H. Effects of Differences in Truck Size and Weights on Testing Procedures

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Four years from the commencement of Anagni field test activities, and after completion of work to improve the launching system, an overview has been prepared of the tests conducted up to now with heavy vehicles. The guardrails tested have been essentially of three types: (a) central reserve (New Jersey-type profile in concrete, single- or double-file, with earth fill); (b) viaduct (New Jersey-type profile in concrete, reinforced and raised); and (c) roadside, in steel.

The vehicles used, limited to heavy vehicles, ranged from two to four axles and from 7 to 29 tonnes in weight.

The launch system used in tests consisted of towing by an auxiliary vehicle and release of the test vehicle near the guardrail (about 50 m). This system entailed limitations on the mass of the vehicle and the launch speed, as well as significant random errors regarding impact angle and impact point. It has been impossible to test vehicles with trailers with weight up to 44 tonnes, and the speed obtained has always been significantly less than that intended.

These limitations were accentuated following Test 21, when it became necessary to reduce the length of the tow track. Figure 7 shows how the space-velocity diagrams corresponding to vehicles of 24 and 44 tonnes were obtained with the power of the tow vehicle and the limit speeds for the various track lengths as parameters. Figure 8 shows the errors in impact angle obtained as functions of weight and speed. The intended impact angle was achieved in about two-thirds of the total number of tests, without any particular relationship between launch speed or vehicle weight, thus confirming the random nature of this error, which was linked to the launch method.

Test Parameters and Results

Characteristic parameters of the tests conducted included vehicle weight, vehicle speed, impact angle, and height of the center of gravity. The tests were conducted for vehicles of four, three, and two axles and various guardrail types; the maximum weight permitted under Italian regulations in the various cases was indicated on the vehicles. Load weights exceeded the maxima permitted under Italian law. In fact, surveys conducted on Italian roads have shown that about 5 percent of the vehicles in circulation violate these regulations, reaching 27 tonnes, as opposed to the prescribed 24 tonnes. At Anagni, loads ran up to 29 tonnes.

A certain inverse proportionality was found between vehicle mass and speed (see Figure 9), except for the case of metal guardrails, to which more severe testing conditions were not applied. This situation corresponds to a certain uniformity in impact energies. In effect, because of the high energies, the potential limit of the system was approached, increasing the probability of tow vehicle driver error.

The spread of the data confirmed that the error in the impact angle was random, in particular being unlinked to the vehicle weight (see Figure 10). The 1.60-m height of the center of gravity, prescribed in the new Italian standards, constituted practically the limit value for the trials conducted (see Figure 11). This height was linked in particular to the loading system adopted up to now, consisting of concrete blocks anchored some 20 to 30 cm up from the bed of the truck.

In the following paragraphs, the most important results of the tests conducted and the suggestions for standardizing the tests that emerged therefrom are summarized. Figure 12 shows types of guardrails as related to types and amounts of traffic and types of roads.

New Jersey-Profile Guardrail

Tests performed on the central-reserve-type, single-file, New Jersey-profile guardrail indicated the need for traction-resistant elements consisting of reinforcing in the prefabricated elements and connections between these to permit funicular-type action. In the absence of reinforcement and given the high impact energy, the guardrail system failed because of rupture of the elements or their disconnection from one another. Moreover, the limited height of 1 m combined with the significant displacements produced by very heavy vehicles resulted in vehicle rollover in cases of high center of gravity.

Tests on the central-reserve-type, double-file, earth-filled, New Jersey-profile guardrail confirmed these deductions. Moreover, they demonstrated that the presence of an energy-absorbing element (in this case, the earth fill) guaranteed safety even in cases of extremely heavy impact.

Tests on viaduct guardrails demonstrated the importance of having a connecting element at a height greater than 1 m (a steel toprail or a concrete beam for

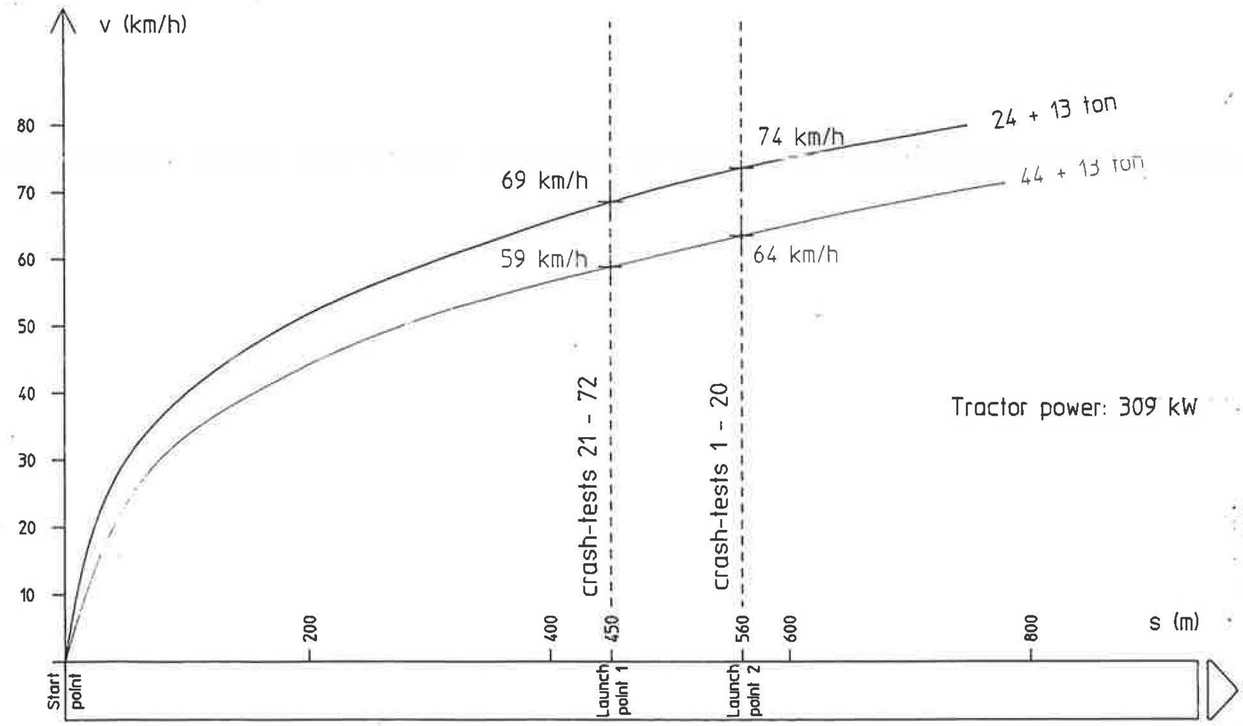

FIGURE 7 Space velocity diagrams for various load classes.

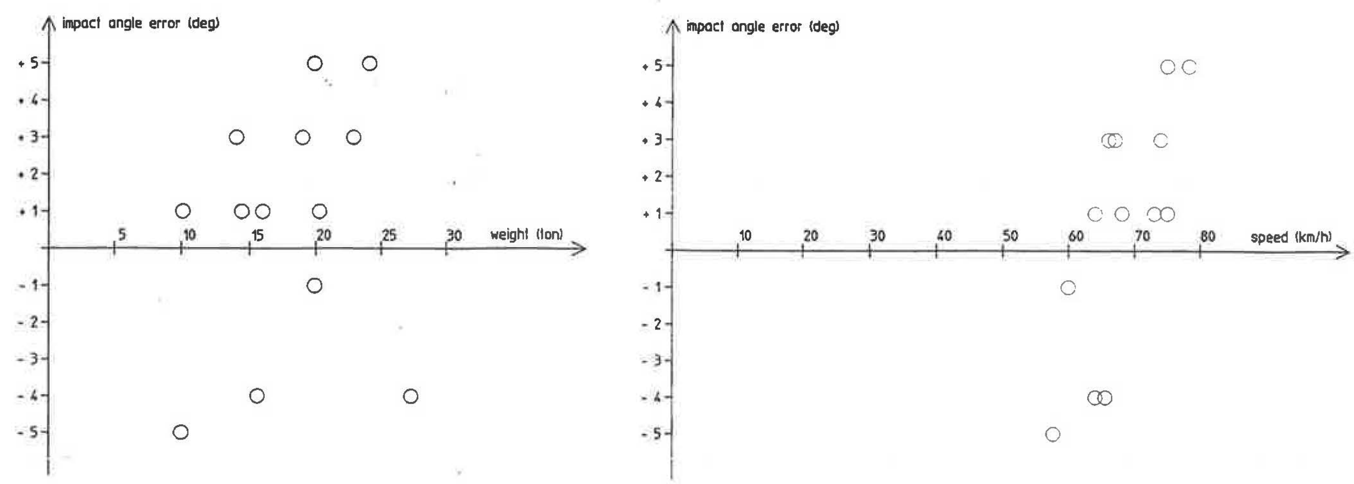

FIGURE 8 Vehicle weight-impact angle error diagrams.

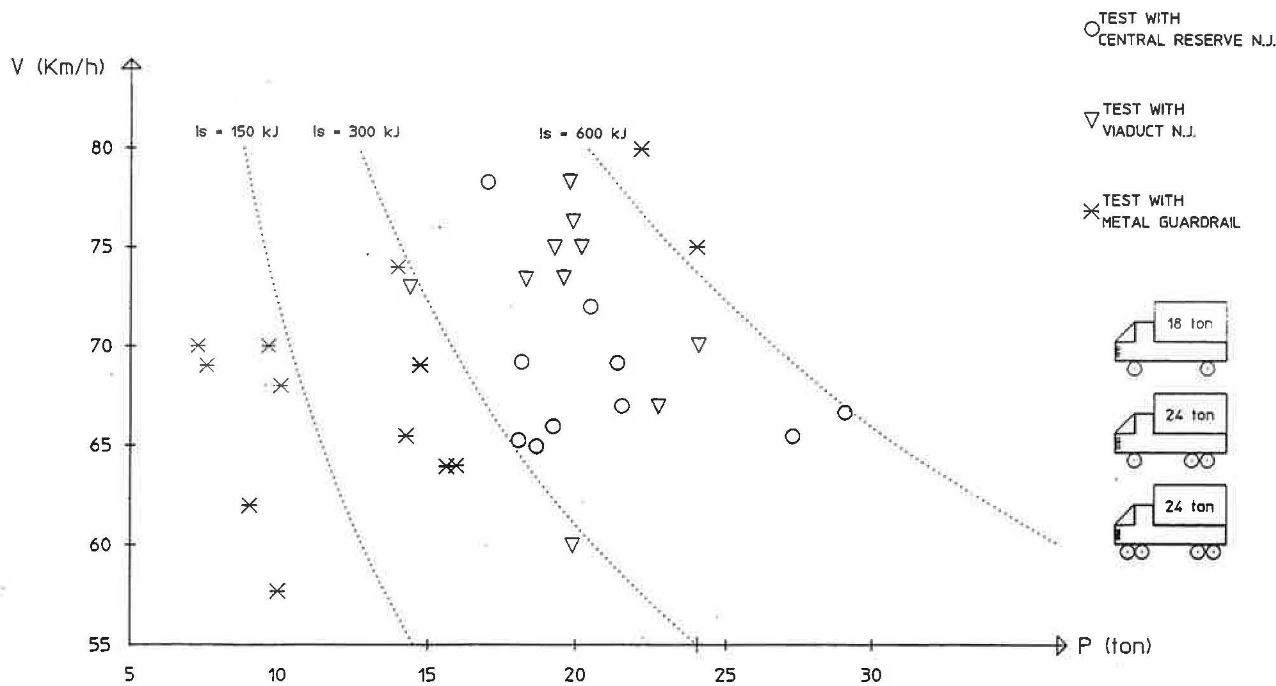

FIGURE 9 Weight versus launch speed diagram.

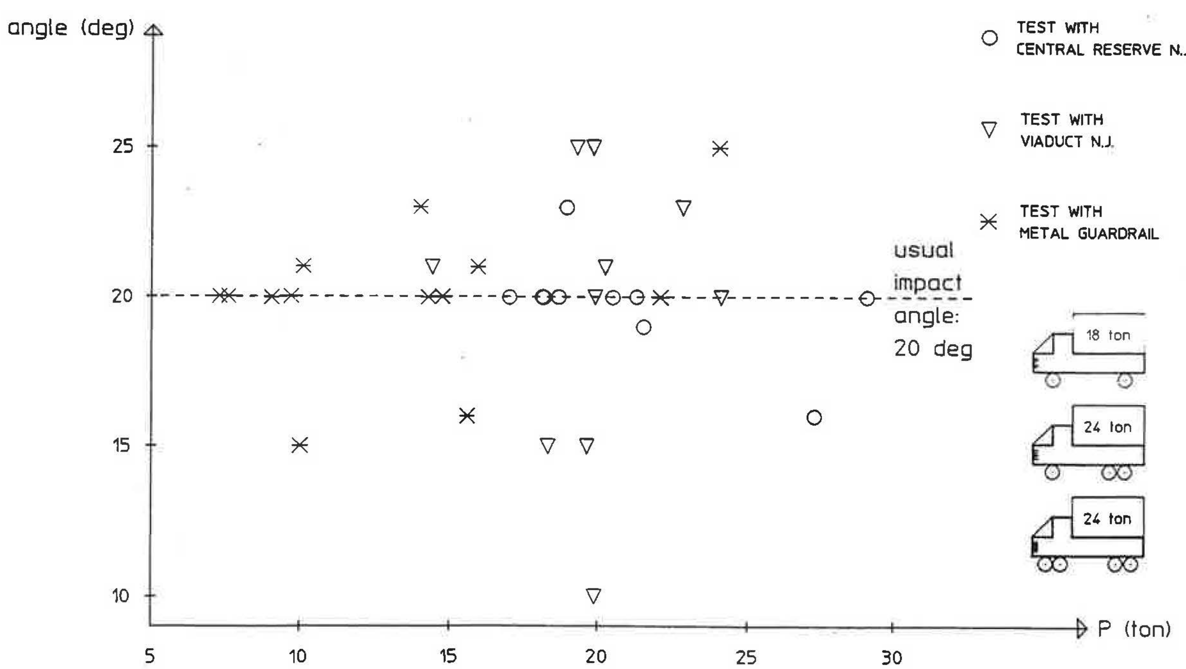

FIGURE 10 Weight versus impact angle diagram.

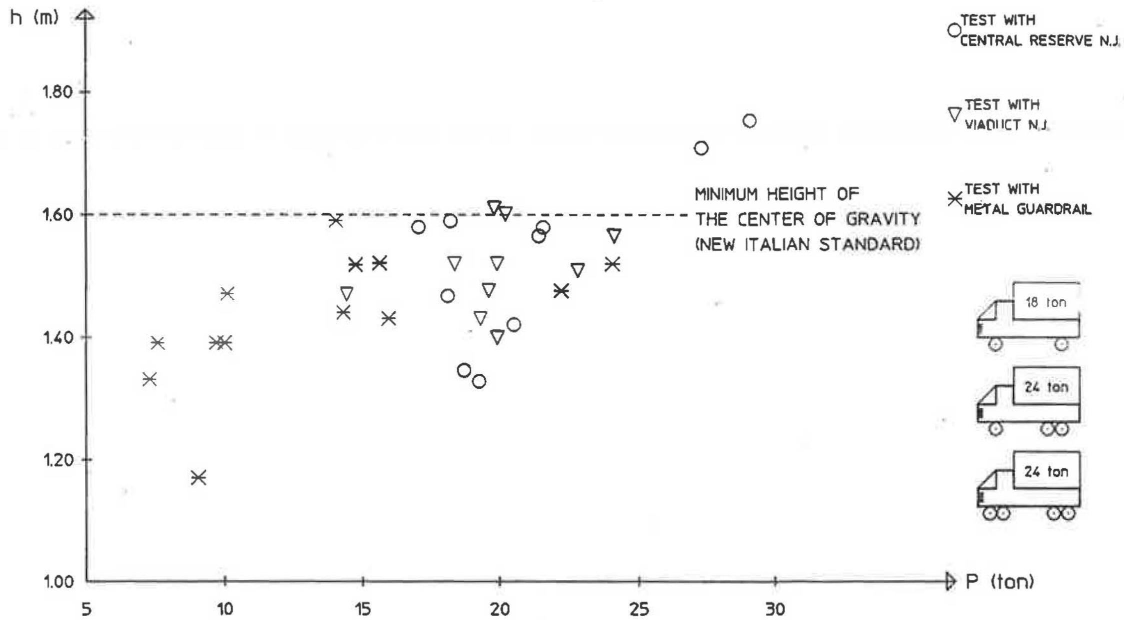

FIGURE 11 Weight versus height of center of gravity diagram.

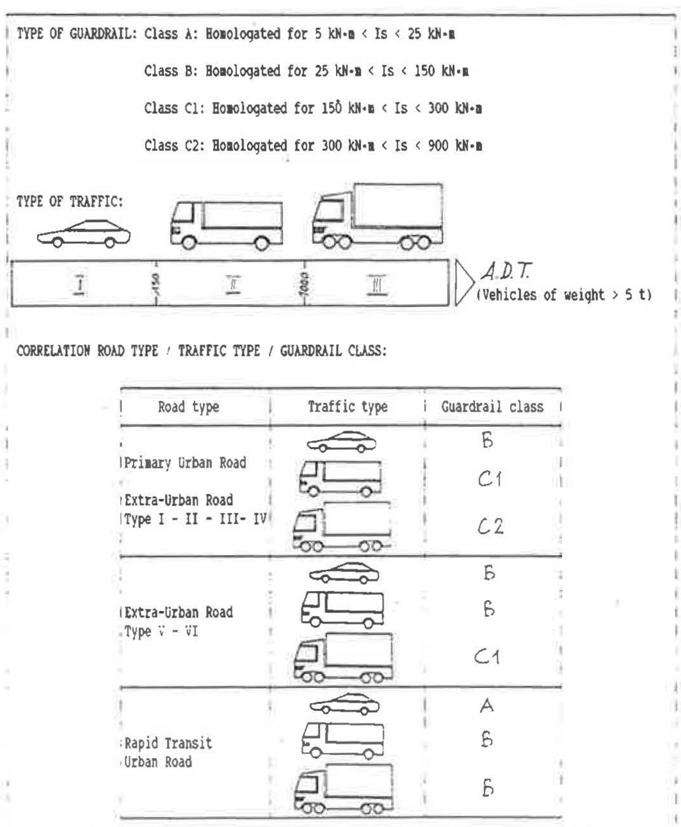

FIGURE 12 Guardrail classification as a function of absorbable energy and in correlation with road and traffic types.

the Colosseum rail), so as to avoid rollover of vehicles with high center of gravity. In fact, in the only test with negative results, a fiberglass toprail lacked sufficient strength, broke under impact, and failed to ensure vehicle containment and effective connection between the guardrail elements.

Steel Guardrail

Finally, the tests on the metal guardrails confirmed the importance of guardrail height and mechanisms to limit height loss under impact so as to prevent rollover of vehicles with high center of gravity, and also the need to increase the strength of the longitudinal strip to compensate for increased impact energy. Two factors emerged as important in verifying guardrail performance: the energy of the vehicle at the moment of impact (especially its component orthogonal to the guardrail) and the height of the center of gravity.

Heavy Vehicles Tested

Italian regulations prescribe the following load limits:

1. Trucks of two axles: 18 tonnes.
2. Trucks of three or four axles: 24 tonnes.
3. Vehicles with trailers: 44 tonnes.

Up to now, the only vehicles tested have been those in the first and second categories. Because tractor and trailer act independently, as confirmed also from actual accident data, tests on vehicles of the third category would be of little additional value. However, the existence of a certain percentage of vehicles in circulation that exceed the official limits on loads and speeds suggests the advisability of using vehicles exceeding 24 tonnes in tests on maximum-strength guardrails.

Accident Cases

New Jersey-type guardrails have been used in Italy for about 3 years, and hence there is already sufficient documentation on accidents to permit verification of their effectiveness. Some particularly significant accidents that were studied included a viaduct guardrail after impact by a 19-tonne trailer truck at 90 km/hr at an impact angle of 30 degrees, with lateral energy about 1500 kJ. The vehicle was contained on the carriageway; in addition, the presence of the steel toprail not only served to redirect the vehicle, but also prevented the parts of the guardrail from falling off onto the underlying buildings. In a similar situation, the vehicle was contained, but the element struck, which was not connected by a steel toprail to its neighboring elements, was pushed off the structure.

In another case, a special guardrail installed on the Adriatica Motorway was almost undeformed. It consisted of two New Jersey-type profiles connected in an almost continuous manner, surmounted by a double-corrugated steel strip (W-beam) toprail. The vehicle, a five-axle tractor-semitrailer of about 25 tonnes, struck the guardrail at an impact angle of about 10 degrees and was redirected onto the carriageway.

Another case consisted of a double-file guardrail without interposed earthen fill or connecting elements that demonstrated a behavior similar to that of a single-file guardrail, insofar as it did not resist the impact, even though it did redirect the vehicle. In this case, the elements were of the older type (little reinforcing) and not connected. Consequently, the element at the point of impact was broken, and the two successive elements were disconnected.

In general, about 25 percent of all accidents consist of collisions against longitudinal guardrails, and except for rare cases, the impact angle is no more than about 12 degrees.

Test Specification

On the basis of the results of the tests conducted to date and accident findings, the Circulation Traffic Inspectorate of the Ministry of Transport has issued technical specifications for guardrail tests; these specifications are currently in process of being published. These specifications, besides defining guardrail performance characteristics, also stipulate procedures for performing the tests, with particular attention to vehicle weights and speeds (and hence the relevant energies), impact angle, height of center of gravity, and instrumentation necessary for proper documentation.

Severity Index

The dimensions, weights, speeds, and impact angles have been prescribed for the various categories of heavy vehicles. The center of gravity of the heavy vehicles is set at a minimum of 1.60 m from ground level. Weight, speed, and impact angle, which are variable so as to permit a certain elasticity in use, must nevertheless be such as to generate the lateral energy (also termed the "severity index" Is) prescribed for the various guardrail categories. The expression is

$$E(\text{lat}) = \text{Is} = W(V \sin a)^2/2g$$

where

E(lat)	=	kinetic energy in direction perpendicular to guardrail,
Is	=	severity index (=E(lat)),
W	=	weight of vehicle,
g	=	acceleration of gravity,
V	=	vehicle speed, and
a	=	incident impact angle.

Anagni Launch System

The variables that must be checked with appropriate instrumentation are speed, impact angle, and the three spatial components of the vehicle deceleration. Taking into account these prescriptions, the Anagni launch system was completely modernized (the testing and final inspection stage have just been completed), to have maximum control over speed and impact angle, the two most important random variables. The new launch system shown in Figure 13 is of the diesel-hydraulic type; propulsion is provided by two coupled turbodiesel engines that drive a winch on which the towline is coiled; the vehicle is drawn by means of a trolley from which it is released a few meters from the guardrail.

The impact angle and point of impact are determined in an almost absolute manner, insofar as the vehicle trajectory is imposed almost right up to the guardrail. The trolley runs along a track. The angles are set at 10 and 20 degrees. The launch speed is controlled by regulating the capacity of the hydraulic system. Special software permits simulation of the test before execution, to optimize the length of track to be used and to obtain a space-speed diagram to follow during the crash test. During the test, the performance of the system is controlled electronically to supply the computer in real time both the spot speed and the distance traveled. In this way, the operator can reduce or increase the towing force to reach the release point at the speed desired. The speed error encountered during the system inspection trials was about 2 percent.

The vehicle trajectory before, during, and after impact is checked by an overhead high-speed motion picture camera at a film speed of 400 frames per second. The deceleration to which the vehicle is subjected with its longitudinal, transverse, and vertical components is measured directly by means of accelerometers installed on the vehicle and controlled by an on-board processor, and indirectly by the films. Using these devices, the crash tests can be performed with minimum deviation from the speed, impact angle, and energy determined beforehand or required by current Italian regulations or by any future international specifications.

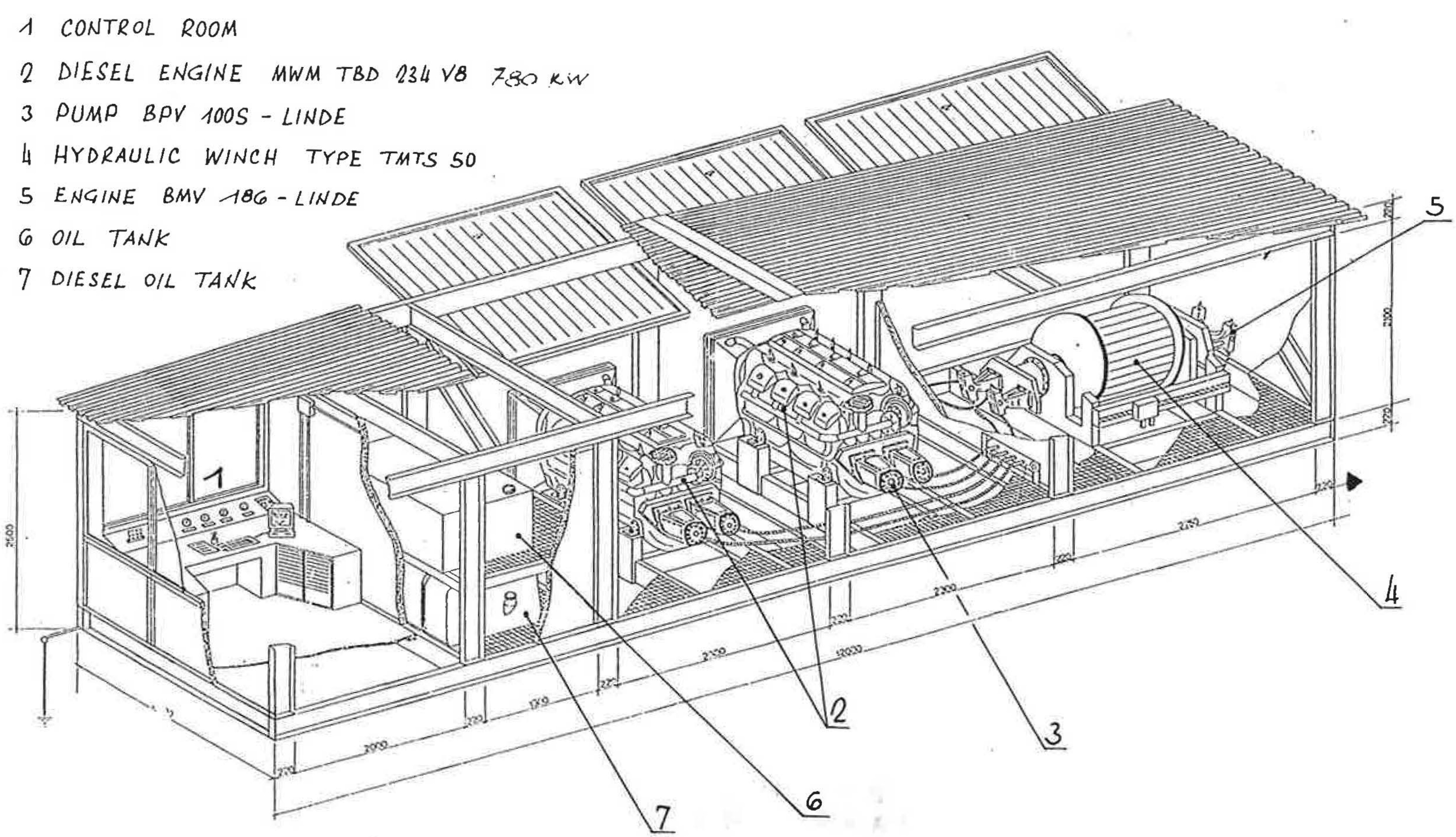

FIGURE 13 Axonometric view of launch system.