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Railway Buffer Stops

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Summary

Track end devices are highly significant structures, not only in rail transport. This paper presents and describes several instances of vehicle collisions with track end devices (buffer stops), demonstrating the substantial impact of these devices on safety, the effectiveness of their design, and the reduction (decrease) of damage. An analysis was conducted of the requirements for older track end device designs according to BN-79 9310-06 "Buffer Stops" and the currently applicable regulations. The paper also outlines the guidelines for newly designed track end constructions, as mandated for PKP PLK railway lines and outlined in the document "Railway Track Superstructure – Volume 1" 2021 It describes examples of track end device designs, including fixed (non-sliding) and sliding types. Explicit finite element method (FEM) calculations were performed using the ANSYS Mechanical R2023 software, simulating the process of a vehicle colliding with a buffer stop (fixed, non-sliding). The design of track end devices constructed according to the requirements of the industry standard BN-79 9310-06, which are still frequently found in railway infrastructure, was evaluated.

Keywords: buffer stop, sliding buffer stops, fixed buffer stops

1. Introduction

Track end devices, in terms of structural solutions, have undoubtedly been analysed by engineers since the inception of railways. In early analyses, the primary objective was to ensure the smooth operation of rolling stock within defined areas (on the tracks), while safeguarding trains and carriages from leaving the track. With the development of railways, rail transport, increased travel speeds, the weight of transported cargo, and growing awareness of safety, there has also been progress in the design of track end devices.

Track end devices are not limited to railways but are also found in broader forms of rail transport, such as metros, trams, sidings, and mines. In Polish terminology and everyday language, the term "kozioł oporowy" (buffer stop) is commonly used to refer to these devices. This term likely originates from the 1979 industry standard BN-79 9310-06 [2], which defined these structures as follows: "a buffer stop is a device with a buffer element installed at the end of a railway track, designed to prevent rolling stock from running off the track." In English, track end devices are referred to as: *buffer stop* (used in British railways) *bumpers*, *bumper block*, or *stopblock* (in the US).

Upon conducting a literature review concerning incidents at the ends of railway lines, one of the most notable cases is the derailment (on 22 October 1895) of a train at Gare Montparnasse railway station in Paris. The express train on the Granville – Paris route failed to stop at the station, collided with the track end device, derailed, and travelled several dozen metres through the station building [11, 13] (Fig. 1). A similar incident, documented photographically, occurred in Dublin on 14 February 1900, where a freight train on the Wexford–Dublin route derailed [5]. Figure 2 shows part of the destroyed building, the steam locomotive, and a section of the track end structure. In the depicted incident "...a 38-tonne locomotive destroyed concrete buffers – the track end device – which were three feet thick …" [5]. These incidents are the first well-documented derailments involving track end devices.

An interesting case concerning track end devices involves incidents on the tram line in Sydney (Fig. 3). Due to the topography at the Athol Wharf terminal station, trams derailed three times and fell into the

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water, with the last incident occurring on 22 January 1958 – Sydney Harbour [1, 18].

Fig. 1. Derailment at Montparnasse Station in Paris in 1895 [6]

A similar incident on Polish railway lines occurred at Zakopane Station on 23 March 1979, where train No. 581, led by locomotive ET21-469, failed to stop at the designated point and collided with a sand cushion and a buffer stop (Fig. 4). The locomotive, after breaking through the buffer stop, shearing off a traction pole, and partially damaging the canopy over the platform entrance, came to a halt on the pavement of Kościuszki Street (now, after reconstruction, the Armia Krajowa roundabout) [7]. It should be noted that Zakopane Station is a terminal station, with side and manoeuvring tracks located on the Poronin side. This layout means that the terminal station has direct track ends equipped with buffer stops. Figure 5 shows the current, modernised solutions for track end devices at Zakopane Station.

These cases demonstrate that track end solutions are crucial from the perspective of safety and the proper functioning of rail transport. These devices serve as safeguards for the ends of railway tracks (e.g., sidings, etc.) and help mitigate potential risks (e.g., damage to railway infrastructure, stations, or platforms).

Fig. 2. Derailment of a train at a station in Dublin, Ireland, in 1900; a fragment of the track end device can be seen beneath the locomotive; National Library of Ireland [8]

a) b)

Fig. 3. (a) Tram after derailment, Sydney Harbour, (b) tram track end; Lindsay Bridge Collection [10]

Fig. 4. Train derailment at Zakopane Station (23 March 1979); the locomotive failed to stop within the station tracks, destroyed the buffer stop, and ended up on Kościuszki Street [7]

Fig. 5. Zakopane Station – terminal station, current solutions for track end devices (17 May 2024) [photo by W. Kowalczyk]

1.1. Railway Buffer Stops

The document that introduced the classification of track end device structures in the Polish railway sector was the industry standard BN-79 9310-06 from 1979. This standard outlined the main division of track end structures into fixed (with rigid and elastic buffer devices) and sliding (with impulse action "braking sleepers" – original wording from BN-79 9310-06). An example of a fixed buffer stop design, commonly found on PKP PLK railway lines, is shown in Figures 6. These structures were built based on the guidelines contained in the BN-79 9310-06 standard [2]. In the article "Application of buffer stops on railway sidings" [12], various types of buffer stop designs were presented, including modern solutions for sliding track end devices equipped with additional buffers and kinetic energy absorbers.

The BN-79 9310-06 standard [2] describes concepts related to track end structures, with several key definitions provided below:

- Buffer stop – a device with a buffer element installed at the end of a railway track, designed to prevent rolling stock from running off the track.
- Buffer stop destructible in case of failure – a device installed at the end of a track. In the event of rolling stock colliding at a speed exceeding the design speed for the buffer stop, the device is destroyed, and the rolling stock runs off the track.
- Buffer stop destructive to rolling stock in case of failure – a device installed at the end of a track. In the event of rolling stock colliding at a speed exceeding the safe speed for the rolling stock when hitting permanently fixed objects, the rolling stock is destroyed.
- Fixed buffer stop – a device permanently installed at the end of a track, designed to stop colliding rolling stock.
- Sliding buffer stop – a device installed at the end of a track, which, in the event of rolling stock colliding with it, moves along the track axis, stopping the rolling stock.

Figure 6 shows a schematic drawing of a fixed buffer stop, as included in the BN-79 9310-06 standard [2]. It should be noted that the parameters *L* and *h* are not defined or described in this document, nor are their values (or range) provided.

The current requirements for track end devices on PKP PLK railway lines are specified in the new document: "Technical standards, Volume I – Attachment ST-T1-A8, Railway Track Superstructure, 2021 version" [17]. The provisions in this document regulate matters related to track ends "…" When designing railway track superstructures, every track not connected to another track should be terminated with a buffer stop. This document also introduces a more detailed (updated) classification of buffer stops into various types of structures, depending on the technical solution, functionality of the buffer stop, and requirements related to the track's operating parameters. The main categorisation of track end devices includes fixed (non-sliding) structures: concrete, steel

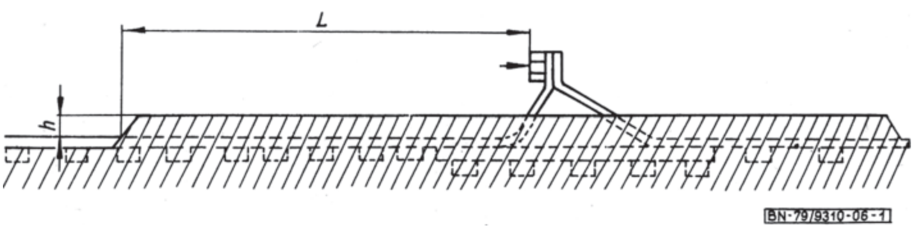

Fig. 6. Example of a track end – fixed buffer stop as described in the industry standard BN-79 9310-06 [2]

(made from rails or profiles), and sliding (braking) structures: friction, hydraulic, and mixed types.

The aforementioned document requires designers to create a device capable of absorbing a minimum amount of kinetic energy (dependent on the operational parameters of the railway line), taking into account a defined safety factor based on the installation conditions of the device. It should be noted that the BN-79 9310-06 standard [2] does not outline requirements in this area. The kinetic energy (design assumptions) that the track end device must absorb in a given event is derived from formulas (1) and (2).

$$E_K = \frac{m \cdot v^2}{2} \, [\mathrm{J}] \tag{1}$$

where:
E_K – kinetic energy of the vehicle J,
m – mass kg,
v – velocity m/s^{-1},

$$W \geq k \cdot E_K \, [\mathrm{J}] \tag{2}$$

where:
W – minimum required energy absorption of the buffer stop [J],
k – safety factor.

The specific design parameters for buffer stops, such as mass, velocity, and accelerations (Tabl. 1–3), are derived from the provisions of the ST-T1-A8 document on railway track superstructures [17].

Table 1

Safety factor depending on the location of the buffer stop (track end device) [17]

***k* factor**	**Description**
1.2	• for freight train traffic • for shunting movements
1.5	• for passenger train traffic • for freight train traffic if infrastructure is located directly behind (up to 30 m) or near the buffer stop
1.8	• for freight train traffic if residential buildings, transport routes, or public infrastructure are located directly behind (up to 30 m) the buffer stop,
2.0	• cliffs or other obstacles where vehicle collision could cause significant economic losses

Table 2

Vehicle collision velocity, data for design assumptions for buffer stops (track end devices) [17]

Vehicle velocity		**Velocity depending on the type of traffic**
2.8 [m/s]	**10.08 [km/h]**	• tracks used exclusively for freight trains • tracks used exclusively for shunting movements – protective tracks for freight train routes
4.2 [m/s]	**15.12 [km/h]**	• tracks used for passenger trains • protective tracks for passenger train routes

Table 3

Vehicle mass, data for design assumptions for buffer stops (track end devices) [17]

Vehicle mass [*t*]	**Type of rail vehicles**
80	• railbuses
200	• electric multiple units
400	• high-speed electric multiple units • electric multiple units in double traction • passenger trains (maximum 8-cars)
800	• high-speed electric multiple units in double traction • passenger trains (maximum 16-cars)
1000	• freight trains

The majority of track end devices used on PKP PLK railway lines are the so-called fixed buffer stops (from the 1970s–1990s). There are many different designs and variations of these structures, examples of which are shown in Figures 7–8.

Fig. 7. Example of a track end device structure at Warszawa Wschodnia Station [photo by W. Kowalczyk]

Fig. 8. Fixed (non-sliding) buffer stops – structures according to the BN-79 9310-06 standard at Warszawa Grochów Station [photo: D. Kowalczyk]

Buffer stop are used on railway lines worldwide. An example of such a structure on railway lines in Japan (Nagasaki Station) is shown in Figure 9.

Fig. 9. Fixed (non-sliding) track end device at Nagasaki Station, Japan [photo by M. Peryt]

1.2. Sliding buffer stop

Sliding buffer stops are among the modern solutions increasingly used in the construction of railways [3], subways, or railway sidings. Below is an example of a sliding track end structure installed at Warszawa Główna Station (Fig. 10) and in the metro (Fig. 11).

Fig. 10. Sliding buffer stop – Warszawa Główna Station [photo by W. Kowalczyk]

Fig. 11. Sliding buffer stop – Metro M2 [photo by D. Kowalczyk]

The operation of sliding buffer stops involves converting the transmitted kinetic energy into friction and partially absorbing the energy, e.g., through buffers, absorbers, or elements designed for permanent deformation (the so-called crumple zone). For such structures, it is required that, within the range of dynamic impact from the colliding vehicle, part of the structure remains rigid (transmitting impact forces), while the braking elements reduce the kinetic energy of the buffer stop through friction. Figure 10 shows five braking elements mounted on the buffer stop structure and five additional elements on the rail (a total of 10 on a single rail).

The stopping capacity of a sliding buffer stop is its ability to absorb kinetic energy. In the case of sliding buffer stops, this is the work of the braking jaws W_a, i.e., the braking force F_i over the braking distance l_i (Formula 3)

$$W_a = \sum_{i=1}^{n} F_i \cdot l_i \tag{3}$$

where:

- W_a – work of the braking jaws in the railway track end device,
- F_i – friction force of the individual braking element (single braking jaw),
- l_i – distance covered by the braking element F_i.

In the energy balance of the buffer stop's operation, it is necessary to consider whether the structure includes additional shock absorbers or other energy-absorbing elements (e.g., a designated crumple zone and deformation elements mounted in the buffer stop's bumper) as well as the deformation of the structure itself during a collision. These factors are also crucial from the perspective of the buffer stop's functionality and, consequently, influence the final, designed, and absorbable kinetic energy (Formula 4).

$$W = W_a + W_d + W_{am} \tag{4}$$

where:

- W – total energy that can be absorbed by the buffer stop,
- W_a – work of the braking jaws in the railway track end device,
- W_d – energy absorbed through plastic deformation of the buffer stop structure (track end device),
- W_{am} – energy absorbed by the vehicle's shock absorbers or other devices and elements.

2. Railway Buffer Stops

Numerical FEM (*Finite Element Method*) simulations are often used to obtain data on processes that are difficult, costly, or hazardous to conduct experimentally. For this reason, this method was applied to evaluate the performance of buffer stop structures. Comparing the provisions of the 1979 industry standard BN-79 9310-06 [2] with the current requirements outlined in Attachment ST-T1-A8, "Railway Track Superstructure", from 2021 [17], the most significant change is the definition of energy absorption requirements for a given track end structure (i.e., buffer stop) and a more detailed classification of structural solutions. Due to the fact that at present there are still many fixed buffer stops structures installed in tracks (constructed according to the requirements of the BN-79 9310-06 standard [2]), the author of this paper performed FEM calculations to determine the performance of these structures during collisions (vehicle impact on the track end structure) and to evaluate these structures based on the results obtained from the FEM simulations.

Observing the described fixed buffer stop structures installed in tracks, it can be noted that there are many variations. However, the basic part of the structure is the same and consists of bent rail profiles (49E1 or 60E1 rails [14]). A 3D model of such a structure was created in SolidWorks, followed by FEM calculations. The definition of mesh parameters, boundary conditions, and the execution of calculations were carried out in Ansys Mechanical 2023R1. The presented FEM simulations pertain to cases of vehicle impacts with fixed buffer stops without a ballast layer covering the track. This simplification aimed to evaluate the main structural part of the buffer stop. It should also be noted that the BN-79 9310-06 standard [2] does not specify the length of ballast on the track that should be present in front of the buffer stop.

Simulation 1

In the simulation of a vehicle colliding with the structure (buffer stop), the following boundary conditions were defined: the rail sections in the track were fixed, and surface contact was applied between the buffer stop's crossbeam and the surface of the approaching vehicle. The buffer stop utilised a 49E1 rail profile made of R260 steel (R_m = 880 MPa). At the ends of the rails, where they are joined base-to-base and at the height of the buffer, bonded contacts were applied, with a track gauge of 1435 mm. The height of the buffer (crossbeam of the buffer stop) was set at 960 mm from the rolling surface of the rail head [4, 15]. The velocity of the approaching vehicle was 3 m/s, with a mass of 50 tonnes (energy to be absorbed: 225,000 J; v = 10.8 km/h). The defined boundary conditions are shown in Figures 12–14. Since the goal of the FEM simulation [19] was to analyse the performance of the buffer stop structure, a simplified mesh for the colliding vehicle's body was used (larger mesh element sizes, defined as a rigid body). The simulation was performed in Ansys Mechanical 2023R1 [1] using an explicit solver.

Conclusions for Simulation 1

As demonstrated by the presented simulation, the buffer stop structure absorbs part of the kinetic energy of the colliding vehicle, which is converted into deformation of the structure (see Fig. 14). A portion of this energy is then converted back into kinetic energy of the vehicle (with an opposite velocity vector). In this case, for the defined boundary conditions, approximately 85% of the vehicle's kinetic energy was absorbed during the event (relative to the energy of the colliding vehicle).

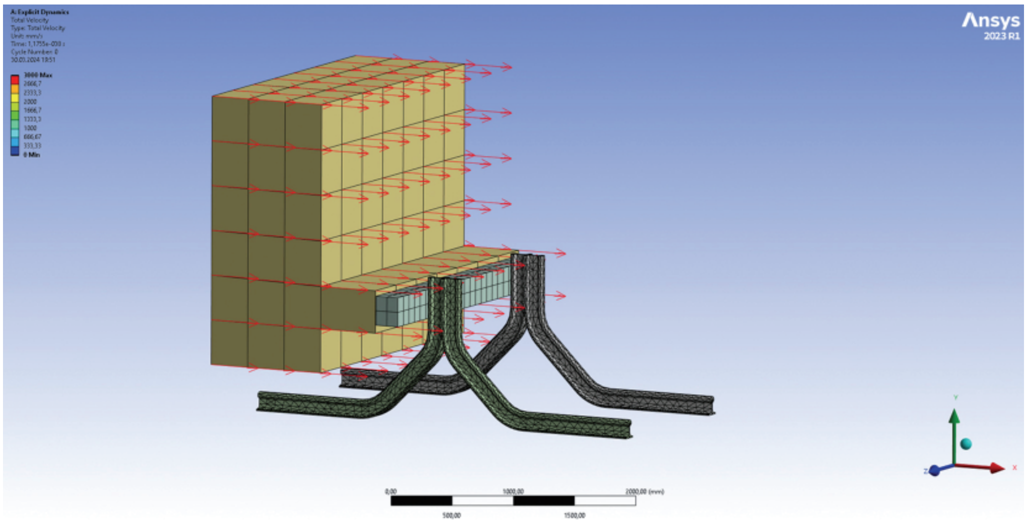

Fig. 12. Velocity distribution (Simulation 1) of individual elements at time $t = 0.007$ s; authors' own elaboration

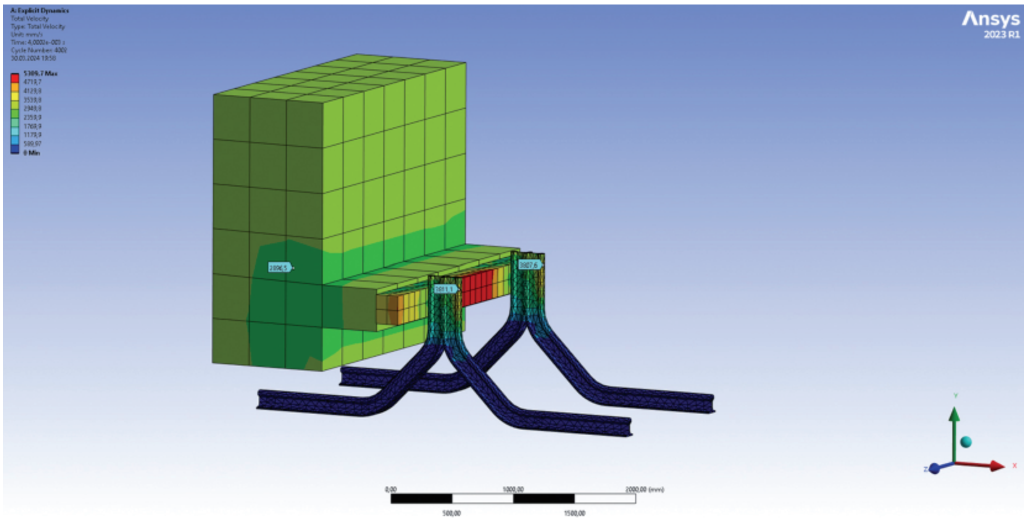

Fig. 13. Velocity distribution (Simulation 1) of individual elements at time $t = 0.03$ s; authors' own elaboration

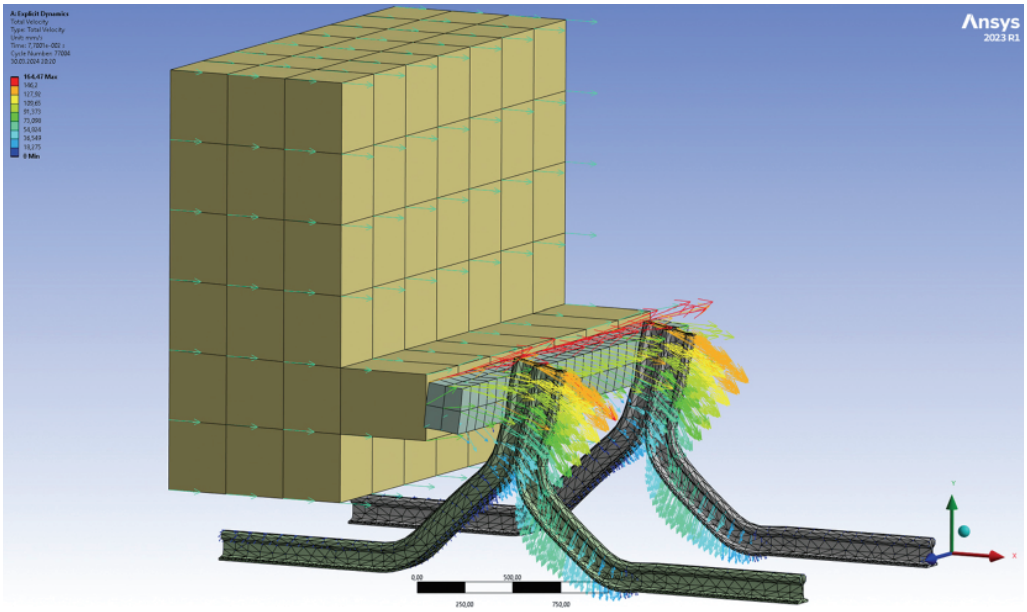

Fig. 14. Velocity distribution (Simulation 1) of individual elements at time $t = 0.077$ s; authors' own elaboration

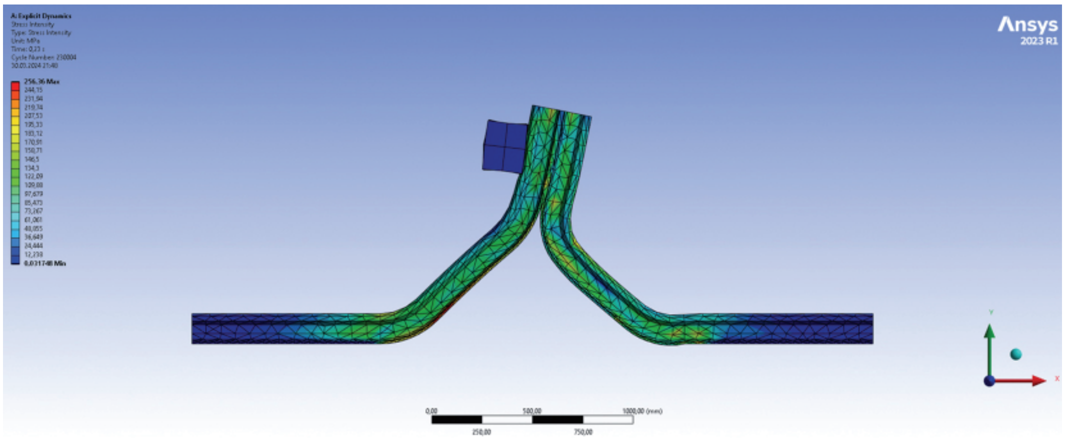

Fig. 15. Stress field distribution (Simulation 1) at time t = 0.22 s; authors' own elaboration

Simulation 2

In Simulation 2 (Figs. 16–19), the same boundary conditions as in Simulation 1 were defined, with the difference being the removal of support under the rails behind the buffer stop (this reflects a weak structural condition, i.e., poor support of the track end structure).

Conclusions for Simulation 2

Poor support of the structure behind the buffer stop results in the vehicle colliding with the buffer stop and only a slight reduction in velocity (from v = 3000 mm/s at time t = 0 s to v = 1685 mm/s at time t = 0.2375 s). This leads to the absorption of only a small amount of kinetic energy (compared to Simulation 1). A vehicle colliding with a buffer stop is not a desirable event, as it results in only partial absorption of the vehicle's kinetic energy by the buffer stop and creates a larger hazard zone associated with derailment (a larger danger zone).

Simulation 3

Simulation 3 (Figs. 20, 21) aimed to replicate the collision with the track end device that occurred on 21 October 2021 at Enfield Town Station in London.

The velocity of the Class 710 train at the moment of collision with the track end device at Enfield Town Station was 12 km/h [7]. The incident involved two EMU (Electric Multiple Unit) type 710 vehicles, with a combined mass of approximately 140 tonnes (one vehicle). The estimated kinetic energy of the impact was around 1600 kJ. Figure 20 shows the destruction of the track end device structure, as well as railway sleepers torn from the track. Based on Figures 20 and 21, it can be concluded that the track end structure is a fixed (non-sliding) device. The buffer stop model used in the simulation is therefore a similar structure. The goal of Simulation 3 was to reconstruct the sequence of events during the vehicle's collision with the track end device and to analyse the results in the

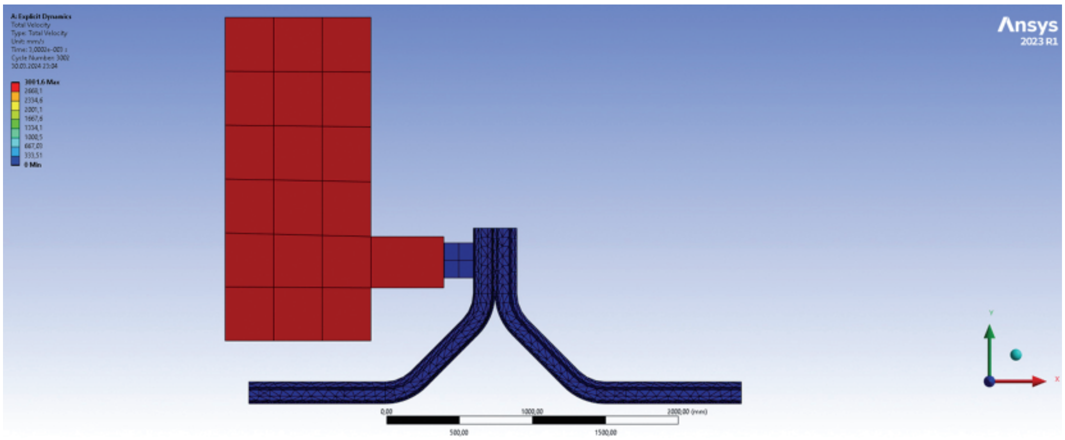

Fig. 16. Velocity distribution (Simulation 2) of individual system elements at time t = 0.003 s; authors' own elaboration

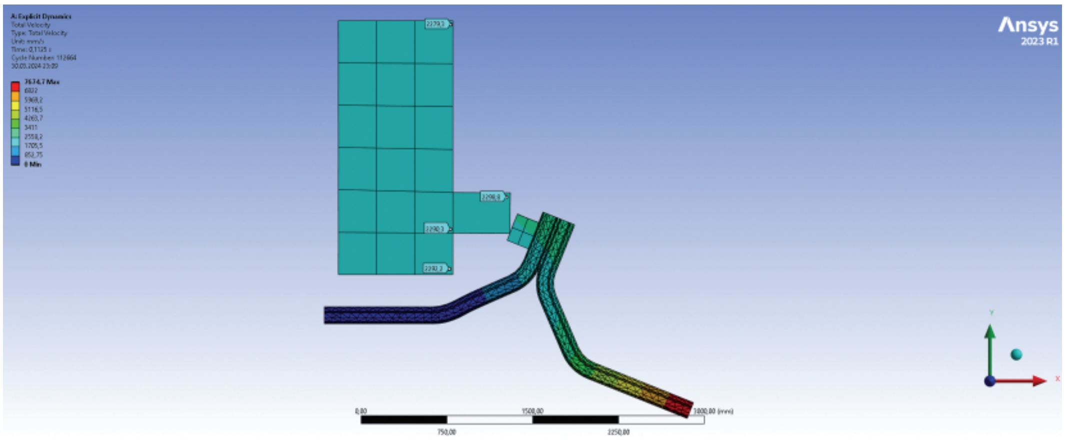

Fig. 17. Velocity distribution (Simulation 2) of individual system elements at time t = 0.1125 s; authors' own elaboration

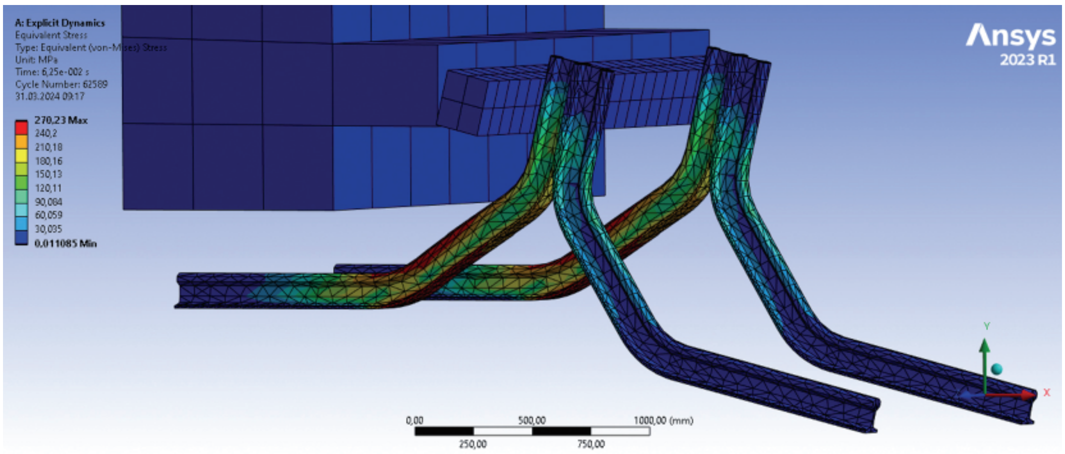

Fig. 18. Stress field distribution in the buffer stop structure (Simulation 2) at time t = 0.062 s; authors' own elaboration

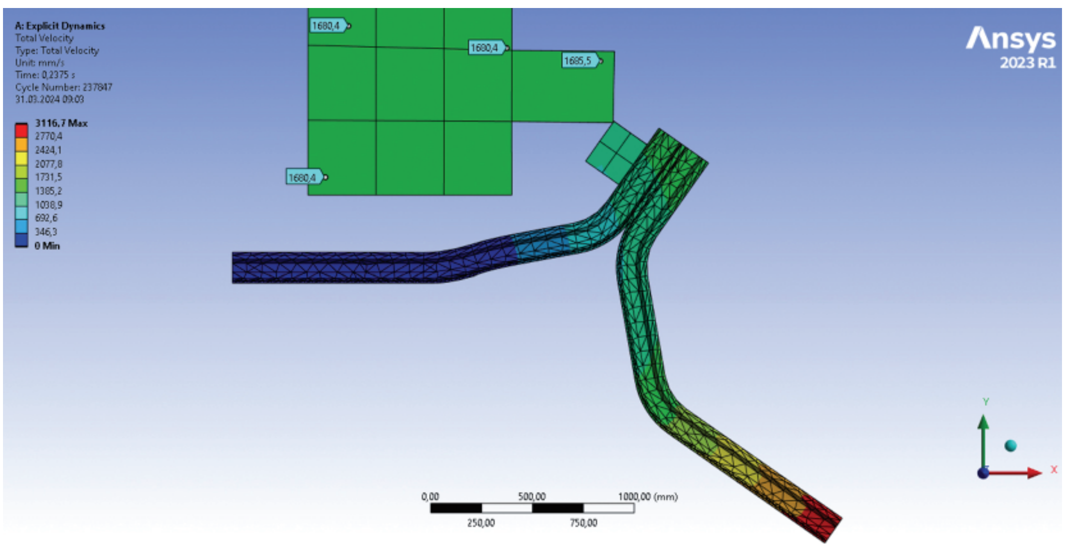

Fig. 19. Velocity distribution of individual system elements (Simulation 2) at time t = 0.2375 s; authors' own elaboration

Fig. 20. Train derailment (12 October 2021) in London at Enfield Town Station – collision with a fixed buffer stop [9]

Fig. 21. Train derailment (12 October 2021) in London at Enfield Town Station; collision with a fixed buffer stop, view from the platform side [9]

context of photographs taken at the scene after the incident. The results of Simulation 3 are presented below.

Simulation 3 – Defined Boundary Conditions

The direct velocity of the vehicle before contact with the buffer stop was 12 km/h, equivalent to approximately 3333 mm/s; Figures 22–28. In the simulation, the colliding vehicle – Class 710 EMU – was modelled as a rigid body. The goal of the simulation was to analyse the performance of the track end device during the collision (in real-world conditions, impact causes deformation of vehicle components, with part of the kinetic energy absorbed by the so-called crumple zone). The simulation was conducted under the most unfavourable condition, meaning that the entire kinetic energy of the vehicle was transferred to the buffer stop structure.

Conclusions for Simulation 3

- t = 0 s – results (Fig. 22) – velocity distribution across individual objects, the track end structure: v = 0 mm/s; the velocity of the colliding rigid body – the EMU 710 vehicle (with a mass of approximately 140 tonnes): v = 3333 mm/s;
- t = 0.0375 s – results (Fig. 23) – contact between the EMU 710 vehicle and the track end device, transfer of kinetic energy, and velocity distribution at individual object nodes. The vehicle's velocity decreased from 3333 mm/s to 2784 mm/s;
- t = 0.0375 s – results (Fig. 24) – displacement distribution at nodes. Calculations show that the track end device deformed by 181 mm at t = 0.0375 s after the collision;
- t = 0.0375 s – results (Fig. 25) – stress field distribution in the buffer stop structure. Parts of the structure experienced stresses exceeding 320 MPa;

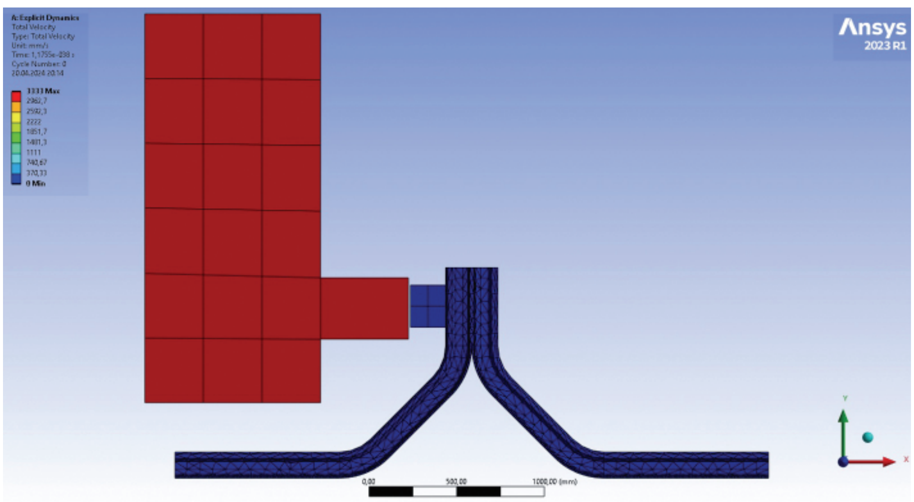

Fig. 22. Train derailment at Enfield Town Station in London (Simulation 3) – event progression at t = 0 s; authors' own elaboration

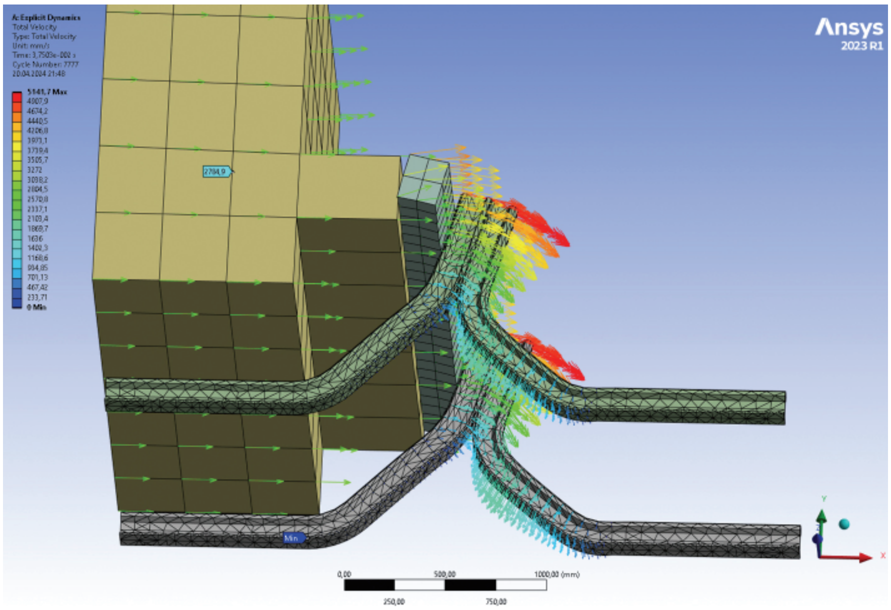

Fig. 23. Train derailment at Enfield Town Station in London (Simulation 3) – event progression at $t = 0.0375$ s, velocity distribution at individual nodes; authors' own elaboration

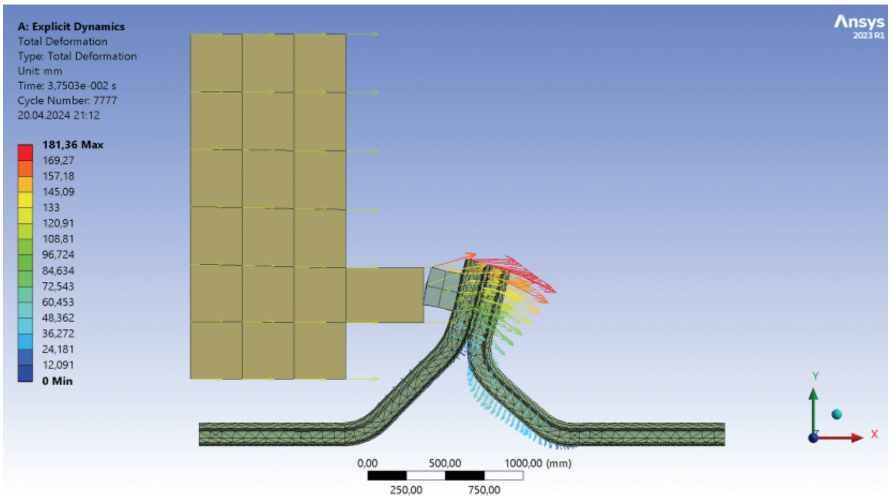

Fig. 24. Train derailment at Enfield Town Station in London (Simulation 3) – event progression at $t = 0.0375$ s, displacement distribution at nodes [mm]; authors' own elaboration

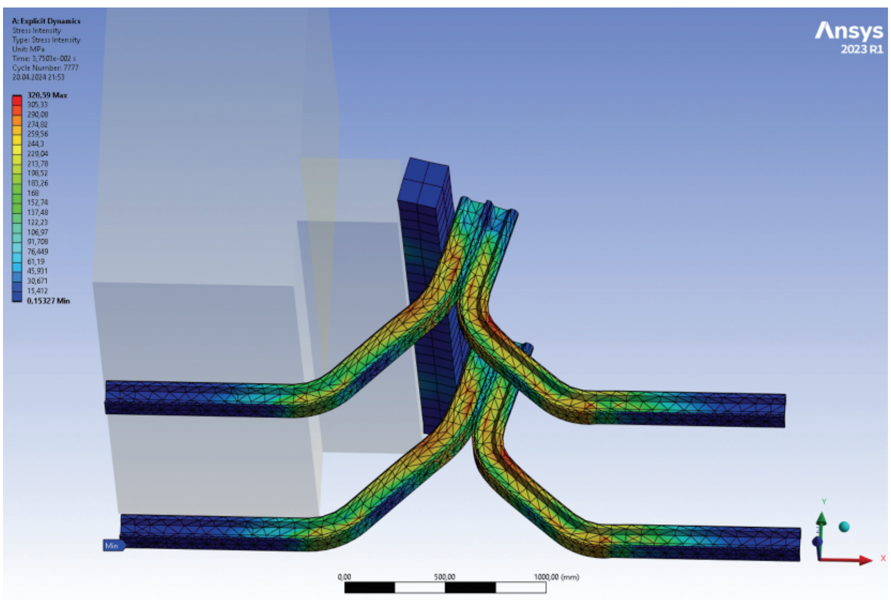

Fig. 25. Train derailment at Enfield Town Station in London (Simulation 3) – event progression at $t = 0.0375$ s, stress field distribution; authors' own elaboration

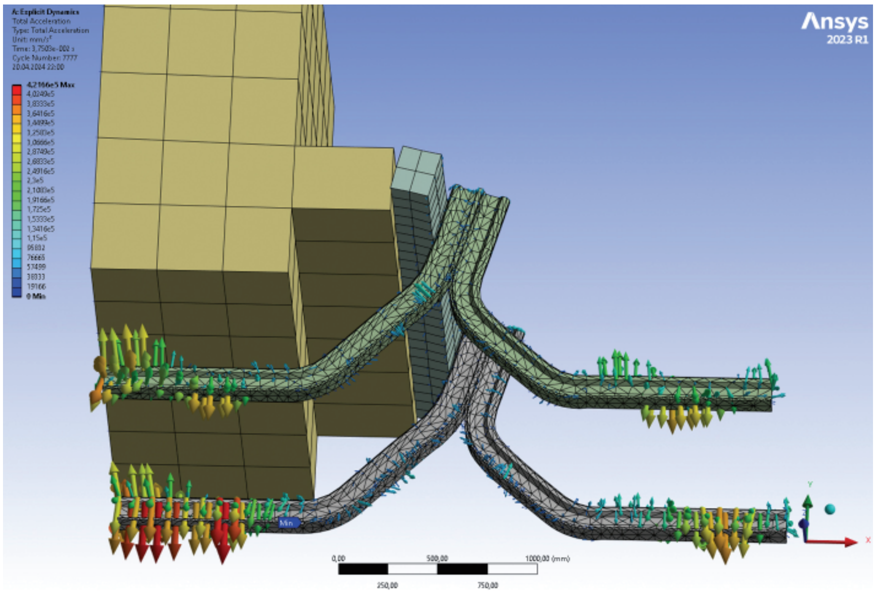

Fig. 26. Train derailment at Enfield Town Station in London (Simulation 3) – event progression at $t = 0.0375$ s, acceleration distribution at nodes; authors' own elaboration

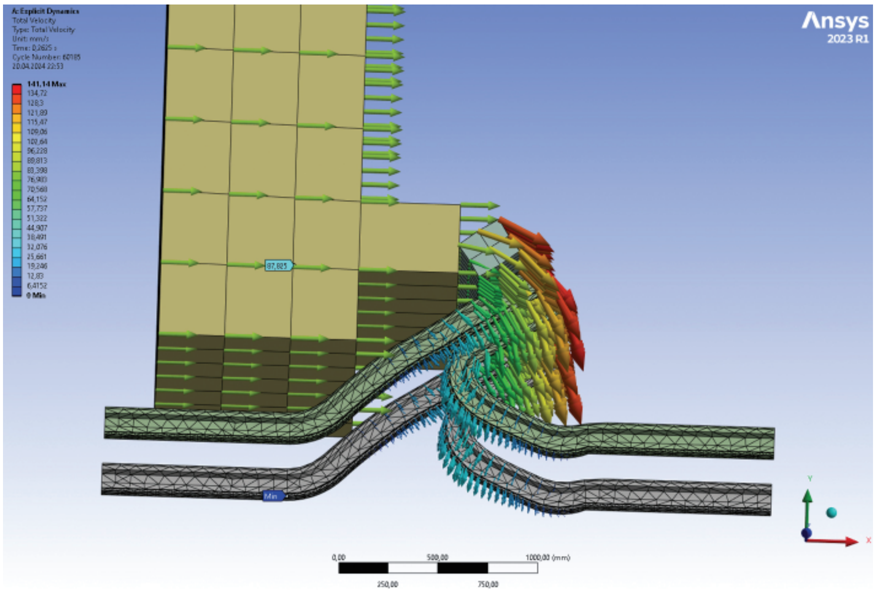

Fig. 27. Train derailment at Enfield Town Station in London (Simulation 3) – event progression at $t = 0.2625$ s, velocity distribution at nodes; authors' own elaboration

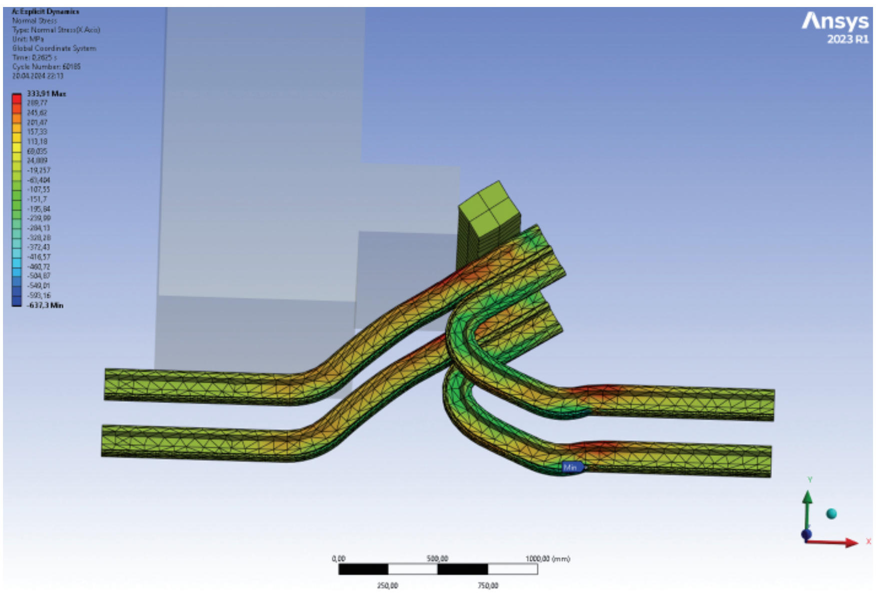

Fig. 28. Train derailment at Enfield Town Station in London (Simulation 3) – event progression at $t = 0.2625$ s, normal stress distribution; authors' own elaboration

- t = 0.0375 s – results (Fig. 26) – acceleration distribution at nodes, compared to photographs taken at Enfield Town Station in London after the incident, explains the cause of damage and the tearing out of sleepers (Figs. 20–21);
- t = 0.2625 s – results (Fig. 27) – acceleration distribution at nodes. The velocity of the EMU 710 vehicle is 87.8 mm/s, which is 0.03% of the initial value. This indicates that the entire event (collision) lasted approximately 0.26 s. Figure 28 illustrates the stress field distribution in the buffer stop structure after the event.

The train derailment at Enfield Town Station, along with the FEM calculations, confirm that rigid buffer stop structures effectively serve their function in protecting the track end. The buffer stop successfully fulfilled its role in securing the track end, limiting the hazard zone and preventing the Class 710 EMU from colliding with the station building.

3. Conclusions

Simulation 1 demonstrated that the fixed buffer stop structure described in the BN-79 9310-06 standard, without defined energy absorption requirements, is a good solution for track end devices. However, in light of the new regulations outlined in Attachment ST-T1-A8 [17], the evaluation of such a structure now depends on specific parameters related to track operation and the rolling stock running on it.

As shown in Simulation 2, the condition of the buffer stop is a crucial aspect. In the case of poorly supported or improperly secured structures (e.g., on old wooden sleepers), the amount of kinetic energy absorbed during a vehicle collision may be lower. Such an event is undesirable, as it could lead to an uncontrolled collision with a larger hazard radius.

Simulation 3 achieved good correlation between the results and the photographs taken after the incident (derailment of an EMU type 710), showing the damage and destruction. The explicit analysis performed in the Ansys software, with defined boundary conditions simulating the event at Enfield Town Station in London, accurately reflects the damage to the track end structure, explains the cause of the sleepers being torn from the track, and the vehicle colliding with the buffer stop.

The conclusions demonstrate how valuable modern FEM computational environments are in analysing incidents and attempting to reconstruct derailments. They can also be used to conduct simulations and analyses to design better and more durable track end devices.

Infrastructural, environmental, and other constraints do not always allow for the use of modern sliding buffer stop structures. Since the operation of sliding buffer stops requires long tracks necessary to absorb the kinetic energy of a colliding vehicle (Fig. 6), fixed (non-sliding) buffer stops will continue to be used in railway infrastructure. This paper confirms that fixed (non-sliding) buffer stops designed and built in the 1980s–1990s still fulfil their role in ensuring track end safety, provided they are properly maintained.

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