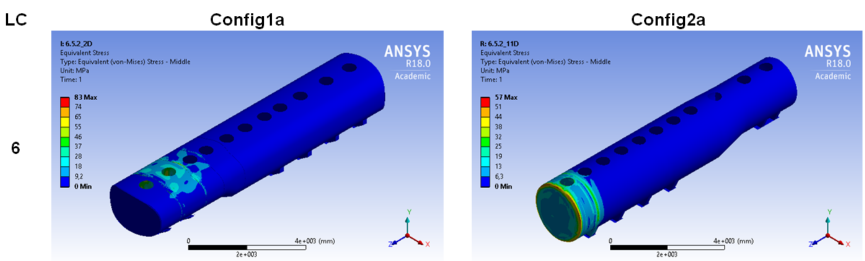


Figure 9. Equivalent Von Mises stress contours for LC6 for configurations 1 and 2

3.2 Construction material

For both configurations 1a and 2a new FE models have been set up using structural steel as construction material. In Table 9 the maximum value of SEQV in MPa for each of LC1-4 is presented, along with the component where it was observed.

Table 9. Maximum value of SEQV per FE model for LCs 1- 4

Configuration	LC1		LC2		LC3		LC4	
	SEQV (MPa)	Component	SEQV (MPa)	Component	SEQV (MPa)	Component	SEQV (MPa)	Component
1_St	78	S1	57	D3	67	D2	86	D4
2_St	35	D1	33	S4	36	K10	35	S3

Likewise, in Table 10 the maximum value of SEQV in MPa for each LC5 & 7 is presented, along with the component where it was observed.

Table 11. Maximum value of SEQV per FE model for LC 6

Configuration	LC5		LC7	
	SEQV (MPa)	Component	SEQV (MPa)	Component
1_St	88	D2	10	D2
2_St	58	D12	5	D12

3.3 Compartmentalization

As mentioned above for configurations 3, 4 and 5 different setups have been constructed and their FE models have been solved for the same LCs. In the Tables 12 – 14 the results for the setups of these configuration are presented. For all configurations the results of setup “a” are omitted since they are presented in the previous tables. In more details, in Table 12 the maximum value of SEQV for LC 1-4 is presented for all setups.

Table 12. Maximum value of SEQV per FE model for LCs 1- 4

Setup	LC1		LC2		LC3		LC4	
	SEQV (MPa)	Component	SEQV (MPa)	Component	SEQV (MPa)	Component	SEQV (MPa)	Component
3b	35	D1	26	S2	33	K10	25	S3
3c	34	D1	29	D7	34	K9	24	S3
4b	39	D1	53	S2	26	K4	42	S2
4c	34	D1	36	S2	27	K4	37	S3

5b	48	S3	52	S2	21	K8	37	S3
5c	47	S3	53	S5	18	K2	36	S3
5d	48	S3	66	S4	21	K6	37	K4
5e	48	K2	69	S4	18	K2	38	K2
5f	49	S3	85	D6	21	D6	47	D6

In Table 13 the same data is presented for LCs 5 and 7.

Table 13. Maximum value of SEQV per FE model for LC 5 & 7

Setup	LC5		LC7	
	SEQV(MPa)	Component	SEQV (MPa)	Component
3b	54	D11	4	D11
3c	55	D11	4	D11
4b	54	D12	4	D12
4c	54	D12	4	D12
5b	45	D8	4	D9
5c	45	D10	4	D10
5d	45	D8	4	D8
5e	45	D8	4	D8
5f	43	D8	3	D8

Lastly, in Table 14 the same results are presented for LC 6 with the addition of the compartment where the maximum value appears.

Table 14. Maximum value of SEQV per FE model for LC 6

Setup	Compartment	SEQV(MPa)	Component
3b	7	54	D10
3c	3	55	D4
4b	10	54	D12
4c	8	54	D12
5b	8	44	D9
5c	4	45	D8
5d	6	44	D8
5e	3	44	D8
5f	2	43	D8

4. DISCUSSION

In the present paper 5 configurations of semi-trailer tank vehicles have been designed and computationally simulated using the FE method in the loading cases prescribed in the European Standard EN13094 for the construction of tanks for the transport of dangerous goods. The minimum overall length (Table 1) of these configurations is 10280 mm while the maximum is 12030 mm in order to be mounted on the semi-trailer that it is presented in Figure 1 and they consist of 10-11 compartments. Furthermore, configuration 1 has a box-shaped cross-section, while the rest circular ones. The range of their payload (Table 2) is between 36000 to 42500 N and their tare weight ranges from 1800 to 2400 N. It is to be noted that the calculated payload is higher than the real one since all semi-trailer tank vehicles are constructed for the transportation of liquid fuels with densities less than 800 kg/m3. All semi-trailer tanks are built with aluminum alloy. In order to lower the overall center of gravity of the semi-trailer tanks all the configurations have a partially wedge shaped section, as it becomes obvious in Figure 2.

In Figure 10 the ratio of the payload to tare weight, which monitors the material exploitation is provided for all the basic configurations in terms of bars. Configuration 4 seems to have the most efficient exploitation of construction material.

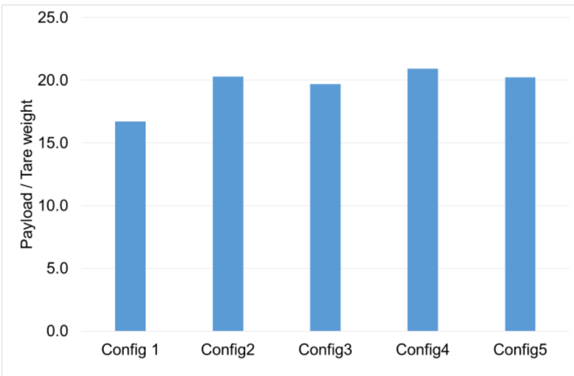


Figure 10. Payload to tare weight ratio for all configurations

In Table 5 is obvious that the FE models of all configurations have almost the same number of FE and nodes except for configuration 1. This happens due to its box-shaped geometry which is more complex than the circular one and needs more nodes in order for convergence to be achieved.

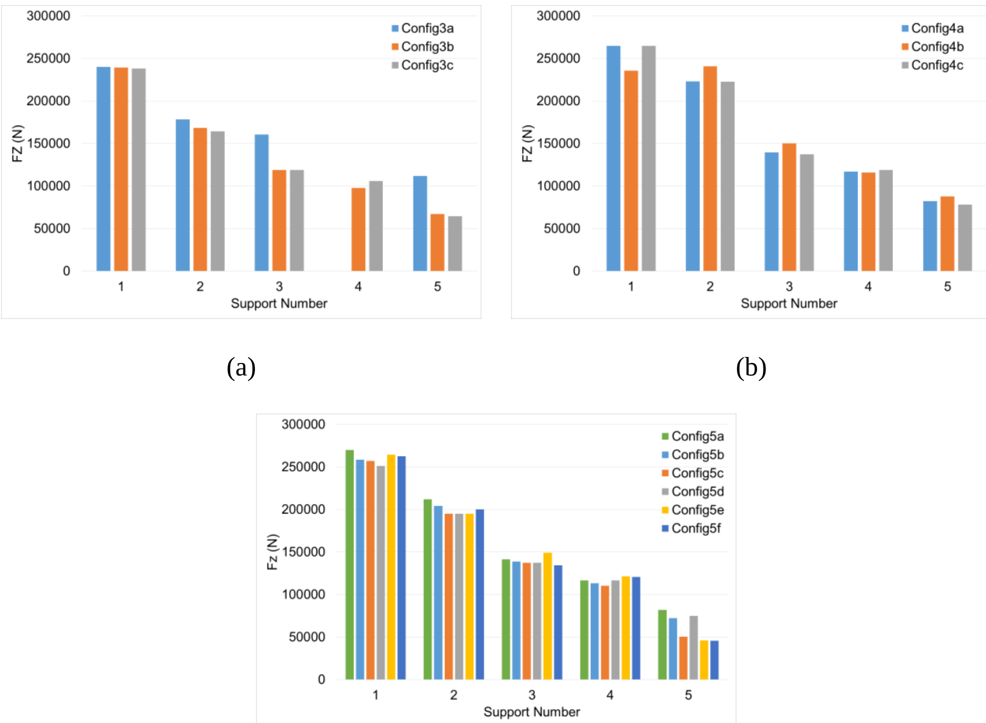
In Tables 6-8 the results of the FE analysis, in terms of maximum value of SEQV for the main configurations are summed up. In all the aforementioned tables is obvious that configuration 1, which has a box-shaped cross section, displays the highest values of SEQV for all loading cases. All the configurations of circular cross-section have stress values of the same order in all LCs. Furthermore, the location where this value appears remains the same in most cases. Comparing the LCs corresponding to the dynamic conditions, LC1 which simulates breaking of the semi-trailer tank vehicle causes the highest Von Mises equivalent stress values. Considering the pressure conditions, LC6, which simulates the test pressure conditions per compartment, leads to highest values of equivalent Von Mises stress.

Observing the stress contours of configuration 1a and 2a is obvious that the way the stresses are distributed on the semi-trailer tank vehicle varies due to the cross-sectional geometry.

The circular cross-section offers a more uniform distribution, while in the box-shaped cross section is obvious that although the sides of the semi-trailer tank vehicle are relieved, this is not the case for its top and bottom. Still though, it needs to be stressed out that even if the box-shaped cross-sectional geometry provides higher stress values they are still below the allowable stress (Table 4).

The same conclusions can be drawn from Tables 9-11 where the results of the setups 1_st and 2_st are presented. The change of construction material raises the values of SEQV in both configurations and for all loading cases, but leaves its location unaltered. Regardless construction material, the semi-trailer tank vehicle with the box-shaped cross-section geometry has higher SEQV values. It is worth mentioning that the highest stress value increase has been 44% in LC3 for configuration 2 which has circular cross-section. On the other hand the maximum allowable stress of structural steel is 88% higher than this of the aluminium alloy, so even if the maximum SEQV values increased the design of the semi-trailer tank vehicle became safer.

Reviewing Tables 12-14 is obvious that the different compartmentalization does not influence particularly the maximum SEQV value in any LC. On the other hand some alterations on the location where it appears exist. In order to investigate the role of the supports in Figure 11, that follows, the reaction forces on Z-axis for LC1 for all SPs for configurations 3 – 5, for all setups are presented.



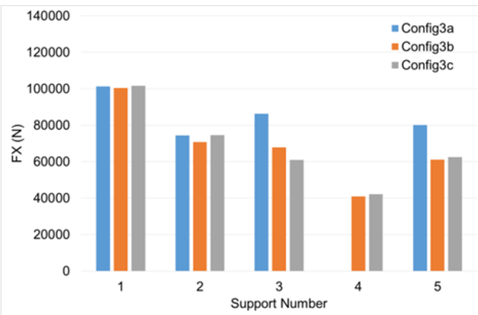
(a) (b)

(c)

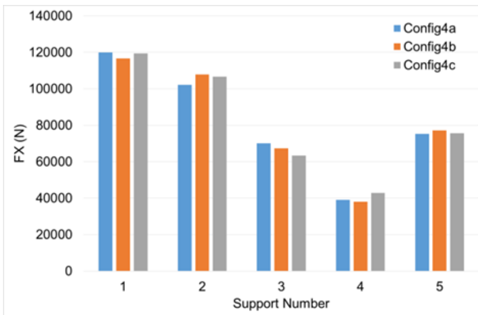
Figure 11. Reaction force on Z-axis on the support plates for LC1

It is obvious that the front support plate (SP1) where S1 and S2 are mounted presents the highest value of reaction force on Z axis, regardless configuration and setup. The front support plate is used for the fifth wheel coupling and it sustains 28 – 35% of the total load of the semitrailer tank vehicle in LC1. The load transferred from the tank to the semi-trailer reduces moving to its rear end from a maximum of 29% to SP2 in configuration 4b to a minimum of 11% to SP5 in the same configuration. It is worth mentioning that the values of the reaction forces on Z-axis are elevated since the tank was simulated as fully loaded with water, which is not the real – world case.

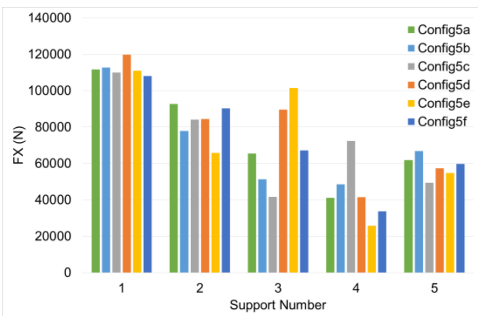
In Figure 12, the reaction forces on X-axis for LC2 for all support plates for configurations 3 - 5 are presented. Again it is obvious that SP1 has the highest value for the reaction force on X-axis regardless configuration or setup. This support sustains a mean of 30% of the total load of the semitrailer tank vehicle in LC2. The rest 4 SP that are mounted on the semi-trailer sustain the rest of the load. In configurations 3 and 4 SP4 has the minimum value of reaction force on X-axis, while SP3 and SP5 have a similar value of reaction force. On the other hand on configuration 5, SP4 displays the minimum value in all configurations, except configuration 5c.



(a)



(b)



(c)

Figure 12. Reaction force on X-axis on the support plates for LC2

5. CONCLUSIONS

In the present paper sixteen (16) different configurations and setups of semi-trailer tank vehicles of maximum payload have been computationally simulated with the use of the FE method and their performance has been monitored in terms of structural integrity. The influence of the cross-sectional geometry of the tank, its construction material and its compartmentalization has been emphasized. As far as the cross-sectional geometry is concerned, the circular one has been found to be more efficient and it is easier to be manufactured. On the other hand since the box – shaped cross-sectional geometry provides lower centre of gravity their dynamic behaviour remains to be evaluated. In terms of construction material aluminium alloy provides lighter structures able to sustain all loading conditions and it is the material of choice of the tank manufacturers. Finally, the compartmentalization does not influence the structural integrity of the tank in terms of stress distributions, but it does influence the load transfer from the tank to the semi-trailer vehicle. Alternative placements of the support plates with respect to the axles of the semi-trailer vehicle remain to be explored.

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