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# Tests of Running Safety Under Large Compressive Longitudinal Forces

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**Summary**
The article presents the cause of derailment of empty two-axle wagons placed in long freight train-sets together with bogie wagons, as well as research conducted to prevent this phenomenon, which was concluded by introducing appropriate statements in the UIC leaflet 530-2, and then in the European Standard EN 15839. It also presents activities undertaken during the preparation and performance of the tests, requirements for the test track and for the wagons' composition in the train-set, conditions during the tests, values being measured and respective evaluation criteria, principles applicable to the result analysis, as well as a sample chart for a single ride and regressions for various criterions. Examples of wagons which were tested in this way are also given.

**Keywords:** running safety; reverse shunting test; longitudinal forces

## 1. Setting the problem

Running safety under large compressive longitudinal forces is a relatively new topic. Such phenomena were noticed for the first time in the 1970s while analysing the causes of accidents. The appearance of these phenomena was associated with a common increase in the use of (four- and six-axle) bogie wagons for transport services, which resulted in an increase in single wagon masses, while historically typical two-axle wagons were still in use. It was noticed that for certain compositions of the long train-sets, in which heavy (loaded) bogie wagons are present in the front and in the rear part of the train-set and light (empty) two-axle wagons are present in the middle part of the train-set, during the braking of such freight train-sets while the train-set changes the track on which it is running to an adjacent one, two-axle wagons are lifted and pushed aside. An additional factor contributing to the appearance of this phenomenon is the speed of the pressure wave which runs along the whole train-set, from the locomotive, after the train driver triggers the continuous brake. After a while, in the case of a long train-set, the wagons which are at the front start to brake, while the wagons in the rear still run at the speed at which the whole train-set was running a moment before. This leads to the appearance of large compressive forces along the train-set, which leads, in combination with the above-mentioned train composition and track configuration, as well as higher position of the empty wagons' buffers in relation to the surrounding wagons (caused by smaller deflection of the springs), to light wagons in the middle of the train-set being pushed aside from the track. Fortunately, all such derailments were observed at low speeds of about 10 km/h. The described situation is shown in Figure 1. The wagons which are marked grey are loaded while the empty wagon is white.

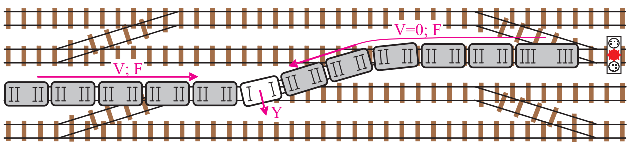

Fig. 1. Set of factors contributing to derailment [photo. A. Zbieć]

At the beginning, research regarding the running safety of the long two-axle wagons was conducted in cooperation by French and German Railways belonging to the International Union of Railways (Union Internationale des Chemins de fer – UIC). A united UIC committee of „Operation" and „Rolling Stock" in June 1981 took the decision to establish, at short notice, a multidisciplinary working group aimed at defining real means for improving the running safety of long two-axle wagons. The Working Group B 12-1, composed of experts from different states associated in UIC, was established within Committee B 12

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in September 1981 to conduct work on this topic. This group took the decision to complement previous analyses and conduct further research aimed at establishing means against derailment.

In 1982, French and German Railways conducted dedicated research. In 1983, supplementary research was performed to clear up some questions. Within those two years, different configurations of wagons forming train-sets were tested (two-axle and four-axle of different construction and different overhang values), using different buffers (with different absorbers and different buffer plate radiuses) taking into account friction forces between the buffer plates (dry and lubricated). The test results are contained in Report 40 [1]. It was demonstrated in the report that it is possible to reduce the mass of the wagon for long two-axle wagons (for wagons of the length with buffers between 14.1 m and 15.5 m, then treated as long ones), while keeping high enough wagon torsional rigidity and equipping such a wagon with an axle guard with progressive stiffness.

On the basis of the obtained results, the leaflets UIC 517 [2] and 530-2 [3] were amended. Axle guards with progressive stiffness were introduced in leaflet 517. The conditions necessary for ensuring running safety for long two-axle wagons (of the length with buffers between 14.1 m and 15.5 m) were introduced in leaflet 530-2. At the same time, as a result of those works, rules were established for testing safety against derailment under the influence of large compressive longitudinal forces for new wagons accepted for operation. This test is called to as the S-shaped curve propelling test or simply the propelling test. The name reflects the fact that, to achieve longitudinal force, the tested wagon is put in a train-set containing braking wagons at the front, which is propelled by a locomotive. Change in the longitudinal force is ensured thanks to a change in the braking level of the braking wagons. This test belongs to the group of tests for running safety. Such a test was first conducted in Poland in 1997 by the Railway Institute on its own Test Track near Żmigród. Up to now, the Railway Institute is the only centre in Poland to conduct such tests and the test track section dedicated for such tests is the only track in Poland on which propelling tests can be conducted.

## 2. Conditions for conducting propelling tests

At the beginning, the conditions for conducting propelling tests were defined in the leaflet UIC 530-2, issue 4 from July 1985, which was elaborated on the basis of the above-mentioned ORE report and amended for this purpose. This leaflet has been amended several times and the latest issue is no. 7 from December 2011. However, the currently binding document, based on which propelling tests are conducted, is the Standard PN-EN 15839 [4]. This standard is referred to in the binding TSI WAG [5]. The TSI WAG refers to EN 15839 issued in 2012, while the latest issue was prepared in 2015.

## 3. Testing track

According to PN-EN 15839, the track on which propelling tests are conducted should be S-shaped composed of two minimum 20 m long curves with a 150 m radius connected by a section of straight track of a length of 6 m. The track for propelling tests is shown in Figure 2. Such a track configuration is intended to reflect the conditions described at the beginning – change to an adjacent track by a ride over two switches with a radius of 150 m connected by a six-metre straight track.

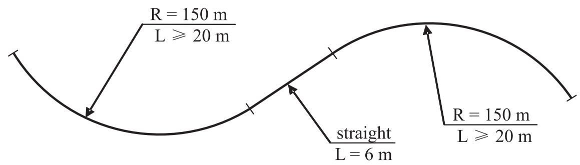


Fig. 2. S-shaped curve for propelling test [photo. A. Zbieć]

The track should be laid without cant. The average track gauge should be between 1450 mm and 1465 mm. The track should be protected against lateral deformation (lateral displacement). Data describing the real S-shaped track section constituting part of the Railway Institute Test Track is given below:

1) the track is composed of two S-shaped curves R = 150 m each, of the lengths 22.95 m and 41.07 m connected by a section of straight track l = 6.05 m, curve R = 404.80 m of the length 11.24 m, curve R = 255 m of the length 127.69 m, and two sections of straight track l = 100 m and l = 79.88 m,
2) the curves are without cant h = 0.00 m,
3) the complete length of the track with the switch S60 1:9 R300 is 482.01 m,
4) usable length of the track from the switch to the buffer stop is 448.78 m,
5) the track horizontal profile has 0‰ slope on its whole length,
6) rails S49 of the length 30 m, of the inclination 1:20, laid on wooden slippers, with indirect type K fastening,
7) broken stone ballast of dimension 10–20 cm, put on the ballast bed with a one-side lateral slope 2.5–4.0%,
8) draining and open drain.

Figure 3 below shows a real view of the track for propelling tests while Figure 4 shows a respective track layout.

Fig. 3. Real view of the track for propelling tests [photo. A. Zbieć]

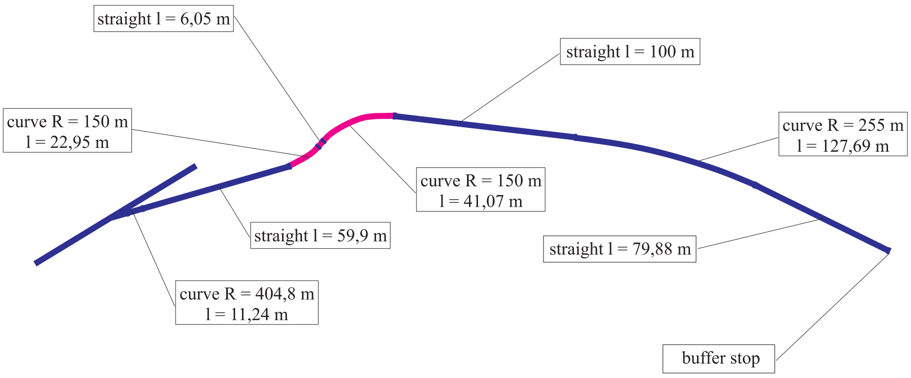


Fig. 4. Track layout of the S-shaped track [A. Zbieć]

## 4. Testing train-set

To ensure the most difficult conditions during tests, the test wagon is put between two barrier wagons: preceding – a type Fcs or type Tds two-axle self-discharging wagon and following – type Rs four-axle platform with extended overhang, longer than the standard for wagons running on the PKP network. Table 1 shows the basic parameters of those wagons.

Table 1

**Basic parameters of the barrier wagons**

| Parameter | Wagon type | |
|---|---|---|
| | Fcs or Tds | Rs |
| **Number of axles** | 2 | 4 (bogie) |
| **Length over buffers [m]** | 9.64 | 19.90 |
| **Distance between axles [m]** | 6.00 | – |
| **Distance between bogie pivots [m]** | – | 13.00 |

Barrier wagons and other wagons in the train-set, except the test wagon, should be loaded up to 20 tons per axle. The test wagon is empty. Two centre couplers are put behind the barrier and intermediate wagons, on both sides in relation to the test wagon, in order to correctly measure the longitudinal forces. The centre couplers are special ones comprising a strain gauges measuring part. Figure 5 shows the testing train-set.

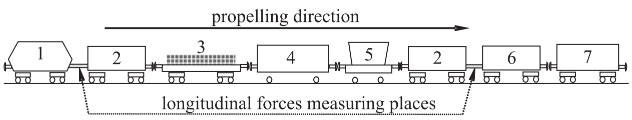


Fig. 5. Testing train-set: 1) locomotive or group of locomotives, 2) intermediate wagons, 3) barrier wagon Rs, 4) test wagon, 5) barrier wagon Fcs or Tds, 6) braking wagon, 7) measuring wagon [A. Zbieć]

The part of the train-set which is between the couplers measuring longitudinal forces does not brake while the tests are being performed. The only braking part is the group of wagons in front of the train-set (wagons marked with digit 6 in Figure 5 – on the right of the coupler for measuring longitudinal force), except the measuring wagon.

Barrier wagons should be equipped with category A buffers, with an end-stroke force of 590 kN, with non-pivoting buffer plates with sphere radiuses of 1500 mm. The test wagon has buffers, which are foreseen for this wagon for operation. Buffer plate surfaces should not have wear marks (deep grooves or burrs).

The screw coupling between the test wagon and barrier wagons should be tightened in a way that ensures contact between the buffer plates without over-tensioning. The height difference between the buffer centre lines of the test wagon and of the barrier wagons should be about 80 mm. This distance is shown in

Figure 6. The buffer plates should be slightly greased with a lubricant.

Fig. 6. 80 mm difference in the height between the buffer centre lines of the test wagon and barrier wagon [photo. A. Zbieć]

For the two-axle wagons of a length over buffers ≥ 15.75 m, an additional variant should be performed, in which the test wagon is surrounded by wagons of the same type, instead of the above-mentioned wagons Rs and Fcs/Tds, keeping the loading and coupling conditions and required state of the buffer plates. However, the buffers themselves should be such as foreseen for those wagons for operation (such as on the test wagon).

## 5. Preparation for tests

During the preparation for tests, special measuring heads for measuring the lateral forces H are mounted on the wheelsets of the test wagon together with special equipment for measuring wheel uplift. These devices, shown in Figure 7, are own solution created in the Railway Institute Rolling Stock Test Laboratory.

Fig. 7. Heads for measuring lateral forces and equipment for measuring wheel uplift [photo. A. Zbieć]

In two-axle wagons, axle guard deflection sensors are mounted. Moreover, special measuring couplers for measuring the longitudinal force $F_{LX}$ compressing the train-set are mounted on intermediate wagons. The place where the measuring couplers are mounted is shown in Figure 5. Sensors measuring lateral displacements are mounted between the test wagon and barrier wagons, for determining buffer plates overlap during tests. Additional measuring sensors are mounted e.g. for measuring speed or reading track markers, which show the moment when the wagon enters individual sections of the track.

All wagons except the test wagon are loaded up to 20 tons per axle. Barrier wagons – platform wagons and two-axle wagons are equipped with category A buffers, with non-pivoting buffer plates with sphere radiuses of 1500 mm. Buffer plate surfaces are checked, before starting the tests, to see whether they do not have wear marks or deep grooves. If they do, the grooves should be removed. Buffer plates are greased with graphite grease. Figure 8 below shows deep grooves and burrs on the surface of a diagonal buffer in a two-section wagon, which were detected during tests.

Fig. 8. Grooves and burrs on the surface of a diagonal buffer [photo. A. Zbieć]

The 80 mm height difference between the buffer centre lines of the test wagon and barrier wagons is achieved by potential regulation of the barrier wagon masses. Screw couplers between the test wagon and barrier wagons are tightened in a way that, on a straight track without any slope, the buffer plates come into contact without over-tensioning.

A special electro-pneumatic system controlling the braking intensity of the braking wagons is mounted in order to keep the same longitudinal force during each test ride. This system has been created in the Railway Institute Rolling Stock Test Laboratory and patented by Railway Institute. The working principle is based on direct control of the brake operating cylinders in braking wagons via a set of electro-valves, which are controlled by a computer, which compares the predefined longitudinal force with the force measured on measuring couplers. Thanks to this solution, differentiation of the value of the longitudinal force during each ride is not higher than ± 10 kN.

After finishing all the preparatory works, an initial equipment check is performed.

## 6. Performing the tests

Propelling tests should be performed with the speed between 4 km/h and 8 km/h keeping approximately constant longitudinal force. During tests, the rails should be dry. A minimum of 20 rides with different values of longitudinal forces should be performed, until one of the criterions or the maximum longitudinal force of 280 kN is reached (since Issue 5 of the UIC leaflet 530-2 in December 2005, the longitudinal force value, up to which tests are performed, has been increased from 200 kN to 280 kN; it was also agreed that the minimum permissible longitudinal force for bogie wagons is 240 kN). If, during the tests, no parameter passes the limit values, there is no need to further increase the longitudinal force over 280 kN.

On the basis of the test rides, regression lines are determined for each parameter. For wagon acceptance in the case of two-axle wagons it is enough to reach the minimum permissible longitudinal force of 200 kN without exceeding any limit value, and in the case of bogie wagons 240 kN. Out of the minimum of 20 rides, at least 10 should be performed with the minimum permissible longitudinal force increased by 10% (namely 220 kN for two-axle wagons and 264 kN for bogie wagons).

If it is necessary to change buffers (e.g. due to buffer plate damage), a minimum of 5 additional tests with the minimum permissible longitudinal force have to be performed. Buffers have to be replaced if, due to their damage, the obtained results significantly differ from the results obtained earlier.

## 7. Measurements

Measurements during the tests cover:

- longitudinal compressive force $F_{LXi}$ acting on a train-set,
- wheel uplift over the top of the rail for each wheel of the test wagon $dz_{ij}$,
- lateral force $H_i$ for each wheelset of the test wagon, with which individual wheelsets affect the track, causing its possible deformation,
- deformation of the axle guards $dy_{Aij}$ for all the wheels of the test wagon (only for freight wagons equipped with axle guards),
- buffer plates overlap $dy_{P1}$ and $dy_{P2}$ between the test wagon and barrier wagons,
- track markers (according to the standard e.g. with a 1 m step; in the case of Railway Institute, registration covers the beginning and end of curves R 150 m and of the straight track between them),
- train-set propelling speed.

Figure 9 below shows the arrangement of the measuring points in an example four-axle wagon (therefore without measuring the axle guard deformation $dy_{Aij}$).

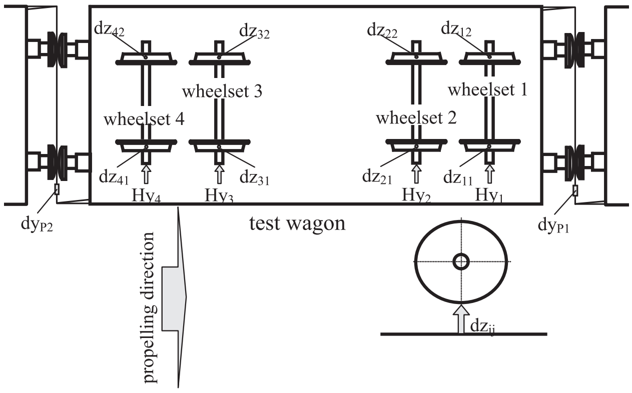


Fig. 9. Arrangement of the measuring points [A. Zbieć]

Additional measurements:

- buffer characteristics of the test wagon and barrier wagons, to verify test parameters,
- track geometry before and after the tests, to verify that the test track parameters have not changed,
- longitudinal and lateral play between the axle box and axle guards, to verify the state of the test wagon and to detect possible damages,
- buffer centre line height over the top of the rail for the test wagon and barrier wagons, to verify the test parameters (to keep the appropriate height difference).

## 8. Assessment criteria

Permissible longitudinal force for wagons is determined by reaching one of the limit values:

- uplift of a non-guide wheel over a distance of 2 m $dz_{ij,lim}$ = 50 mm,
- axle guard deformation measured at 380 mm from the lower edge of the wagon sole-bar, $dy_{Aij,lim}$ = 22 mm,
- lateral force $H_{lim}$ (2 m) = $25+0,6\cdot 2Q_0+25$ [kN] (where $Q_0$ – mean force of wheel on rail),
- minimum buffer plates overlap $dy_{P,lim}$ = 25 mm,
- climbing of a guide wheel $dz_{ij,lim}$ = 5 mm – only in the additional variant in which the test wagon is surrounded by two identical wagons (two-axle wagons of a length over buffers ≥ 15.75 m).

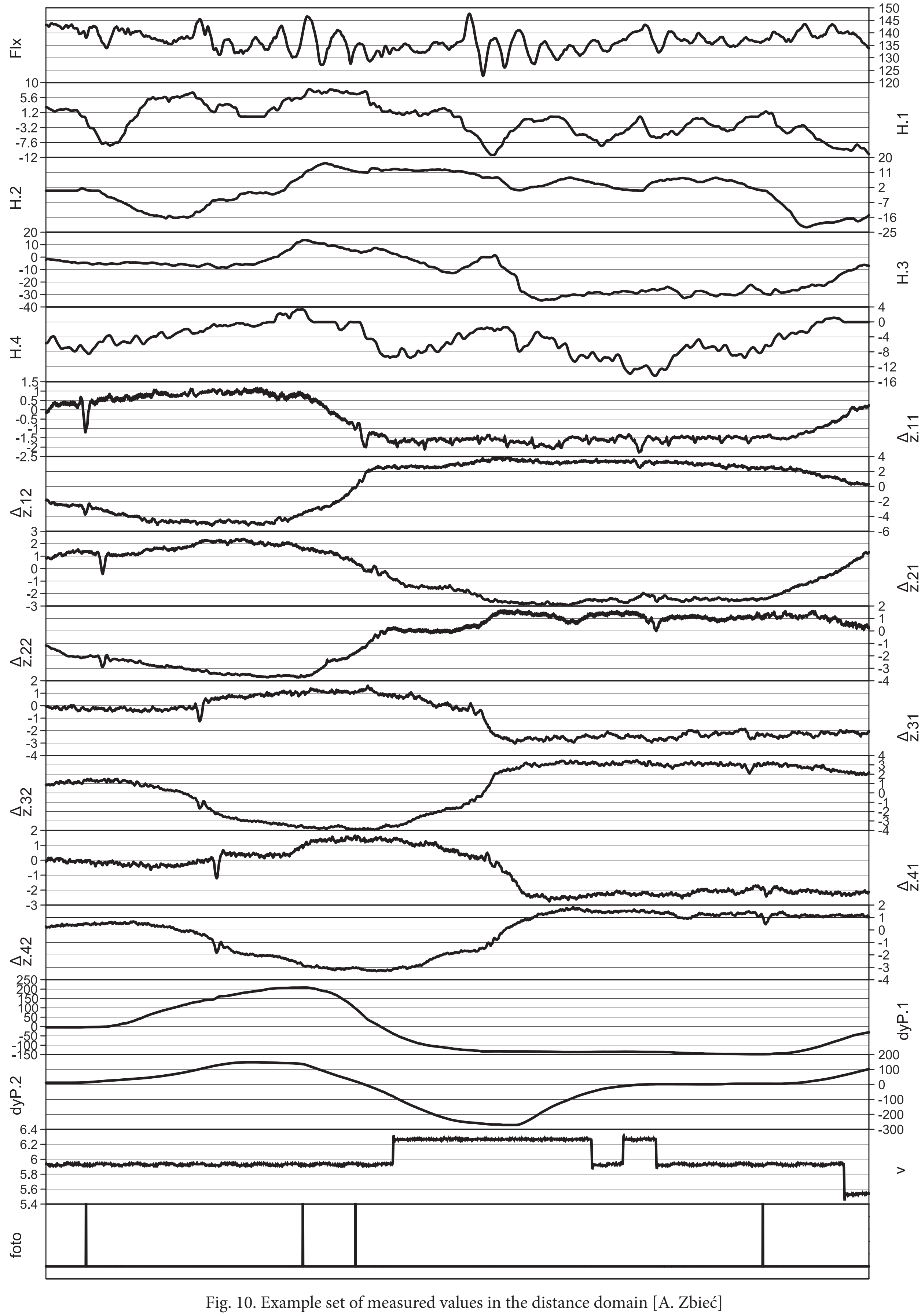


Fig. 10. Example set of measured values in the distance domain [A. Zbieć]

If any of the above mentioned parameters exceed the limit value or derailment takes place before longitudinal force reaches the value:

- 200 kN – for two-axle wagons,
- 240 kN – for bogie wagons

the wagon is determined as not fulfilling the running safety criteria.

## 9. Result analyses

The test report contains registered results for each of a minimum 20 rides presented in a graphic form. An example set of such graphs for one ride, taken from the works done by the Railway Institute Rolling Stock Test Laboratory, is shown in Figure 10. The graphs show all the measured values in the distance domain. Additionally, points corresponding to the first wheelset entering individual track sections are marked in the „Foto" frame (vertical strokes).

On the basis of the recorded results for each test ride, the following data is determined:

- compressive longitudinal force $F_{LXi}$,
- lateral force $H_i$ over a distance of 2 m,
- uplift of a non-guide wheel $dz_{ij}$ over a distance of 2 m,
- axle guard deformation $dy_{Aij}$ (for two-axle wagons),
- buffer plates overlap $dy_P$,
- climbing of a guide wheel $dz_{ij}$ – only in the additional variant in which the test wagon is surrounded by two identical wagons (two-axle wagons of a length with buffers ≥ 15.75 m).

The determined values are used for statistical analyses. A regression line is determined for each assessed parameter in the domain of longitudinal force $F_{LXi}$. Then, theoretical permissible longitudinal force is determined on the basis of the regression lines. Theoretical permissible longitudinal force for the wagon is the lowest of all the obtained values. The way that theoretical permissible longitudinal force is determined for the assessed parameters is shown in Figure 11.

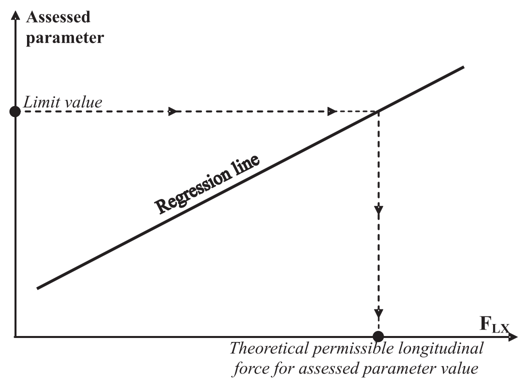


Fig. 11. Determination of the theoretical permissible longitudinal force [A. Zbieć]

Figures 12–15, taken from work conducted by the Railway Institute Rolling Stock Test Laboratory, show examples of graphs with regression lines for different assessed parameters.

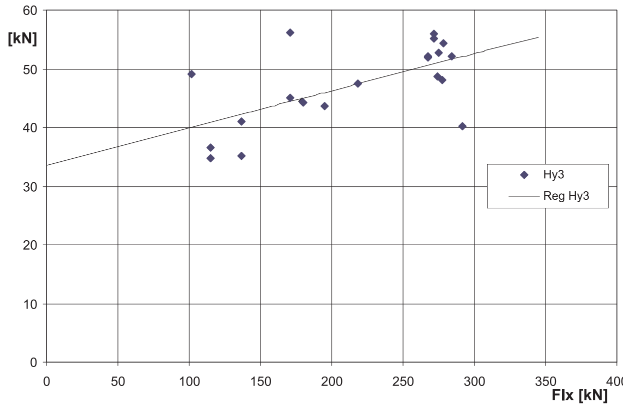


Fig. 12. Regression for lateral force H

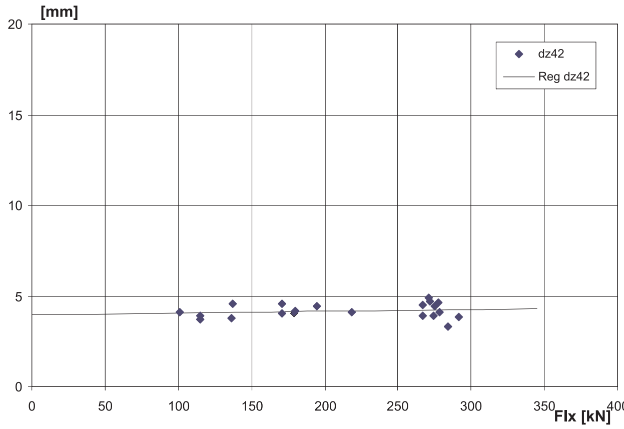


Fig. 13. Regression for wheel uplift dz

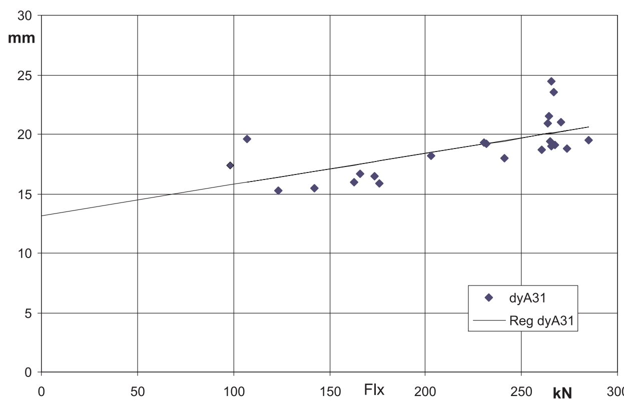


Fig. 14. Regression for axle

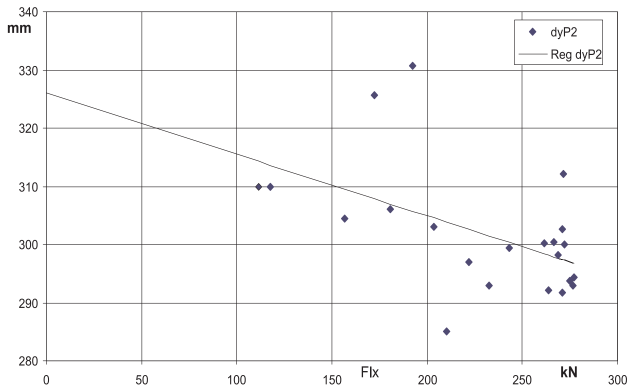


Fig. 15. Regression for buffer guard deformation $dy_{Aij}$ plates overlap $dy_P$

## 10. Example tests

As already mentioned at the beginning of the article, the first propelling test was conducted in Poland in 1997–21 years ago. Since then, the Rolling Stock Test Laboratory has conducted about 40 such tests on its own Railway Institute Test Track near Żmigród. Tests were performed for two- and four-axle wagons, but also for two-axle and four-axle short-coupled wagons and articulated wagons (with three bogies, one of which is common for two sections). The figures 16–23 show examples of wagons subjected to propelling tests.

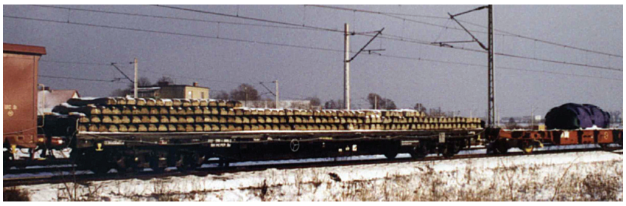

Fig. 16. Two-axle platform of the length 17.4 m and long overhang 3.7 m [photo. A. Zbieć]


Fig. 17. Bimodal unit in a railway composition [photo. A. Zbieć]


Fig. 18. Covered with movable top cover bogie wagon [photo. A. Zbieć]

Fig. 19. Four-section short-coupled self- discharging wagon with two-axle sections photo. A. Zbieć]


Fig. 20. Two-axle wagon with sliding walls tested in the additional variant in which the wagon is surrounded by two identical wagons [photo. A. Zbieć]

Fig. 21. Two-section platform wagon on four bogies [photo. A. Zbieć]

Fig. 22. Two-section platform wagon on three bogies – two leading bogies and one middle bogie [photo. A. Zbieć]

Fig. 23. Two bogie 27.5-metre-long platform for railway switch transportation [photo. A. Zbieć]

## 11. Conclusions

This article is the first publication to present the topic of running safety under large compressive longitudinal forces in a comprehensive way, including establishment of the problem source and works conducted to solve it. The fact that, until recently, many wagon producers learnt about the necessity to perform such tests only when wagon tests were contracted to Railway Institute indicates that the topic is relatively new.

The aim of the article is to make producers aware of the need to conduct such tests and to introduce, already at the wagon design phase, the performance of appropriate computer simulations. Poor results could be then used as a basis for constructional changes aimed at meeting the binding requirements. The main parameters influencing positive test results are geometrical wagon parameters, like length and overhang and the distance between bogie pivots, stiffness parameters, like wagon torsional rigidity and axle guard stiffness (for two-axle wagons), as well as buffer characteristics and own wagon mass. If individual limit values are exceeded by already produced wagons, appropriate changes can be introduced. And so:

- for exceeded lateral force H, it is possible to increase wagon mass (however, of course, it depends on cost/benefit analyses for wagons with increased mass),
- for exceeded wheel uplift and climbing values, it is also possible to increase wagon mass or wagon torsional rigidity; this, however, requires larger constructional changes, which will also increase the wagon mass,
- for exceeded axle guard deformation, it is enough to increase their stiffness; this should not significantly influence the wagon mass,
- for exceeded buffer plates overlap, it is enough to use buffers with wider buffer plates.

It could be stated, on the basis of our own experience obtained over more than twenty years, that most presently produced two-axle and bogie wagons fulfil requirements regarding running safety under large compressive longitudinal forces, regardless of the fact that many contemporary two-axle wagons are longer than 15.5 m and that the minimum permissible longitudinal force for bogie wagons was increased from 200 kN to 240 kN.

## Literature


1. Report 40 ORE B12 „Propelling tests with long two-axled wagons", Utrecht, April 1984.
2. UIC 517 „Wagons – Suspension gear – Standardisation", 7th edition, April 2006.
3. UIC 530-2 „Wagons – Running safety", 7th edition, December 2011.
4. PN-EN Standard 15839+A1:2015-12: „Railway applications – Testing for the acceptance of running characteristics of railway vehicles – Freight wagons – Testing of running safety under longitudinal compressive forces".
5. COMMISSION REGULATION (EU) No 321/2013 of 13 March 2013 concerning the technical specification for interoperability relating to the subsystem 'rolling stock — freight wagons' of the rail system in the European Union and repealing Decision 2006/861/EC (EU OJ L 104 dated 12.4.2013 with changes).