Movement analysis of the semitrailer with the tank-container at hard braking - the case study

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Abstract. Transport of liquid, gaseous, powdered or granulated substances is an integral part of the industry in each country. This type of cargo is most often transported by companies that are a part of petrochemical, food or also other types of industry. Increased attention should be paid to transport of tank-vehicles and tank-containers from the point of view of road safety and environmental protection. The volume of such types of transport is growing every year. The extensive trend relates mainly to the developed world economies, which are experiencing economic growth, which includes also Slovakia according to the Statistical Office of the Slovak Republic. This article deals with evaluating the movement of semi-trailer trucks with a tank container during and immediately after hard braking. The movement of the semi-trailer truck with a tank container will be analysed and evaluated immediately after the vehicle is stopped. The movement of the vehicle will be analysed by video analysis. The focus is on analysing behaviour of the semi-trailer truck with a tank container during and immediately after braking. The article compares semi-trailer trucks with tank container with breakwater plates and tank containers without breakwater plates. An important feature of this comparison was processing of videos capturing these vehicles during hard braking in video analysis program.

1. Introduction
Transport of goods in tank vehicles and tank containers is important for several types of industry in the Slovak Republic and whole Europe [1–3]. This article discusses in detail issues that directly affect safety of goods transport in tank containers, especially the situation that occurs during hard braking of such vehicles transporting liquid substances [4].

It is important to compare behaviour during braking of a semi-trailer truck with a tank container with breakwater plates inside, a tank truck without breakwater plates and a semi-trailer truck with tarpaulin transporting bulk goods [5]. We assume that tank trucks without breakwater plates will, due to their behaviour when the truck is braking sharply, represent a significantly higher level of road traffic hazard than the other two mentioned types of semi-trailer trucks.

Theoretical foundations from which we have started include mainly the knowledge of the issue of transport of dangerous goods by the European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR), the knowledge of fluid movement in a closed container while this container is moving, the basic knowledge of constructions of tank containers, as well as the knowledge of the dynamics of semi-trailer trucks movement under hard braking.
Safety during transport of dangerous goods in tanks and tank containers is, according to the European Agreement on the Transport of Dangerous Goods by Road (ADR), achieved by a number of measures and trainings of employees [6-10]. However, these trainings are more theoretical than practical, and do not pay sufficient attention to the driver's practical skills and their training considering abnormal behaviour of the load during hard braking of such vehicles [7, 11 – 13]. So far, no one has specified and dealt with this issue in Slovakia, so it is not possible to build on existing research in this area. Given the theoretical background, we assume that the effect of fluid movement in a tank container on vehicle movement during sharp braking will be less pronounced for a tank container with breakwater plates than without them [6]. We also assume that driving behaviour of a tank container truck with breakwater plates inside will be similar to that of an ordinary tarpaulin semi-trailer truck transporting non-liquid goods (under hard braking) [14].

2. Methodology
The case study carried out for the purposes of this article may be described as an applied form of research, since its results and resulting information can be practically applied during transport of liquid goods [15].

The planning and implementation part of the research was focused on collection of data on the movement of tank semi-trailer trucks with breakwater plates, tank semi-trailer trucks without breakwater plates and tarpaulin semi-trailer trucks. The phase of data collection using cameras represented the most difficult part in the framework of the research task, as the video quality has a major impact on the possibility of further relevant image processing.

Recording of braking process (video) and data collection on the movement of semi-trailer trucks with tank containers were carried out with every change in the quantity of goods in the tank (with or without breakwater plates). It should be noted that, between the individual braking events of the trucks, a part of the transported fluid was gradually removed from both the tank with breakwater plates and the tank without them. Subsequently, the video was analysed and evaluated using a program that serves to track the movement of objects, to create kinematic and dynamic models of mass points, and to create data.

After that, further braking was performed with a conventional tarpaulin semi-trailer truck on which non-liquid goods were transported in order to compare behaviour of this type of semi-trailer truck with a tank semi-trailer truck. The videos were re-analysed and evaluated using the above-mentioned computer program.

3. General information (the procedure)
A total of 31 videos of a semi-trailer truck with tank container with or without breakwater plates were recorded. On four of the videos, the movement of the tarpaulin semi-trailer truck transporting non-liquid goods was recorded [14]. After analysing all the videos for evaluation, two videos of the tarpaulin semi-trailer truck carrying non-liquid goods, thirteen videos of the semi-trailer truck with tank container with breakwater plates, and nine videos of the semi-trailer with tank container without breakwater plates were selected. Other videos were discarded for several reasons, for example, due to an insufficient length of recording to draw relevant conclusions, or due to camera movement during video recording of the semi-trailer truck to such an extent that it could not be used for further analysis of vehicle movement. Another reason for discarding a video for detailed analysis and data acquisition was that the camera could not focus on a moving semi-trailer truck in a quality that would give a meaningful analysis result.

All the selected videos were inserted into the program, where the analysis of the movement of the semi-trailer truck was carried out. After its completion, obtained outputs could have been inserted into tables. This procedure was repeated for each video being evaluated. Based on the tables, graphs with the course of the acceleration change over time were developed [16].

4. Measurement results
The analysis in the program yielded output values that were arranged in tables. From these data, graphs of the courses of speed and acceleration achieved at the end of braking and immediately after stopping of the semi-trailer trucks were made. Each measurement is marked so that it can be identified easily and so that it is clear from its name what type of graphical representation it refers to. Designation consists
of the measurement number, designation of the variable being measured (speed/acceleration), designation of direction of the vehicle (forward/reverse) and initial speed.

The following part of the paper will provide the analysis of the movement of all three types of semi-trailer trucks during braking and their subsequent movement immediately after stopping. With all the trucks, the vehicle was stopped, and the brake pedal was released. The analysis in the program shows that the tarpaulin semi-trailer truck behaved in such a way that the change in the acceleration value of the tarpaulin semi-trailer truck after stopping was low. This means that after the driver stopped and released the brake pedal, the truck no longer tended to move forward or backward. The course of speed of the semi-trailer truck from two selected measurements is shown in Figure 1 and the course of acceleration of the same measurements is shown in Figure 2.

Braking of the semi-trailer truck with a tank container is specific because fluid in the container moves during braking and, after stopping, generates a pressure wave on the container wall. In order to reduce the undesirable effect of the pressure wave, various means have been introduced for reducing them, such as partitions, breakwater plates, outer or inner rings. In terms of video evaluation, the movement of the semi-trailer truck with a tank container with breakwater plates (transverse breakwater plates in all cases) was analysed first and then the analysis of movement of the semi-trailer truck without breakwater plates followed. Because two identical semi-trailer trucks were compared differing only in equipping/not equipping the container with breakwater plates, only speed changes and the change in acceleration over time are evaluated only after the trucks stopped.

Following graphs show the course of speed (Figure 3 and Figure 4) over time for nine different measurements of the semi-trailer trucks with tank containers with breakwater plates just from the moment after trucks stopped. A clear subsequent forward or reverse movement of the truck can be observed. However, it does not exceed the value of 0.3 m·s⁻¹ in the positive direction and the value of -0.2 m·s⁻¹ in the negative direction. Although the truck is moving, the movement can be considered slight.

For better illustration of the findings, we also provide a graphical representation of the course of speed before stopping and after stopping the truck with a tank container with breakwater plates. The change in speed after stopping the vehicle does not show large deviations in relation to the course of speed at which the semi-trailer trucks moved before stopping.
Figure 2. The course of acceleration of tarpaulin semi-trailer truck over time within measurements 01aF_14 and 02aF_24.

Figure 3. The course of speed of semi-trailer truck with tank container with breakwater plates over time for measurements 03vF_15, 04vF_15, 05vR_3, 08vR_6, and 09vR_3.

Figure 4. The course of speed of semi-trailer truck with tank container with breakwater plates over time for measurements 10vF_35, 11vF_17, 14vR_6, and 15vR_6.
In the following graph (Figure 6), we can see the course of speed over time for four measurements of a semi-trailer truck with a tank container without breakwater plates from the moment the vehicle stopped. The graph clearly shows the significant movement of the vehicle just after stopping and releasing the brake pedal of the semi-trailer truck. The movement of the whole vehicle was caused by the forward and backward movement of liquid inside the tank container.

It should be noted that in case of stopping the vehicle in forward direction and subsequent releasing of the brake pedal, the movement of the liquid inside the tank container caused that the whole vehicle moved in the backward direction. Quite the opposite, that is the subsequent movement of the vehicle forward, happened when the vehicle was stopped when moving in backward direction (i.e. when reversing).

![Graph](image_url)

**Figure 5.** The course of speed of semi-trailer truck with tank container with breakwater plates over time for measurements 06vF_21, 07vF_20, 12vR_8, and 13vR_6.

**Figure 6.** The speed of semi-trailer truck with tank container without breakwater plates over time for measurements 20vF_13, 21vF_11, 22vF_13, and 23vR_11.
The following graph (Figure 7) also shows the course of speed over time for five measurements of a semi-trailer truck with a tank container without breakwater plates. In these measurements, the subsequent movement after stopping is not as considerable as in the previous graph. This is because, during the measurements, the tank container was filled either to the maximum possible total volume or, on the contrary, to the minimum allowable volume of the container. In both of these cases, the free surface area of transported fluid in the tank container was smaller in comparison to the free surface area when the tank container is filled to about 50%. Thus, during the measurements, the wave motion of liquid did not manifest in full force and fluctuations were lower than \(-0.3 \text{ m} \cdot \text{s}^{-1}\) to \(0.2 \text{ m} \cdot \text{s}^{-1}\). Measurement no. 18vF_22 was carried out with a fully filled tank container of approximately 26,000 litres. Approximately 13,000 litres of liquid were drained from the tank container prior to measurement 20vF13. Thus, this measurement was performed with an approximately half-filled tank container.

Approximately 5,000 litres of liquid were drained from the tank container prior to measurement 22vF-13. Thus, measurements 22vF_13 and 23vR_11 were performed with a tank container filled with approximately 8,000 litres of liquid.

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During measurements 20vF_13 and 21vF_11, the tank container was approximately half-full, and the free area of liquid was the largest when compared to other measurements. Therefore, the highest amplitudes, within the range of \(-0.63 \text{ m} \cdot \text{s}^{-1}\) and \(1.11 \text{ m} \cdot \text{s}^{-1}\), occur during these measurements.

In the last graph (Figure 8) we compare three most significant courses of speed for all three types of semi-trailer trucks. The graph shows the course of speed after stopping the vehicle for the semi-trailer truck with tarpaulin indicated by blue colour (02vF_24). The semi-trailer truck with a tank container with breakwater plates is shown in green colour (03vF_15). The semi-trailer truck with a tank container without breakwater plates is shown in red colour with (21vF_11).

Although the lowest speed (only 11 km·h⁻¹) was reached during braking in 21vF_11, speed variations achieved after stopping the vehicle show the greatest dispersion. From this it can be concluded that this type of semi-trailer truck is most risky with regard to road safety.
5. Conclusions

After comparing the results of graphs from Figure 6 and Figure 7, which show the subsequent movement after stopping the vehicle with the tank container without breakwater plates, it can be stated that when the tank container is filled to the maximum possible extent, there is smaller subsequent movement of the vehicle immediately after stopping in comparison to a tank container filled approximately to 50% of its total volume [17]. From the safety point of view, as well as economical use of tank containers, it is necessary to fill tank containers to the maximum possible volume, i.e. to about 95 percent. It is not allowed to fill the tank container to 100% of its volume, as the transported fluid needs some space to expand [18].

The comparison of graphs in Figure 1 and Figure 6 reveals that after stopping the semi-trailer truck with tarpaulin, a speed change range of -0.39 m·s⁻¹ to 0.28 m·s⁻¹ was achieved. In case of the vehicle with a tank container without breakwater plates, these values ranged from -0.76 m·s⁻¹ to 1.1 m·s⁻¹ in each measurement. In case of the semi-trailer truck with tank container with breakwater plates, values in the range -0.19 m·s⁻¹ to 0.14 m·s⁻¹ were achieved. After the analysis of the measured values, it was found that during braking with a semi-trailer truck with a tank container without breakwater plates, the subsequent movement of the vehicle immediately after stopping it is more extreme than the movement of a semi-trailer truck with tarpaulin carrying non-liquid goods [19]. The movement of the tank container without breakwater plates after stopping has a significant repetitive forward and reverse movement over time. The movement of the tarpaulin semi-trailer truck is shorter in time and less rapid than the tank truck without breakwater plates [20]. The semi-trailer truck with a tank container with breakwater plates behaves similarly to the conventional semi-trailer truck with tarpaulin. This can be clearly seen in Figure 8. At approximately 2.5 seconds after stopping, the tarpaulin semi-trailer truck and the tank-container semi-trailer truck with breakwater plates were completely stationary. On the other hand, the semi-trailer with a tank container without breakwater plates moved forwards and backwards for a long time [21].

The evaluated results of the semi-trailer truck with a tank container with breakwater plates are very close to the measured results of the tarpaulin semi-trailer truck. This is because the breakwater plates mounted inside the tank container, by their design, almost completely eliminate the undesirable waves caused by the movement of the truck. Elimination of waves occurs because the breakwater plates inside
the tank divide the interior into smaller sections and thus, reduce the wave motion force caused by the truck movement.

The results of this research can be put directly into practice. However, further research is needed in the field of tank-container and tank-vehicle transport, for example, in relation to the shape of individual intersections and possibilities of these vehicles at a given intersection to bring the vehicle to a stationary condition, i.e. to a complete stop.

6. References

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