1. SAFETY ON TERMINAL TRACKS

Accidents in terminals seriously affect public confidence and following an accident it is vital to provide clear proof that safety measures have been improved in order to regain that confidence.

Human and technical errors occur for a variety of reasons, and unfortunately, such events can lead to an accident. The objective is to find a means of reducing the likelihood of an accident occurring, or in the event of an accident, to reduce its impact. In other words, when all else fails, there has to be a means of stopping the train. Such measures have to be applied without producing any of the following:

- Serious injury to passengers and drivers.
- Serious injury to passengers or the general public in the arrival area of the train suffering from deficient braking.
- Excessive damage to the locomotive and rolling stock.
- Excessive damage to the station infrastructure and services, as well as to the arrival track.

This document offers a summary of the projects carried out by the authors for Renfe and TIFSA (Tecnología e Investigación Ferroviaria, S.A.), aimed at developing a standard buffer stop pre-design capable of stopping a train on terminal tracks with complete safety and without causing damage, thereby preventing a catastrophe and the costs for the damage caused, as well as the expense and time involved in repairing equipment.
2. AIMS AND OBJECTIVES OF THE BUFFER STOP DESIGN

A buffer stop is essentially a safety measure. As a result, the main objectives will be based on this feature. However, various considerations are also included which, although of lesser importance, do constitute additional requirements which may improve the functional design of a buffer stop.

2.1. MAIN OBJECTIVES

The objectives below must obviously be met, provided that the conditions of impact fall within the design parameters of the buffer stop in question, basically determined by the maximum train speed on impact and its tonnage.

2.1.1. TRANSPORT SAFETY

- **Passenger safety**: the fact that a buffer stop brings a passenger to a halt should not compromise passenger safety, and should minimise contusions and other types of injury as far as possible

- **Freight safety**: A maximum risk level must be established for the potential stopping of a freight train or a section of carriages by a buffer stop.

- **Safety of those people located around the buffer stop area.** These may be people awaiting the arrival of the train or railway staff working in the station. The buffer stop should be designed in such a way as to minimise the risk of flying parts during the stopping of a train, as well as to guarantee that the train comes to a halt within the braking distance established to this effect, thereby preventing the train from running over anything should it overrun the said distance.

2.1.2. TRANSPORT SYSTEM SAFETY

- **Minimum damage to the rolling stock**: in the event of impact of a train on a buffer stop, damage should only occur to the buffer stops themselves or to the shock absorbers attached to them.

- **Minimum damage to the fixed material.** The halting of a train by a buffer stop should not imply serious damage either to the buffer stop itself (which should continue to be in working order following the incident), or the to the track, adjacent platforms or station structure.
2.2. ADDITIONAL OBJECTIVES

- **Easy installation.** The design of a buffer stop should be such that it does not require complicated mechanical equipment or work. Work on installing the buffer stops should be completed in the shortest time possible, thereby having only a minimum effect on normal platform and terminal station activity.

- **Easy to put back into service following an impact.** The buffer stop design should enable it to remain operational following an impact, by non-specialised staff and without the need for complex mechanisms or tools.

- **High degree of reliability.** The buffer stop must be capable of carrying out its functions regardless of weather conditions, amount of surrounding dirt, etc.

- **Minimum maintenance.** A buffer stop should not require special attention from station maintenance staff. Furthermore, non-specialised staff should be able to carry out the necessary maintenance.

- **No need for extra-long platforms.** The real buffer stop braking distance should be determined by the maximum conditions born by the passenger (basically deceleration) and the material (fundamentally force), and the available platform space at the track head.

- **Purchase cost and reasonable maintenance.** The buffer stop design should contemplate the use of materials that are not excessively costly or hard to obtain. Likewise, maintenance should not require special tools, material or specialised staff that would contribute to raising maintenance costs.

3. RIGID BUFFER STOPS

Rigid buffer stops were the first mechanisms to be used on the railways. They come in a number of designs, which basically consist of a frame or block (the buffer stop) fixed rigidly to the rails or the ground. Although its design features are far from ideal, this type of design has continued to be used until the present day, to the extent that on a number of railways, it is practically the only kind of buffer stop in use. This is the most widely used type of buffer stop on Renfe’s railway network.

3.1. PROBLEMS ASSOCIATED WITH RIGID CONCRETE BUFFER STOPS

Figure 1 shows the elevation of a rigid reinforced concrete buffer stop. The lower section of the buffer stop base is more than one metre from the upper edge of the rail (in the Renfe
design it is exactly 1150 mm away). This base practically doubles the visible length of what is known as the buffer stop. Part of this base is introduced under the rails of the track like a corbel. This corbel guarantees its stability and provides protection against overturning with less weight, as, during a theoretical impact, the weight of the first train vehicle involved is used.

Figure 1.

The train impact, together with the resulting discharge of concrete and destruction of the buffer stop, generally makes this kind of buffer stop non-operational (Figure 2).

Figure 2.
Although it is true that the breakage of the buffer stop absorbs the train’s kinetic energy, this breakage can hardly be considered acceptable, as the buffer stop is seriously damaged and is no longer usable.

It could be claimed that the efficiency of the buffer stop could be improved by reinforcing the rigid concrete buffer stop in certain strategic places, using materials capable of resisting previously calculated tension levels. However, we must remember that, due to the commonly known principle of action and reaction, the acting on the buffer stop has the reverse effect on the impacting train. It may also occur that, as shown in figure 3, the train is unable to resist the force of the impact.

![Figure 3.]

Finally, even if the rigid concrete buffer stops and the vehicle frame are reinforced, the resulting decelerations are clearly unacceptable. Without the need to refer to more complex studies, bringing a vehicle in motion to a halt 5 km/h. in 12 mm. implies an average deceleration of 80 m/s² (8.2 g).
In conclusion, concrete buffer stops cannot be considered an acceptable solution to the problem of bringing trains suffering from deficient braking to a halt.

Improvements have been made to this design over the last few years. The use of viscous elastic materials in buffer stops (air/oil, silicon, etc.) allows for a certain degree of buffer stop distortion, which can prove an efficient solution for certain levels of kinetic energy. It is possible to use several sets of viscous-elastic elements on a single buffer stop, thereby enabling us to bring the train involved to a halt (Figure 4). However, when large amounts of kinetic energy are involved (large tonnage and considerable impact speed), these short braking distance buffer stops are insufficient, due to their inability to dissipate the train’s energy by means of viscous friction or the resulting decelerations.

![Figure 4.](image)

**4. FRICTION BUFFER STOPS**

As has already been mentioned in the first section of this text, the idea is to come up with a buffer stop design which, in the event of impact by a train, is capable of stopping the train using reduced decelerations which prevent injury to passengers and does provoke vehicle solicitations in excess of those for which they have been designed. One of the technological answers available today for this dual requirement is the friction buffer stop. However, it is important to point out that other technical solutions were also analysed in the study carried out for Renfe, which are not included in this document for reasons of space.
When a vehicle suffering from deficient braking for any reason whatsoever is heading towards the track terminal, it is vital to transform its residual kinetic energy (produced by the movement of the train mass at the track end approach speed), by means of an appropriate buffer stop design. In the case of friction buffer stops, this kinetic energy is transformed into heat resulting from the friction of a series of elements which mover together with the buffer stop frame.

The stopping capacity is always determined according to the maximum train weight in use on the terminal track and the maximum speed at which the system failure may occur. In practice, it is impossible to determine the exact train weight and speed at the moment of impact. The standard calculation is based on a maximum speed for a passenger train under such conditions ranging between 10 and 15 km/h. more specifically, DB uses a speed calculated at 10 km/h. for terminal tracks. Renfe proposes the load and speed combinations shown in table 1.

![Table 1.](image)

### 4.1. BRAKING SYSTEMS FOR FRICTION BUFFER STOPS

#### 4.1.1. BUFFER STOP FRICTION JAWS

One of the most commonly used systems in this type of buffer stop are gripping jaws which, attached to the buffer stop frame, hold the rail head by means of screws (Figure 5). Theses jaws are the elements which, when the convoy hits the buffer stops and the resulting movement is produced, transform the train’s kinetic energy into heat by means of friction. The degree of resistance to the movement of the buffer stop may be pre-determined with considerable accuracy knowing the number and load on each screw, i.e.:

\[
F_{FMD} = \mu \cdot Q_t
\]

Where \( Q_t \) represents the total hold load exerted by the screws.
The friction factor ($\mu$) of the elements held by the gripping jaws at the rail head can be considerably improved by means of a special part inserted between the rail head and the gripping jaw and acting upon the former. This piece is made from a bronze and phosphorous alloy.

Generally speaking, the load acting upon the gripping jaw generally remains constant throughout the whole of the braking action thanks to the use of a double screw elastic washer, with a load of 3 000 daN, used on each of the screws. In an average situation, a tightening load of 14 daN·m on each screw provides a braking force of approximately 1 000 daN for each screw of the braking element, which can be taken as constant during the first 5 metres of braking.

For distances in excess of 5 m, the braking force drops, due to the wear on the braking elements. Between 5 and 8 m, the braking force drops to approximately 900 daN, whilst for distances between 8 and 12 m, it falls to 800 daN. It is not advisable to consider distances over 12 m, as this produces excessive wear on the braking elements and consequently produces a weaker braking force.
The stopping capacity of light friction buffer stops with a braking force of up to 40 000 daN is determined by the braking distance. For instance, for a 5 m braking distance, the following applies: $40\,000 \times 5 \times 10 = 2\,000$ kJ.

4.1.2. ADDITIONAL FRICTION JAWS BEHIND THE BUFFER STOP

In order to increase stopping capacity, it is necessary to reinforce the buffer stop sections and add braking elements behind the buffer stop. For standard equipment, it is possible to add from 2 to up to 8 pairs of elements of 8 000 daN. In order to obtain a steady and gradual increase in braking force, these elements are spaced out behind the buffer stop (Figure 6).

![Figure 6.](image)

With eight pairs of braking elements, the braking distance should be at least 9 m, although each element should be effective with a maximum distance of 1 m. A buffer stop using the maximum number of additional retarding elements has an energy absorbing capacity of 6 125 kJ over a braking distance of 9 m. This corresponds approximately to the impact of a 1000 t train travelling at 10 km/h. using a safety factor of 1.5.
It is important to point out that those friction buffer stops with more than 6 braking elements require track reinforcement. This measure is in any case particularly recommendable, as the force exerted on the rails by the buffer stop normally causes them to become distorted.

### 4.1.3. SLEEPERS PRIOR TO THE BUFFER STOP AND BRAKING SLEEPERS

A different buffer stop design has been used up till now in order to bring such trains to a halt. Apart from the buffer stop retarding elements, this construction also has a set of wooden sleepers which are connected to form a smooth area in front of and under the buffer stop (Figure 7). These sleepers are laid out between the concrete base and the running track. On impact, the whole set of sleepers is dragged along the concrete base by the buffer stop. Empirical trials have shown that the friction factor between the wood and concrete is 0.6, even if the concrete base is slippery.

![Figure 7](image)

In order to obtain an even greater braking force, a number of braking sleepers can be connected to the buffer stop. Each sleeper is connected by expandable links (see figure 5). This system allows for a gradual increase in the stopping effort, due to the fact that a new sleeper comes into action due to the expandable links.
The braking force is proportional to the weight of the first vehicle to reach the set of sleepers. As a result, a heavy locomotive will experience a greater stopping force than a light passenger carriage, which therefore enables the buffer stop to adapt to the kinetic energy of the train impacting upon it. It is true that it is impossible to guarantee that the first vehicle will always be the locomotive, as impacts often occur where the first vehicles are carriages incorporating the drivers’ cabin. In order to provide sufficient stopping force under these circumstances, additional reinforced retarding elements are usually added behind the buffer stop, using 10 screws instead of 8, thereby increasing the braking force from 8 000 to 10 000 daN.

In conclusion, the use of buffer stops which combine the retarding elements inside and behind the buffer stop and sleepers in front, makes it possible for up to 20 000 kJ of kinetic energy to be absorbed, (the approximate equivalent of the impact of a 1500 t train travelling at almost 20 km/h), as long as there is sufficient stopping space.

5. MODELISATION OF THE BRAKING PHENOMENON BY MEANS OF FRICTION BUFFER STOPS.

In order to be able to study the influence of certain factors on the stopping process of a train using a friction buffer stop, a simple mathematical model has been developed. A series of prior simplifications have been used in order to obtain the equations governing this model, which are described in the following section.

5.1. PRIOR SIMPLIFICATIONS

The train is considered as a single rigid solid element, and not as a set of solids linked elastically. This hypothesis is acceptable if we take into account the fact that when a convoy reaches the buffer stop it is braking. It therefore appears logical to assume that the vehicle buffers are compressed, and so we can practically assume that once they have covered the distance available, they will act as rigid elements.

The buffer features of both the impacting vehicle and any possible buffer stops are replaced by a single equivalent buffer. This buffer responds to a classic Kelvin-Voigt model. It is possible to simulate the behaviour of any normal combination of buffers by means of this mechanical system. However, the model will also accept the introduction of other types of equivalent mechanical models.

An initial approximation does not contemplate the possibility of any collapse zones in the impacting bodies (buffer stop and train). This is an erroneous simplification, as it fails to contemplate the absorption effect of the kinetic energy of the train which is transformed into energy which distorts part of the buffer stop structure or the locomotive. Nevertheless, we must remember that one of the objectives was to avoid damage to both vehicles and the buffer
stops themselves which would prevent them from continuing to be used. Consequently, this hypothesis is considered to be coherent with the desired objectives. As mechanisms which transform the train’s kinetic energy, only friction buffer stops, the elastic energy stored in the springs and the braking system of the train itself have been taken into consideration. Furthermore, only the inertia of the train and the buffer stop frame will be considered, and the mass of the braking elements behind the buffer stop compared with the solid elements will be ignored.

5.2. THE MATHEMATICAL MODEL

Using the simplifications described above, a mathematical model was developed enabling us to study the phenomenon. Figure 8 represents the initial stage of the study, defined as the moment when the train buffer touches the buffer stop buffer, but prior to any force being transmitted. At that moment, the reference axes are defined that will allow the train and buffer stop movement to be referred to them.

![Figure 8](image)

Considering the set of forces acting upon the train, the following immediate deduction is made:

\[
m_t \frac{d^2 x_t}{dt^2} = m_t \frac{d^2 x_B}{dt^2} + K [(x_{BS} - x_t) - \text{REF}] + C \left( \frac{dx_{BS}}{dt} - \frac{dx_t}{dt} \right)
\]
On the other hand, if the forces acting upon the buffer stop are taken into consideration, the following equation is obtained:

\[
m_{\text{BS}} \frac{d^2 x_{\text{BS}}}{dt^2} = -K \left[ (x_{\text{BS}} - x_t) - REF \right] - C \left( \frac{dx_{\text{BS}}}{dt} - \frac{dx_t}{dt} \right) - \sum F_i
\]

Force \( F_i \) corresponds to the \( i \) braking elements located in and behind the buffer stop. It will depend on how many have entered into action, which in turn depends on the degree of buffer stop frame displacement, their pressure on the railhead and the variation curve of the friction coefficient.

Therefore, the integration of the second system of differential equations, made up of the above equations, provide us with the train position and speed for each \( t \) instant. This system has been numerically resolved using the 4\(^{th}\) Runge-Kutta method.

6. RESULTS

Using the model described in the above paragraph, a computer program was developed to simulate, by means of the above simplifying hypotheses, the impact of a train on a friction buffer stop with braking elements. The aim of this program is not to validate a buffer stop design, but to simulate situation, detect irregular situations and in short, to establish criteria which would prove extremely costly if they had to be obtained from track trials.

6.1. BUFFER INFLUENCE ON THE BUFFER STOP

At first sight, it would appear that the critical factor of a buffer stop depends on the braking elements present in the buffer stop. Indeed, the braking distance, for a certain uncontrolled kinetic energy, depends basically on the friction work generated by these elements, as in comparison the energy dissipation of the buffers is insignificant. Moreover, the amount of kinetic energy of the train is so great that the existence of a buffer to cushion the decelerations is of little or no consequence.

However, the results obtained from the developed model indicate that during the buffer stop design process, care must be taken over the choice of buffer or deformable element to be fitted in the buffer stop. Indeed, let us suppose that we have a buffer stop fitted with 3 pairs of braking elements, and a further 6 pairs of braking elements situated behind it, impacted by a
600 t train travelling at 10 km/h, without brakes. The following figures show the results obtained by varying the rigidity of the buffer located in the buffer stop ($K_1$) and the element located in the vehicle ($K_2$):

The decelerations acting on the train can be compared in figure 9, where we can observe how the second combination provides greater train deceleration peaks.
The following conclusions may be drawn from all of the above:

- Generally speaking, it is recommendable to fit a buffer or elastic element between the train and the buffer stop, as, if the correct choice is made, this allows for deceleration peaks.

- If the buffer is only slightly rigid (as in the case of the carriage buffer), it will immediately cover the distance, and will therefore be lacking in efficiency.

- If the buffer is extremely rigid, then it will tend to behave accordingly, thereby increasing the decelerations.

Consequently, it is necessary to carry out a study into the rigidity of the buffer or elastic element to be fitted into the buffer stop for each type of buffer stop and train.
6.2. THE EFFECT OF FITTING BRAKING ELEMENTS TO THE BUFFER STOP ON ACCELERATION PEAKS.

At first sight, it would seem that adopting a design incorporating buffer stop braking elements such as those in figure 10 would reduce the first deceleration peak (at the moment of impact), as each of the braking elements would enter into action gradually, thereby producing a more progressive deceleration.

![Figure 10](image)

In order to prove this, a simulation was set up for the impact of a 600 Tm train travelling in an uncontrolled manner at 10 km/h. on various types of friction buffer stops, with the braking elements acting in stages and all together. The conclusions obtained are listed below:

- The gradual activation of the buffer stop braking elements generally serves to reduce the first deceleration peak.

- Therefore, the less rigid the impact contact (equivalent buffer), the more effective the reduction will be in terms of percentage. This means that a correct choice of buffer stop buffers is more efficient than this special assembly of the buffer stop braking elements.

- Should the equivalent buffer prove highly rigid, not only would there be a minimal reduction in the first deceleration peak, but also those corresponding to the second and successive peaks would become sharper, until the speed of the train had dropped considerably. This has a simple explanation: if a peak occurs with the activation of a single pair of braking elements, then another will occur when the second pair are activated, due to the fact that their proximity means that hardly any of the energy from the first peak will have dissipated. As a result, the impact with the second pair of elements is practically a repetition of what occurred with the first pair.
6.3. ANALYSIS OF THE IMPACT OF A LIGHT TRAIN ON A BUFFER STOP DESIGNED FOR HEAVY TRAINS.

This question must be raised as, although many terminal stations do have special tracks, operating conditions may require a commuter train to pull in on a track destined for heavy trains. Should this train fail to brake correctly, then an impact would be produced on a buffer stop adapted to receive the impact loads from heavier trains. It would be logical to think that it would be brought to a halt faster (travelling at the same arrival speed). Yet the question remains, how would the decelerations vary?

In order to provide an answer, we have simulated the arrival of two trains: 1 120 t train, and another 600 t one, travelling in an uncontrolled manner. Impact speed is 10 km/h.

The buffer stop has 3 pairs of braking elements, creating a pressure on the rail of 45 000 daN. 4 pairs of braking elements have been fitted behind the buffer stop frame, at a distance of 2, 3, 3.5 y 4 m. respectively from the system. Each element is 30 cm long and exerts the same pressure on the rail as those fitted in the buffer stop.

The results obtained were as follow:

- The distance required to bring the 1 120 t train to a halt is 4.9 m. The initial deceleration peak is –0.9 m/s² and the absolute maximum –1.33 m/s² (produced when the train has travelled 2.37 m).
- As far as the 600 t train is concerned, the stopping distance is 3.1 m. An initial deceleration peak occurs of –1.68 m/s², whilst the absolute maximum is -2.31 m/s² (produced when the train has travelled 2.43 m.).

6.4. INFLUENCE OF DEFICIENT BRAKING ON THE PHENOMENON OF A TRAIN BEING BROUGHT TO HALT BY A BUFFER STOP.

It seems fairly likely that the majority of impacts on buffer stops are due to deficient train braking. We can include a whole range of situations under this heading, including a failure in the train’s braking system which only allows the locomotive to brake, or an error of judgement by the driver regarding the stopping distance. In any case, the train will reach the buffer stop with a greater of lesser degree of braking capacity. It is unlikely that it would arrive in an uncontrolled manner, with the brakes failing to work.

The following questions therefore arise: Should the conditions corresponding to the braking of the train be taken into consideration? To what extent does it affect the peak and average decelerations?
In order to answer these questions, a simulation has been carried out for the impact of the same 120 Tm. train travelling at 10 km/h., but with its brakes activated, on the same buffer stop as in the previous section. The decelerations obtained with standard braking for a 118 t locomotive stand at around 0.9 m/s$^2$ with service braking and 1.12 m/s$^2$ with emergency braking, at speeds of less than 50 km/h. In this case, we have used just 0.2 m/s$^2$ for the whole train.

Using these data, the stopping distance has dropped from 4.9 m to just over 4 m. The absolute maximum deceleration peak in this case was $-1.39$ m/s$^2$ (when the train had travelled 2.3 m.), only slightly higher than the $-1.33$ m/s$^2$ obtained in the previous case (2. 37 m. from the stopping distance).

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