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Strength Verification of Semi-Trailer's Self-Supporting ADR Tank Body

This paper analyzes load distribution throughout the tank body suspension zone. It points out the importance of influence that the design of the link between the tank wall and the base of the tank vehicle (suspension cushion zone) has on the structure behaviour and reliability. In this study, the current state is considered, giving comments on the requirements and the criteria which make a normative regulation of this segment.

The basic purpose of this study is to point out the inconsistency and inaccuracy of current regulations as well as to offer a technically adequate way of resolving the stated problems in the segment of identification of behaviour and verification of construction from the strength point of view. In addition, we have illustrated how a developed methodological approach has been applied to a particular model of self-supporting ADR tank body of semi-trailers in the fifth wheel coupling pin zone, including the characteristic graphic presentation of carried out calculations and necessary explanation and comments.

Keywords: *support structure optimization, numerical prototyping, ADR tank body suspension.*

1. INTRODUCTORY DISCUSSION

The need for harmonization and determination in the aspect of ADR tank body calculations, production technology, providing necessary equipment, etc., has been emphasized [1-4]. However, there is an outstanding inconsistency and inaccuracy in the current regulations regarding problems of the tank body suspension, contrary to the fact that the issue of the tank body suspension has a great influence on tank body behaviour, regarding the aspect of its strength and reliability [5]. The main purpose of this study is to point out inadequate ADR requirements present in current practice and to offer a method for improving the actual state, as a contribution to increase traffic safety relating to ADR transport.

2. SUMMARY OF CURRENT REGULATIONS

The regulations of United Nations Economic Commission for Europe (UN/ECE) [6], i.e. Directives of European Commission (EC) [7] present the highest level of regulations in the area of vehicles. UN/ECE Regulation No. 105 [8] and EC Directive 98/91 [9], which are completely compatible, refer to the issue of ADR tank strength performance. ECE Regulation No. 105, defining the aspect of homologation of the vehicles aimed for carriage of dangerous goods by road, will be commented in details. Considering the aspect of strength, UN/ECE Regulation No. 105 completely corresponds to the requirements of ADR (European Agreement Concerning the International Carriage of Dangerous Goods by Road) [10]. The stress in the structure (σ) is a basic evaluation parameter where the criterion is presented as the maximum permissible stress value $\sigma = 0.75\ \sigma_T$ (σ_T – yield strength) which must not be exceeded under any conditions, in any of tank construction zones. The aspect of link between the tank shell and the base of the tank vehicle is the very specific segment regarding stress response. Relevant calculation regimes i.e. inertial load-forces (Table 1) have been defined in chapter 6.8 paragraph 6.8.2.1.2 (ADR, 2011). It is essential to provide the distribution of these forces through the construction in accordance with the above mentioned stress criterion. It is important to emphasize the fact that such definition of this aspect of ADR requirements has existed since the adoption of this Regulation in 1957 without any modifications.

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Table 1. Characteristic calculation regimes

Characteristic regime	Force direction and intensity
CR1	in the direction of travel, twice the total mass (2g)
CR2	at right angles to the direction of travel, the total mass (1g)
CR3	vertically upwards, the total mass (1g)
CR4	vertically downwards, twice the total mass (2g)

In addition, it is essential to point out practical inapplicability of the regulations both from the aspect of design and calculations and laboratory verification of the construction. The most drastic inconsistency refers to the distribution of load in the direction of travel (CR1, Table 1), which is considered to be a critical and competent regime. Actually, loads in the vehicle travel direction correspond to the braking regime which is limited by friction coefficient (with the maximum value of approximately φ = 0.8 on good-quality asphalt).

Bearing this fact in mind, the defined deceleration load of 2*g* corresponds to the extremely hard conditions, which might be realized hypothetically only in the situation of intensive braking and facing a vertical obstacle. These conditions are more likely to appear in the situation of a traffic accident than under regular usage conditions, due to the following reasons:

- In order to realize the deceleration of 2*g* in the direction of travel, it is necessary to provide the braking force of twice the value of the total vehicle weight.
- Supposing that the vehicle should face a vertical obstacle, in the conditions of intensive braking, extreme loads/forces would appear on one axle only (simultaneous facing the obstacle of all axles is impossible).
- Suspension system components failure, in case of facing a vertical obstacle, would appear under much lower loads than those necessary to realize deceleration of 2*g* of the total vehicle-tank weight.

Consequently, unknown distribution of inertial load on separate tank “suspension cushions” (there are several of them on each tank) presents the problem which compromises the accuracy of tank stress calculations.

This is the chance to distinguish two aspects of the shell link with the base of tank vehicle [11,12]. The first one concerns the very contact of shell wall and “suspension cushion”, which presents a set of elements in the direct contact with the shell and through which the link with the suitable element of the base of the tank vehicle is constructively solved. The second aspect treats the link between shell “suspension cushions” with the corresponding element of the base of the tank vehicle. The second aspect is of minor importance and is not related to the basic problems, so the effects of optimization cannot have any specific significance for the matter.

Besides the current regulations, the design of ADR tank “suspension cushions” depends on directives and recommendations defined by chassis-base manufacturers. These directives and recommendations refer to load distribution from “suspension cushions” towards chassis, neither considering nor eliminating or simplifying the issue of load distribution in the immediate tank shell contact zone. Taking ADR tank suspension into consideration, it is important to emphasize current orientation towards self-supporting trailer tank vehicles where the role of designers is more important, due to the fact that practically they are not limited in designing. In such cases, it is essential to make a clear identification of the construction behaviour in the tank suspension zone, i.e. verification of the defined criteria in respect of stress response (as the basic parameter of ADR regulation regarding the tank construction strength).

On the basis of everything mentioned above, it can be concluded that a detailed recognition of load distribution in the tank suspension zone has a great importance when considering its strength and reliability. In order to obtain a comprehensive identification of the critical zone behaviour, a specifically modified methodological approach for identification of trailer support structure behaviour [13-15] has been applied, the characteristics of which will be separately discussed.

3. METHODOLOGY OF ADR TANK BEHAVIOUR IDENTIFICATION

A developed methodological approach is based on numerical prototyping (NP), i.e. simulation and structure strength calculation using the Finite Elements Method (FEM) [16]. Thus, it is possible to identify the behaviour and to follow the construction response optimization, i.e. improve and develop characteristic zone’s design. The characteristics of the developed methodological approach have already been presented to professionals [5,13,17], so this is the opportunity to emphasize the features significant for verification of the ADR tank strength:

- Simulation of real interaction between ADR tank shell and chassis, i.e. definition of partial tank suspension cushion loads. Based on the stress response of the integral discrete model, it is possible to identify global behaviour of the construction. Figure 1 shows a characteristic example of the above mentioned integral discrete model. Additionally, such models are very important for researching the influence of element stiffness (in the chassis and superstructure link) on relevant ADR tank stress response.

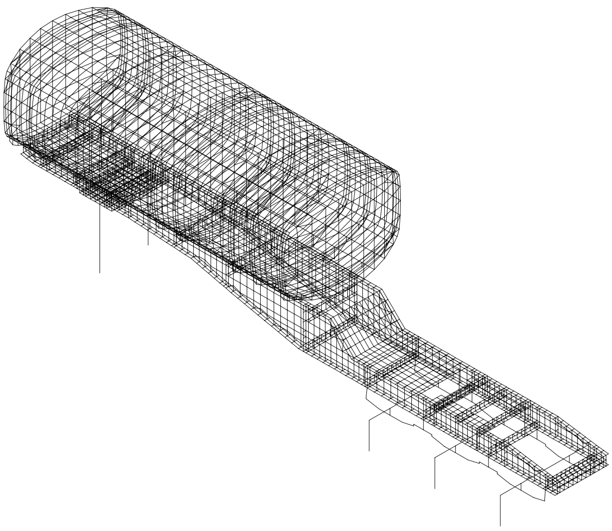

Figure 1. Characteristic example of integral discrete model

- The case of self-supporting ADR trailer tanks (characterized by the absence of chassis) is particularly specific in terms of partial examination of interesting suspension cushion zone’s behaviour. Actually, a separate tank segment is adequately fixed at a sufficient distance from the suspension cushion zone which is being researched (discrete model of fifth wheel coupling pin zone of semi trailers, Fig. 2). In such conditions, inverse load distribution is suitable due to the fact that it is possible to determine forces at the contact point of tyres and ground surface easily and directly (they are real and measurable ground surface reactions).

- Inverse load distributions (through to the suspension cushion zones) is particularly characteristic and suitable in terms of possible purposeful laboratory verification of discrete model, i.e. calculation responses. This results from an easy definition and inclusion of the relevant load, as well as a simple provision of boundary conditions of considered suspension segment in laboratory research conditions.
- Providing stress response at a significantly higher quality level than the one required in ADR regulation (stress response in detailed and illustrated way, membrane and bending stress distribution in observed interesting areas, deformation energy analyzing possibilities, etc.). These possibilities make prerequisites for both a comprehensive, objective and better-quality evaluation of a particular construction solution and optimization of considered structures.
- The principle of comparative analysis of results from several different considered versions aimed at determination of a certain construction segment's influence and/or possible corrections in construction behaviour, i.e. its stress response. Actually, the analysis of one construction version behaviour makes the basis for further possible corrections of the structure.

The positive capacities of this approach will be illustrated on a particular characteristic example of the optimized design of fifth wheel couplings pin zone of a semi-trailer's self-supporting tank for oil derivatives.

4. NUMERICAL PROTOTYPING OF FIFTH WHEEL COUPLING PIN ZONE

The discrete model of considered structures (fifth wheel coupling pin zone of a semi-trailer's self-supporting tank) is shown in Figure 2a (with projections included). Figure 2b shows boundary conditions, which provided inverse load distribution through the suspension cushion zones (inclusion of ground surface reactions).

Table 2. Calculation versions – description and remarks

Calculation versions	Description / Remark
Version 0	Basic construction solution (link shell wall and semi trailer support plate is given in Fig. 2 and Fig. 3a)
Version 1	Including of plate reinforcement of shell wall in link with "suspension cushion" (Fig. 3b)
Version 3	Including of striped reinforcement of shell wall in link with suspension cushion (Fig. 3c) and excluding transverse ribs in semi trailer support plate zone (Fig. 3d)
Version 4	Including of longitudinal plates in link of suspension cushion and semi trailer support plate (Fig. 3e)
Version 6	Reconstructed of longitudinal supports in link of shell wall and semi trailer support plate (Fig. 3f)
Version 7	Reduced thickness of plates of "suspension cushions" (5 to 4 mm)

Real interaction between fifth wheel coupling of truck and a semi-trailer's self-supporting tank is realized by lowering the sheet and by including beam elements, which provide vertical and horizontal load distribution through suspension zone (Fig. 2c).

Table 2 and Figure 3 show details of various calculation versions (on the optimization process of a particular construction solution), along with all the necessary remarks and explanations.

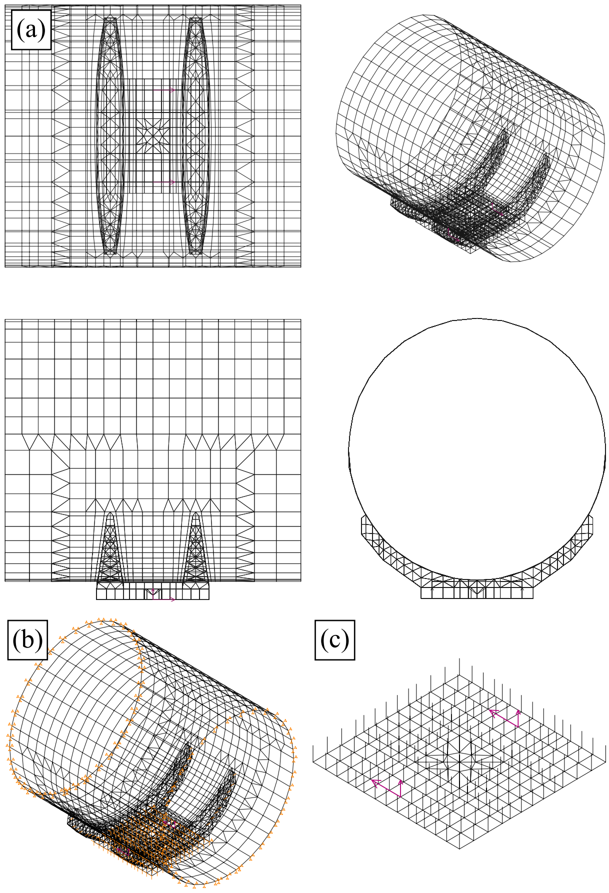

Figure 2. Discrete model of fifth wheel coupling pin zone

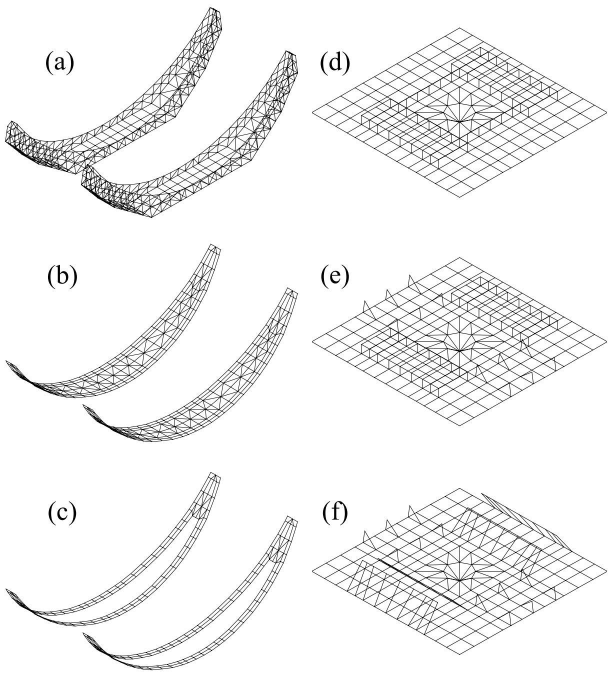

Figure 3. Various calculation versions

The behaviour of the fifth wheel coupling pin zone for characteristic regime CR1 (Table 1) is presented in this paper in detail and with comments on the calculation process. Bearing in mind that ADR regulation defines the stress in the structure (σ) as a basic evaluation parameter from the ADR tank stress aspect, Table 3 presents the maximum stress values for all calculation versions (explained in Table 2), including reserve (in percentage) from the point of view of material strength performance.

Also, Table 3 comprehends the percentage of participation of membrane stress in characteristic segments (suspension cushions and tank wall) of the observed fifth wheel coupling pin zone of a semi-trailer's self-supporting tank, as well as dead weight parameters for each analysed calculation versions.

Graphic presentation of isometric stress lines (Table 4) refers to the relevant influence of structure redesign. Characteristic illustrations are marked with respective model identification. To better understand the stress conditions of considered zones, each presentation covers both the maximum value of stress occurring in plate elements of suspension cushions and the maximum value of stress occurring in plate elements of tank wall in the fifth wheel coupling pin zone, as well as a distribution of membrane and bending stress in the observed interesting zones. These results aim to point out the remarkable differences of characteristic stress responses (in the considered fifth wheel coupling pin zone) as consequences of some very small and simple design reconstructions. That's why a detailed identification of stress response has become necessary as well as a developed methodological approach application. This is even more important from the aspect of a wide practical use of numerical prototyping in automobile regulations, related to the structure strength verification aspect.

5. CONCLUDING REMARKS

This study identifies and discusses inaccuracy and inconsistency of ADR requirements in the aspect of tank strength. Stress is defined as a basic evaluation parameter, where its value as an evaluation criterion is accurately and clearly defined. However, inaccuracy and inconsistency of ADR requirements refer to load regimes relevant in the verification of critical ADR tank suspension zone. This inaccuracy is particularly emphasized in the case of maximum lengthwise (in the direction of travel) load distribution. The solution for this situation generally implies the definition of ADR tank suspension cushions partial load, taking into consideration real interaction between ADR tank and vehicle chassis. Knowing that these structures are extremely different regarding their torsion stiffness, i.e. behaviour, identification of their real interaction is practically impossible without an adequate application of numerical prototyping approach.

The discussions regarding this zone make an adequate clarifying example of ADR tank strength aspect complexity. In addition, the described analyses present the abilities of a developed methodological approach in an illustrative way, as well as its importance and contribution to the development, design and verification of a particular construction solution. On the basis of everything stated above, it can be concluded that an adequate system application of a developed methodological approach presents a qualitative contribution to a safer and more reliable carriage of dangerous goods by road.

ACKNOWLEDGMENT

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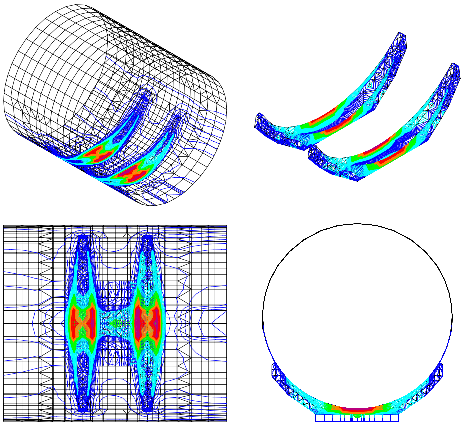
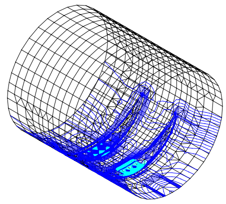
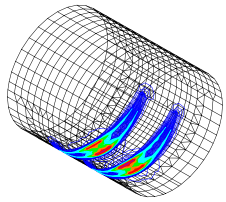
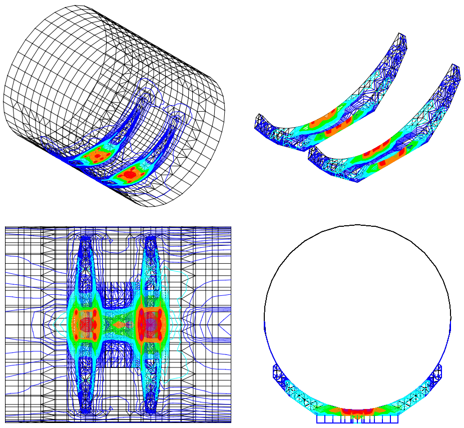
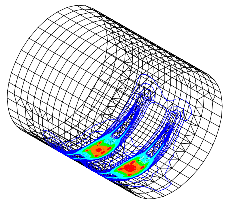
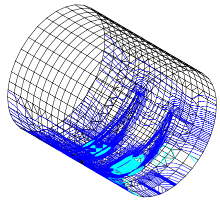
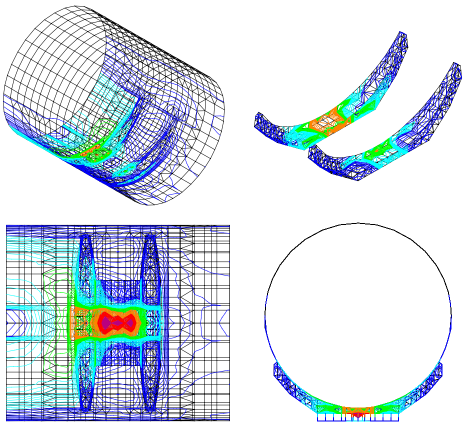
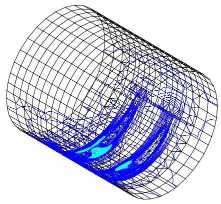
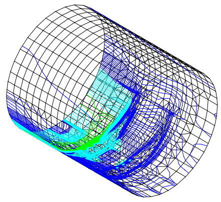
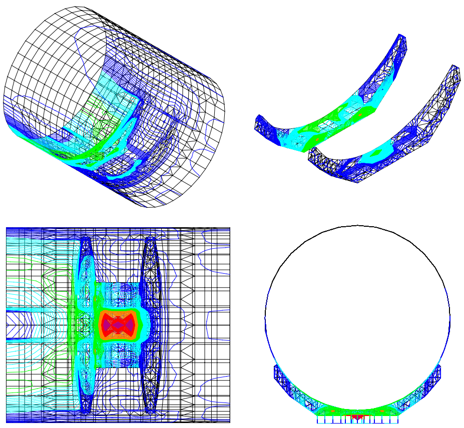
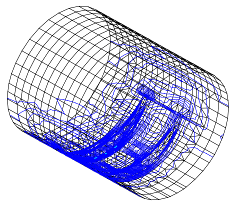
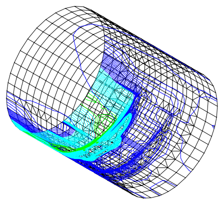
Table 3. Characteristic results for particular construction solution

Calculation versions	Interesting zones	Maximum stress values [kN/cm^2]	% of σ_T / % of version 0 stress response	% of membrane stress participation / % of version 0 stress response	Dead weight [kg] / % of version 0 dead weight [kg/%]
Version 0	Shell wall	56.7	162 / 100	30.13 / 100	395.2 / 100
	Suspension cushion	55.4	158.3 / 97.7		
Version 1	Shell wall	29.7	84.9 / 52.4	33.18 / 110.1	430.4 / 108.9
	Suspension cushion	63.5	181.4 / 112		
Version 3	Shell wall	37.2	106.3 / 65.6	32.59 / 108.2	414.5 / 104.9
	Suspension cushion	55.1	157.4 / 97.2		
Version 4	Shell wall	14.6	41.7 / 25.7	52.87 / 175.5	416.8 / 105.5
	Suspension cushion	18.1	51.7 / 31.9		
Version 6	Shell wall	11.0	31.4 / 19.4	59.24 / 196.6	409.5 / 103.6
	Suspension cushion	13.2	37.7 / 23.3		
Version 7	Shell wall	10.8	30.8 / 19	60.27 / 200	394.8 / 99.9
	Suspension cushion	15.1	43.1 / 26.6		

Table 4. Graphic presentation of isometric stress lines

	**Version 0** Maximum stress values [kN/cm^2] *Shell wall* 56.7 *Suspension cushion* 55.4 Membrane stress participation: 30.13 % 3.66E+01 ... 4.39E+01 2.93E+01 ... 3.66E+01 2.20E+01 ... 2.93E+01 1.46E+01 ... 2.20E+01 7.32E+00 ... 1.46E+01 0.00E+00 ... 7.32E+00	Distribution of bending stress  Distribution of membrane stress 
	**Version 3** Maximum stress values [kN/cm^2] *Shell wall* 37.2 *Suspension cushion* 55.1 Membrane stress participation: 32.59 % 2.71E+01 ... 3.20E+01 2.17E+01 ... 2.71E+01 1.63E+01 ... 2.17E+01 1.08E+01 ... 1.63E+01 5.42E+00 ... 1.08E+01 0.00E+00 ... 5.42E+00	Distribution of bending stress  Distribution of membrane stress 
	**Version 4** Maximum stress values [kN/cm^2] *Shell wall* 14.6 *Suspension cushion* 18.1 Membrane stress participation: 52.87 % 1.84E+01 ... 2.21E+01 1.47E+01 ... 1.84E+01 1.11E+01 ... 1.47E+01 7.37E+00 ... 1.11E+01 3.68E+00 ... 7.37E+00 0.00E+00 ... 3.68E+00	Distribution of bending stress  Distribution of membrane stress 
	**Version 7** Maximum stress values [kN/cm^2] *Shell wall* 10.8 *Suspension cushion* 15.1 Membrane stress participation: 60.27 % 1.85E+01 ... 2.22E+01 1.48E+01 ... 1.85E+01 1.11E+01 ... 1.48E+01 7.40E+00 ... 1.11E+01 3.70E+00 ... 7.40E+00 0.00E+00 ... 3.70E+00	Distribution of bending stress  Distribution of membrane stress 

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NOMENCLATURE

g	gravity of Earth (gravitational constant)

Greek symbols

σ	stress in the structure
σ_T	yield stress
φ	coefficient of friction

ВЕРИФИКАЦИЈА ЧВРСТОЋЕ САМОНОСЕЋЕГ АДР РЕЗЕРВОАРА ПОЛУПРИКОЛИЦЕ

Бранислав Б. Ракићевић, Саша Р. Митић, Владимир М. Поповић, Горан С. Воротовић, Јован Д. Радивојевић

Проблематика рада односи се на дистрибуцију оптерећења кроз зону ослањања резервоара. У раду се потенцира значај утицаја који конструкција ослоних јастука резервоара, односно интеракција са доњим постројем цистерне има на његово понашање и поузданост. У раду је разматрано актуелно стање, уз коментар захтева и критеријума који нормативно регулишу овај сегмент. Основни циљ рада је да укаже на недоследност и непрецизност актуелне регулативе и понуди начин за превазилажење уочених проблема примерен стању технике у сегменту идентификације понашања и верификације конструкција са становишта чврстоће. У овом смислу представљена је конкретна примена развијеног методолошког прилаза на примеру специфичног решења ослањања самоносећег АДР резервоара полуприколице цистерне у зони вучног чепа, уз илустративно представљање прорачунских одзива карактеристичних варијанти и режима оптерећења, укључујући сва потребна појашњења и коментаре добијених резултата.