

Tests for the assessment of devices for securing semi-trailers during transport on a freight wagon

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ARTICLE INFO

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DOI: <https://doi.org/10.46793/ET26.B02M>

PAGES: B11 – B16

ABSTRACT

The WAG TSI defines requirements for devices used to secure semi-trailers on freight wagons. The device must hold the semi-trailer in a safe position by withstanding longitudinal, lateral, and downward vertical forces in accordance with the design operating state. Following a 2019 accident, in which a semi-trailer detached during a severe storm and struck an oncoming passenger train, Denmark introduced controls and restrictions that have now been accepted and included in the WAG TSI. Additionally, the device must lock semi-trailers by withstanding upward vertical forces caused by crosswinds at the minimum crosswind stability; in the absence of this data, the upward force must be at least 85 kN. This paper presents real-world tests of a device for securing a semi-trailer to a freight wagon, along with an assessment of its conformity with EU regulations.

KEYWORDS

Semi-trailer, Kingpin, Securing device, Vertical upward force

1. INTRODUCTION

During rail transport, cargo must be adequately secured. Depending on the wagon type and freight characteristics, various measures and solutions are implemented to ensure safety in compliance with relevant European standards [1, 2]. In inter-modal transport, particularly regarding semi-trailer shipments, ensuring the secure engagement of the kingpin within the locking device (hitch) is of paramount importance. Modern hitch designs must possess sufficient structural strength and feature clear, visually identifiable indicators of proper positioning and locking. Although the volume of semi-trailer and complete truck transport by rail has increased due to environmental benefits and economic efficiency, inadequate cargo securing has previously led to severe railway accidents. Specifically, due to insufficient locking forces under intense lateral loads, the connection disengaged, causing semi-trailers to encroach into the clearance gauge of the adjacent track and collide with oncoming trains. A critical example occurred in 2019 on the Great Belt Bridge in Denmark, resulting in eight fatalities, followed by a similar non-fatal incident in 2021. Consequently, the Danish authorities [3] banned semi-trailer transport during stormy weather, tightened operational controls, and strictly defined responsibilities for cargo securing. These events initiated a comprehensive re-evaluation of locking device designs; in addition to the conventional longitudinal, lateral, and downward vertical load cases, a new requirement was introduced for upward vertical resistance [4].

To evaluate the structural integrity and compliance of the locking device with the updated WAG TSI requirements, a comprehensive testing methodology was developed. The experimental framework combines laboratory-controlled, non-destructive load testing with real-world field trials under operational conditions. The primary objective is to verify that the locking mechanism can withstand the newly mandated upward vertical force of 85 kN, in addition to standard longitudinal and lateral operational loads. Conceptually, this device is engineered not only to ensure a secure connection but also to protect the payload (i.e., the semi-trailer) from excessive longitudinal accelerations during uncontrolled or improper shunting operations. This protection additionally accounts for standard braking and acceleration phases, during which lower levels of longitudinal acceleration occur.

To evaluate these conditions, buffing impact tests are conducted in accordance with standard [5]. Further investigations [6, 7] revealed that a complex interplay of extreme crosswinds, cyclic aerodynamic pressure waves generated during train passings, and vertical dynamic oscillations of the wagon traversing bridge spans induces a severe leverage effect. This phenomenon generates an upward vertical force capable of physically extracting the kingpin from its housing, provided the mechanism lacks positive mechanical locking across all degrees of freedom. In the absence of section-specific aerodynamic data, the locking device must withstand a minimum upward vertical lifting force of 85 kN to guarantee semi-trailer stability. Figure 1 illustrates the hitch devices, crash elements, and the air brake valve activator, which triggers emergency braking in the event of hitch displacement resulting from crash element deformation.

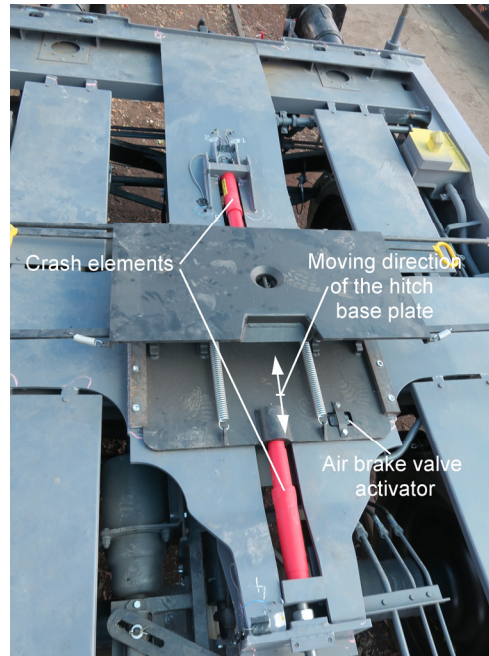


Figure 1: Hitch on the pocket wagon [8]

2. TEST OF THE POCKET WAGON LOADED WITH A SEMI-TRAILER

2.1. Buffing Impact Test

In accordance with structural strength requirements for freight wagons, buffing impact tests shall be conducted using a fully loaded configuration with a semi-trailer weighing 40 tons. Given that the vehicle belongs to the F-II category for combined transport, it is specifically designed for careful shunting operations. Consequently, the baseline certification tests were performed at impact speeds up to 7 km/h. As the partner (impact) wagon was used Eaos wagon loaded to a total mass of 80 tons (Figure 2). During these baseline trials, no structural damage or permanent deformations were observed on either the wagon frame or the trailer hitch mechanism. The peak longitudinal accelerations recorded on both the wagon and the semi-trailer chassis stabilized at approximately 1g.

Within the scope of research regarding the development of sacrificial crash elements [8], further experimental trials were carried out at higher impact velocities to evaluate cargo protection under improper shunting conditions. The integrated crash elements within the trailer hitch are designed to deform plastically and dissipate kinetic energy when shunting speeds exceed 7 km/h, thereby capping the acceleration transmitted to the cargo at a maximum threshold of 2g. To determine the ultimate structural margins of the coupling, extreme testing scenarios were conducted using compromised or rigid elements. Under these severe conditions, the longitudinal interface between the trailer hitch and the wagon was subjected to extreme accelerations reaching up to 3g. Despite these highly elevated dynamic loads and the resulting severe pitching moments, the structural integrity of the connection was maintained, and no unlocking or slippage of the kingpin from the trailer hitch occurred, demonstrating compliance with the safety margins [5].

When a pocket wagon undergoes a buffing impact, the primary load is longitudinal. However, because the semi-trailer's center of gravity is located high above the hitch level, this sudden deceleration generates a severe pitching moment (rotational leverage). This moment manifests as a structural reaction at the coupling point. During buffing, impact kinetic energy transforms into a simultaneous dynamic upward vertical force and a high bending moment on the locking jaws.

Based on the conducted analyses and operational experience, the most critical scenario occurs under strong crosswinds combined with an empty semi-trailer. This condition stands in stark contrast to the scope of the conventional buffing impact test, where the semi-trailer is evaluated under a maximum gross weight of 40 tons. Consequently, the supplementary tests applying an 85 kN upward vertical force to the hitch connection are designed to simulate the quasi-static equivalent load induced by aerodynamic effects and the vertical dynamic oscillations of a wagon carrying an unladen semi-trailer [6, 7].



Figure 2: Buffing impact test [8]

2.2. Tensile Vertical Upward Force Test

The validation test on the Sdggmrss wagon involved applying a vertical tensile load of 85 kN to a secured, ECE Regulation 55-compliant H50-type kingpin, with load monitoring and testing continuing until the wagon lifted from the rails [7]. The procedure, conducted with the securing device in the mandated position, verified that the locking capacity exceeds the required minimum [1, 7].



Figure 3: Tensile upward force [9]

To ensure measurement accuracy, the dead weight of the test adapter was excluded from the tensile force data by taring the load cell system while the adapter was suspended but not yet locked [9]. The experimental procedures were conducted at the specific operational positions designated for the securing device. Prior to and following each test cycle, a thorough visual inspection of the locking mechanism, locking pin, and securing device was performed to verify proper functionality and ensure the absence of visible damage or permanent deformation. To guarantee reproducibility, the test was repeated three times for each designated configuration. Vertical tensile load tests were systematically executed at three distinct securing device heights: 880 mm, 980 mm, and 1130 mm (Figure 4).



Figure 4: Hitch positions during testing (880, 980, 1130 mm) [9]

3. TEST RESULTS

3.1. Buffing Impact Test Results

Category A long-stroke buffers with a 150 mm stroke were tested on the wagon, with measurements, for this purpose, focusing on acceleration responses on the wagon and semi-trailer structure during impacts. Tests were conducted with the trailer hitch base plate in both upper and lower positions, using sensors A1–A3 as shown in Figure 5.

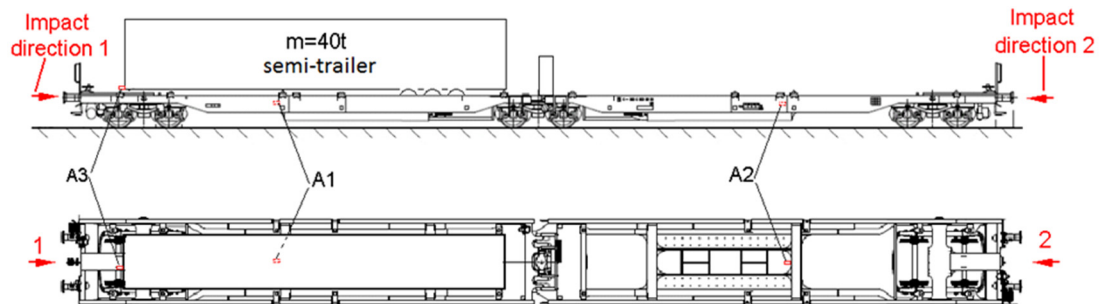


Figure 5: Acceleration transducers displacement [8]

The diagram in Figure 6 illustrates the measured accelerations as a function of the wagon's impact speed. The experimental data indicate that at standard shunting speeds of up to 7 km/h, the recorded accelerations remain at approximately 1.0 g, while elevated impact speeds of around 10 km/h result in values between 2.0 g and 3.0 g [8]. Furthermore, the results demonstrate that variation in hitch height has a negligible effect on the intensity of the measured accelerations.

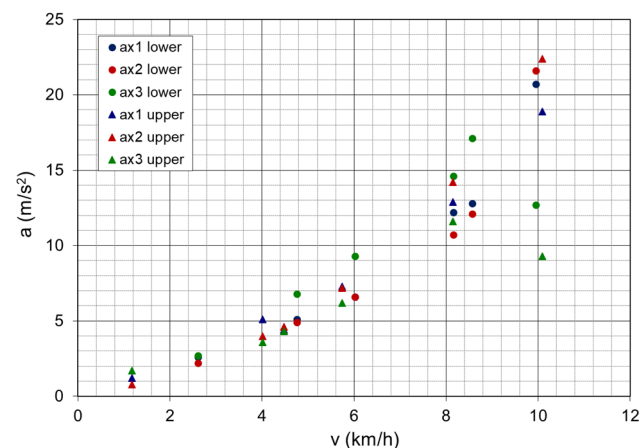


Figure 6: Accelerations on the wagon and semi-trailer vs. impact speed [8]

3.2. Tensile Vertical Upward Test Results

Vertical tensile load tests were systematically conducted across three distinct securing device heights: 880 mm, 980 mm, and 1130 mm. For each configuration, three experimental trials were executed to ensure reproducibility. During each test run, the tensile force was gradually increased until reaching a maximum recorded load of approximately 114 kN, which corresponded to the physical lifting of the wagon frame from the rails. This peak load was held in equilibrium for approximately 10 to 20 seconds. The experimental results demonstrated a highly repeatable quasi-static mechanical response of the securing device across all three tested positions, with no evidence of autonomous unlocking or anomalous structural behavior under load.

As a representative example, Figure 7 illustrates the force-time history recorded at the 1130 mm hitch configuration. No autonomous disengagement or loss of operational functionality was observed either during or after the completion of the testing cycles [9].

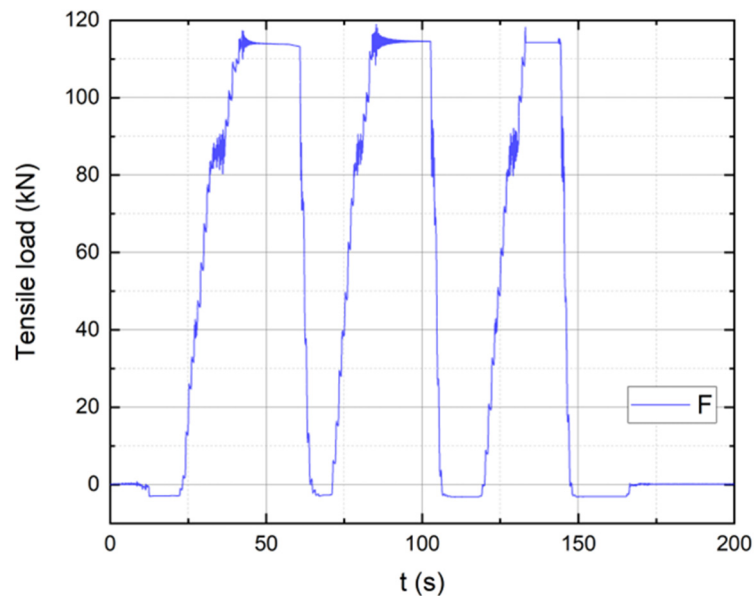


Figure 7: Vertical tensile force vs. time for test at hitch position 1130 mm [9]

Figure 8 illustrates the post-test condition of the kingpin and locking mechanism, confirming the preservation of structural integrity with no visible damage or permanent deformation. Inspection revealed only minor, superficial paint degradation, indicating that the component's functionality was not compromised.



Figure 8: Kingpin and locking mechanism after testing –no visible damage [9]

Furthermore, the locking device must incorporate a robust mechanical-visual indicator system designed to unequivocally verify full mechanism engagement. Validation of this safety subsystem requires intentional obstruction of the kingpin entry to confirm that the external visual indicators fail-safe to a distinct "Not Locked" status. The operability, contrast, and legibility of these mechanical indicators under degraded light levels and adverse environmental conditions must be optimized to ensure that trackside inspection personnel can reliably and efficiently verify locking integrity.

4. CONCLUSIONS

Based on buffing impact and vertical tensile tests [8, 9], the semi-trailer securing device on the Sdggmrss wagon withstood loads exceeding mandated thresholds [1, 4, 7] with no autonomous unlocking or damage observed. These validation results provide technical assurance that, with proper operational locking, the tested type of securing device will prevent the recurrence of similar structural failures.

ACKNOWLEDGEMENTS

The results presented in this paper are the results of research supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia under the Agreements No. 451-03-34/2026-03/200105 and No. 451-03-33/2026-03/200105, dated 05.02.2026.

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