

Tramway front end design



Subject:

In accordance with the provisions laid down in decree No. 714 of 31st July 2001 relating to the creation of STRMTG, STRMTG produces technical guides and reference bases in liaison with its professional partners.

This document discusses the design of rolling stock front ends in relation to collisions with third parties and between train sets in the context of tramway and tram-train systems operating in urban environments.

This guide is applicable to tramway and tram-train rolling stock which operates in an urban environment as covered by chapters II, III and VI of amended decree No. 2003-425 of 9th May 2003, relative to the guided public transport safety.

Drafting and circulation:

The national "*Front end aggressiveness*" working group chaired by STRMTG drafted this guide. The list of participants in this working group appears in appendix 1.

This guide is intended for all professional actors in the tramway and tram-train sector (guided urban rolling stock manufacturers, AOT, operators, project managers, design offices, OQA).

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1. Introduction

Traditionally, the distinction is made between "active" safety, which involves designing a transport system to avoid accidents and "passive" safety, which seeks to reduce the severity of the consequences of an accident.

While "active" safety remains the approach to be favoured when designing a transport system, "passive" safety is often taken into account much less.

When designing rolling stock, it is possible to reduce the severity of the consequences of a collision with a tramway via the design of front ends for the following scenarios:

- Collision with a pedestrian (reduction in physical damage)
- Collision with a road vehicle (reduction in the risk of derailment and reduction in personal injury)
- Collision with a tramway (reduction in personal injury)

2. Subject and limits of the guide

2.1. Subject

This technical guide constitutes a reference base for clients, project managers and urban guided rolling stock manufacturers.

The urban environment in which the tramways and tram-trains operate has significant interaction with road users. In the absence of a reference base for the design of urban guided rolling stock front ends in relation to the damage caused to third parties, it appeared important to define which front end design elements may enable reduction in the severity of a collision between a tramway and a third party or another train set.

This guide has been drafted in the context of a working group in which participate, in particular, tramway and tram-train manufacturers (see appendix I List of working group members).

2.2. Limits

This guide discusses front end design in relation to collisions with third parties and between tramways (or tram-trains).

Only the severity reduction measures covered by the rolling stock design are studied in this document.

This guide provides design rules based on the most common accidents and the associated risks. Therefore, the requirements do not cover all the possible accident scenarios but will enable the consequences of an accident to be reduced, when the active safety provisions prove to be insufficient. The requirement is to provide a protection level appropriate to the probable collision risks that cause serious and fatal injuries.

The third parties are represented in this guide by the most vulnerable users in the category:

- Soft mode user category (cyclists, roller-skaters, etc.) represented by pedestrians;
- Road vehicle user category (trucks, utility vehicles, etc.) represented by light vehicle users.

It is considered that the measures to reduce the severity of injuries to these users will benefit all user categories.

The recommendations defined in this guide constitute the minimum acceptable without justification. However, other solutions may be proposed if the equivalence of the safety requirements can be justified.

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2.3. Scope of the guide

The requirements defined in this guide apply to all new rolling stock running on tramway, rail or tyres, as well as to tram-trains when they are required to operate in an urban environment in the same way as a tramway.

Rolling stocks on tyres which have received road accreditation are excluded from this guide.

"New rolling stock" means any rolling stock acquisition project which has not yet been approved at the DPS (Safety Preliminary Case) stage when this guide is published. For projects which have not yet been commissioned and which have already been approved at the DPS (Safety Preliminary Case) stage, the requirements in this guide will be taken into account where possible.

The following projects (renewal of design) will be dealt with on a case by case basis based on an analysis of deviations from the guide:

- Contracts which refer to a framework agreement signed before the guide was published,
- Definition of the conditional ranges of a contract signed before the guide was published,
- Train set acquisition contract for fleet reinforcement identical to the existing train sets.

The term "tramways" will be used throughout this document for all types of guided rolling stock operating in urban environments (including tram-trains in particular), except where stated to the contrary.

3. Collision with a pedestrian

3.1. Feared event

Following feedback analysis, the feared event is a tramway colliding with a pedestrian.

The pedestrian is hit side-on (pedestrian crossing the platform).

Two categories of pedestrian are identified:

- A 6-year-old child, 1.10 m tall¹
- A medium-sized adult, i.e. 1.75 m tall²

The **impact surface** is defined as the front surface of the tram up to a height of 1.75 m from the ground (the average height of an adult) and the width between the main pillars at 1.75 m from the ground (running surface). It is shown in red in the following illustration.

When the width between pillars at the bottom of the windscreen is less than the width at 1.75 m high (pillars that flare towards the top), the side limits for the impact surface are such that the width of the surface is equal to the width between the pillars at 1.75 m, minus 10 cm on each side.

1 Source: DINBelg 2005, P5, research project for anthropometric data on the Belgian population

2 Source: NF EN 894-4, Machine safety - Ergonomic requirements for design of displays and control actuators - Part 4: Location and arrangement of displays and control

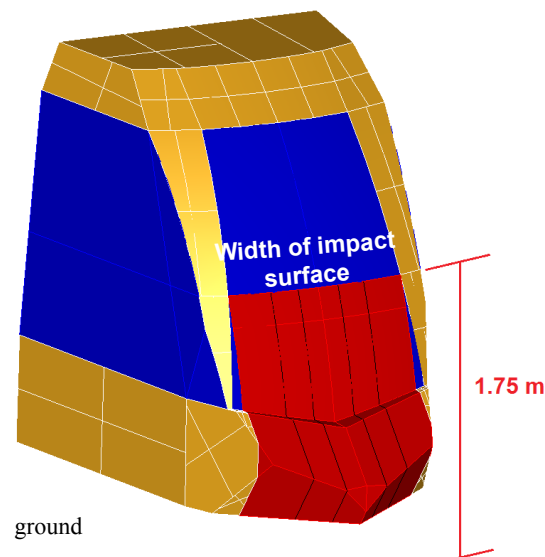


Illustration 1: Impact Surface

The tramway is considered as running at 20 km/h, the speed at which it is not acceptable to kill a pedestrian and where it is possible to limit the severity of the pedestrian's injuries by working on only the front end geometry. The criterion used to consider the injuries as fatal is the HIC³. This must not exceed the value of 1000.

3.2. Severity reduction measures: geometric criteria

3.2.1. Geometric parameter definition

All of the following parameters must be measured at all points on the impact surface.

The following geometric parameters are taken into account:

³ Head Injury Criterion, calculated from the resulting linear acceleration measured at the centre of gravity of the head. The contact head on rigid surface during less than 15 ms, the HIC is calculated over one duration of 15 ms.

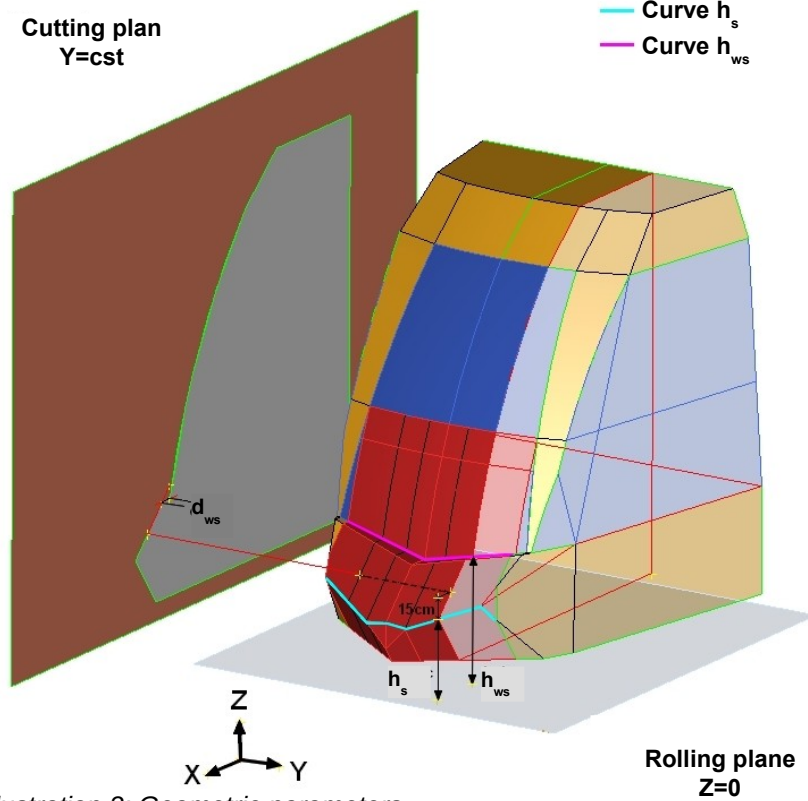
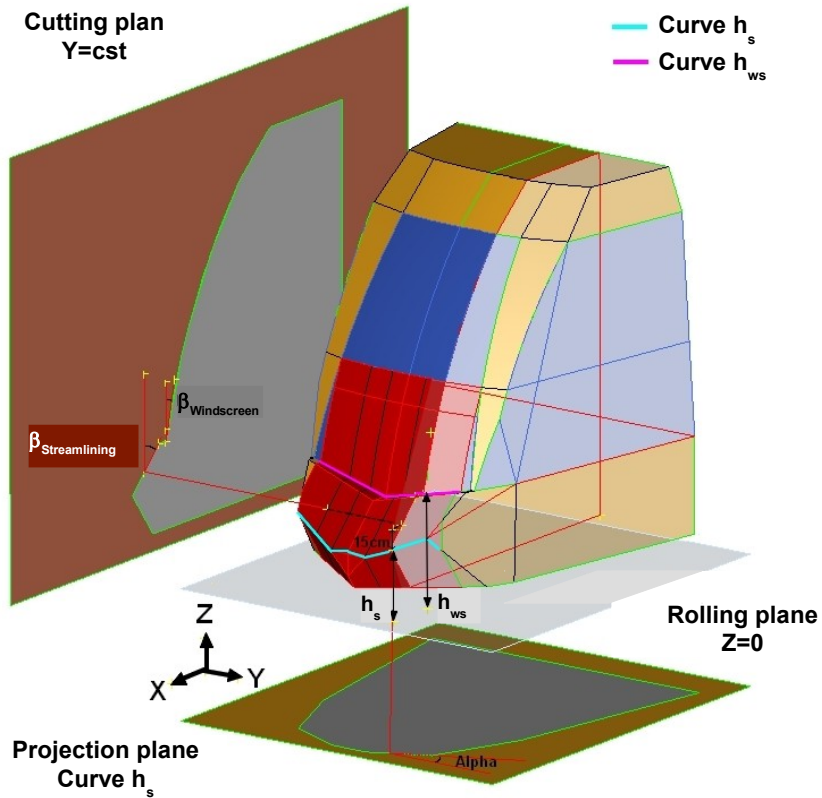


Illustration 2: Geometric parameters

Parameter	Definition
h_s	<p>It is recommended to stand on the intersection curve between the impact surface and a plane $Y = \text{constant}$ (cst.).</p> <p>h_s is the Z coordinate of the maximum X abscissa point on the previously defined curve.</p> <p><i>Note: An intersection curve with a vertical slope at the maximum abscissa point gives several values of h_s.</i></p>
h_{ws}	<p>It is recommended to stand on the intersection curve between the impact surface and a plane $Y = \text{cst}$.</p> <p>h_{ws} is the Z coordinate of the bottom of the windscreen.</p>
α	<p>It is recommended to project all the h_s in a plane $Z=\text{cst}$.</p> <p>The two-dimensional curve obtained represents the envelope of the impact surface in the xOy plane.</p> <p>At $Y=\text{cst}$, α is the angle between the Oy axis and the tangent at the previous two-dimensional curve. The angle will be turned α in a trigonometric direction.</p>
$\beta_{\text{streamlining}}$	<p>It is recommended to stand on the intersection curve between the impact surface and a plane $Y = \text{cst}$.</p> <p>$\beta_{\text{streamlining}}$ is the angle between the Oz axis and the tangent to the previous two-dimensional curve in $Z = h_s + 15\text{cm}$. The $\beta_{\text{streamlining}}$ angle will be turned in a clockwise direction.</p> <p><i>Note: increasing h_s by 15 cm makes it possible to take the fabrication constraints into account .</i></p> <p><i>Note: For an intersection curve with a vertical slope at the maximum abscissa point resulting in several values of h_s, $\beta_{\text{streamlining}}$ is the angle between the Oz axis and the tangent to the previous two-dimensional curve in $Z = \min(h_s)+15\text{cm}$</i></p>
d_{ws}	<p>It is recommended to stand on the intersection curve between the impact surface and a plane $Y = \text{cst}$.</p> <p>d_{ws} is the distance, in the plane $Z = h_{ws}$, between:</p> <ul style="list-style-type: none"> - The point of intersection of the tangent at the curve in $Z=h_s+15\text{cm}$ and the straight line $Z=h_{ws}$ <p>And</p> <ul style="list-style-type: none"> - The point on the impact surface in the windscreen zone at $Z=h_{ws}$. <p><i>Note: increasing h_s by 15 cm makes it possible to take the fabrication constraints into account.</i></p> <p><i>Note: For an intersection curve with a vertical slope at the maximum abscissa point resulting in several values of h_s, the first point is defined by taking the tangent to the curve in $Z = \max(h_s)+15\text{cm}$</i></p>
$\beta_{\text{Windscreen}}$	<p>It is recommended to stand on the intersection curve between the impact surface and a plane $Y = \text{cst}$.</p> <p>$\beta_{\text{Windscreen}}$ is the angle between the Oz axis and the tangent at the windscreen. The $\beta_{\text{Windscreen}}$ angle will be turned in a clockwise direction.</p>

Each position of pedestrian is associated an impact surface to be assimilated at the following two plane surfaces :

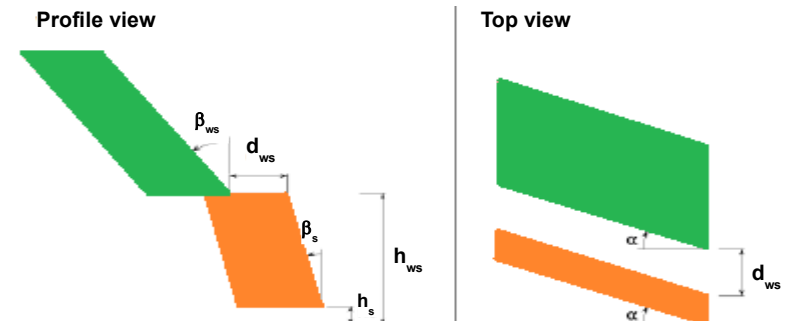


Illustration 3: Impact surface modelling

The streamlining and the windscreen are each represented by a plane characterized by the parameters defined above. It should be noted that the α angle is applied to the two planes although it only exists at the height h_s .

3.2.2. Definition of specific points

Although the criteria mentioned below make it possible to ensure, at all points of the potential impact surface, that the front end geometry that was defined minimizes the risk of fatal head injury, i.e. $HIC_{15} < 1,000$, the table below identifies the specific points at which the geometric parameters should be calculated. These values shall be transmitted to STRMTG.

In order to ensure compliance with the criteria, the values of the geometric parameters at the specific points shall be measured. In case of a symmetrical tram according to the xOz plane, the values of the following table could be measured for a half-tram alone.

Please remember that the width of the impact surface is equal to the width between the main pillars at 1.75 m from the ground. When the width between pillars at the bottom of the windscreen is less than the width at 1.75 m high (pillars that flare towards the top), the side ends of the impact surface are then at 10 cm less on each side than the side ends defined in general.

Geometric parameters to calculate in:		Lines			
		h_s	$h_s + 15 \text{ cm}$	h_{ws}	$Z=1,75 \text{ m}$
Y section planes :	at 15 cm from the centre	α	$\beta_{\text{streamline}}$	$h_{ws} / d_{ws} / \beta_{\text{Windscreen}}$	$\beta_{\text{Windscreen}}$
	at 30 cm from the end of the impact surface	α	$\beta_{\text{streamline}}$	$h_{ws} / d_{ws} / \beta_{\text{Windscreen}}$	$\beta_{\text{Windscreen}}$
	End of the impact surface	α	$\beta_{\text{streamline}}$	$h_{ws} / d_{ws} / \beta_{\text{Windscreen}}$	$\beta_{\text{Windscreen}}$

Table1: Identification of specific points

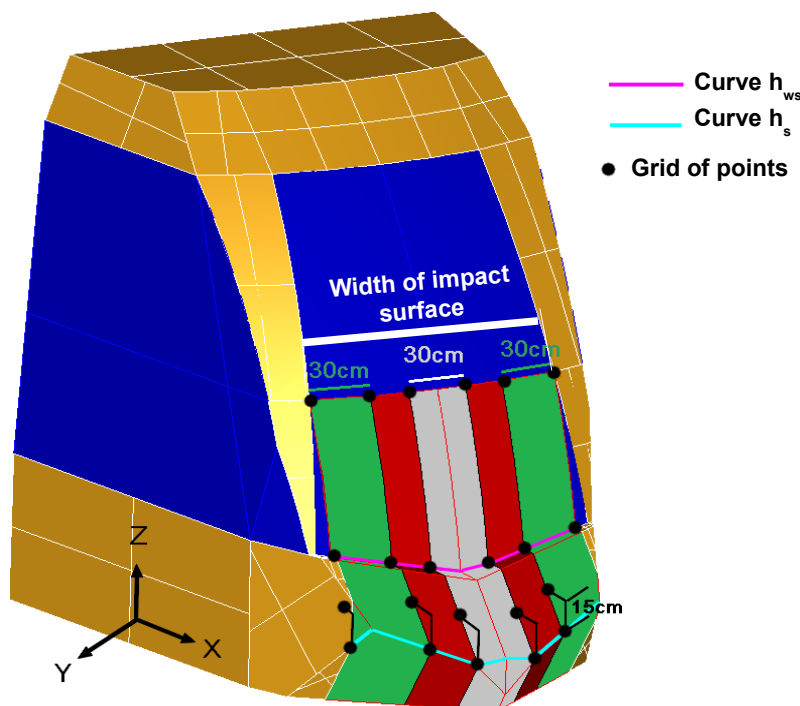


Illustration 4: Identification of specific points

3.2.3. Pedestrian kinematic

3.2.3.1. Objective of the desired kinematics

In order to limit fatal injuries, in particular to the head, the body kinematic to be favoured is to block the shoulder or torso as quickly as possible while limiting the rotation of the trunk. The head contact zone must then be pushed back from the shoulder charge zone.

3.2.3.2. Deflection to the side

Objective

All rolling stock must have a design that enables a body to be deflected rather than be lifted up during an impact. The objective is to limit the intrusion of a pedestrian, including a child, under the tramway. The pedestrian is considered to have been deflected onto the side once they have been moved beyond the main pillars.

Criterion on angle $\beta_{\text{Windscreen}}$ and angle $\beta_{\text{streamlining}}$

Windscreens that are tilted forward must be prohibited ($\beta_{\text{Windscreen}}$ negative) to prevent the pedestrian from being thrown to the ground flush with the tramway.

A front surface that is too vertical ($\beta_{\text{Windscreen}} < 15^\circ$ and $\beta_{\text{streamlining}} < 15^\circ$) does not allow deflection of the pedestrian to the side and is consequently forbidden.

Criterion on h_s

The curve of the most advanced points of the front end (curve of the h_s points) should have the lowest Z coordinates possible in order to hit the pedestrian below the knees: $h_s \leq 35$ cm.

Note: If there are several values for h_s (see the table "definition of parameters"), the lowest value of h_s will be considered.

Criterion on angle α

A 30 cm wide surface at the centre of the train set, centred on the train set's lengthwise axis, may not meet the following criteria in order to take account of the production constraints. This width represents the side-on envelope of a medium-sized man. However, this central surface should have no sharp edges.

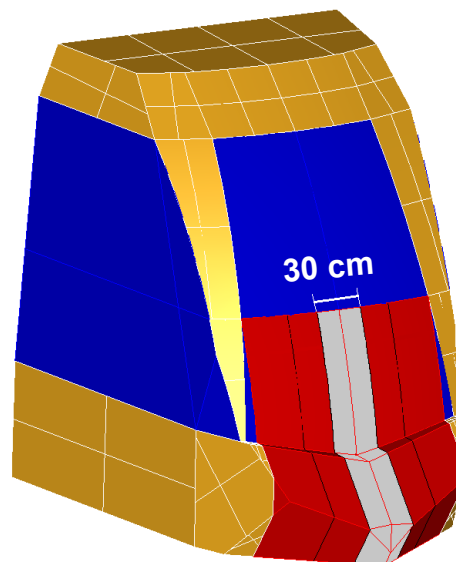


Illustration 5: Tramway central surface

"Flat" front ends ($\alpha < 15^\circ$) do not enable deflection of the pedestrian to the side and are therefore forbidden.

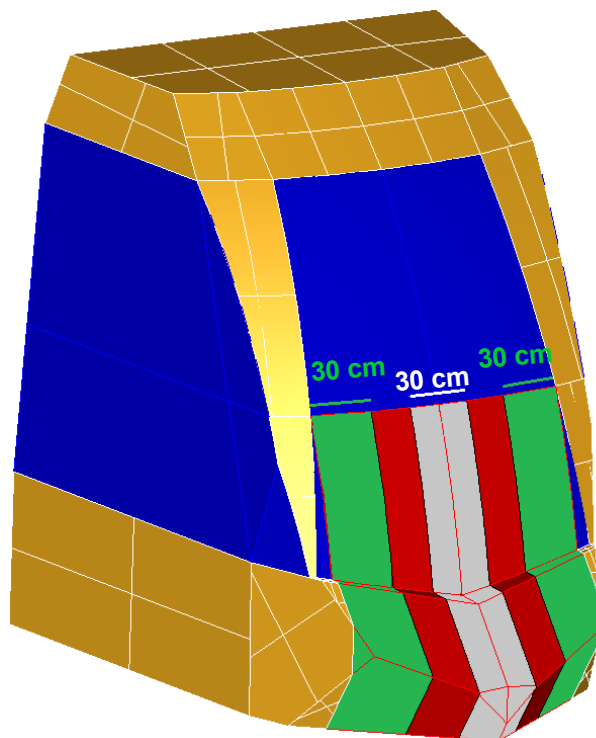
Front ends with quite a narrow α angle ($\alpha \leq 20^\circ$) should not have a vertical windscreen ($\beta_{\text{Windscreen}} < 15^\circ$ forbidden).

Front surfaces located less than 30 cm from the ends of the impact surface according to y should have an angle of $\alpha \geq 30^\circ$ at all y points.

It should be noted that at a given α (therefore a given position y of the pedestrian), the higher the $\beta_{\text{streamlining}}$, the more the pedestrian will be deflected to the side.

Summary

This section contains no new requirement or recommendation and summarises the requirements to be met in the section on Deflection to the side.



Red zone and green zone :

α	β_{ws}	$\beta_{streamlining}$
$\geq 15^\circ$	$\geq 15^\circ$	-
$> 20^\circ$	$0^\circ \leq \beta_{ws} < 15^\circ$	$\geq 15^\circ$

Green zone :

$\alpha \geq 30^\circ$

Illustration 6: Summary of the geometrical criteria **to respect** (deflection to the side)

3.2.4. Front end geometry

3.2.4.1. Sharp edges and protruding parts

All protruding parts or sharp edges on the impact surface* of the vehicle between Z=90 cm and Z=175 cm (zone potentially in contact with the head of a 6-year-old child or an adult of medium height) and accessible by a sphere of 100 mm in diameter are forbidden. The minimum radius allowed in the predefined zone is set at 6 mm (10 mm recommended).

* in case of pillars that flare towards the top, the requirement for the absence of sharp ends is valid for the width between the pillars at Z = 175 cm for the entire range between Z = 90 cm and Z = 175 cm (no exclusion of the 10 cm on each side).

The following elements located on the impact surface should be covered: flood lights, windscreen wiper motor output shaft (as for the windscreen wiper blades, they are considered to be flexible).

Coupling elements on rolling stock should be covered and the rigidity of their structure should not constitute a risk of aggravating injuries in relation to other nearby structures.

3.2.4.2. Avoid tram-surfing

There should be no possibility of maintenance or parking outside, on the lateral and front surfaces (notably at the level of the headlights and the windscreen wiper motor shaft outlet) and between the vehicle bodies.

There should be no possibility of hooking on protruding or external built-in parts, on the lateral and front surfaces and between the vehicle bodies.

3.2.4.3. Minimise the severity of pedestrian injuries

Criterion on d_{ws}

At all points of the windscreen where the bottom line might be lower than 1.15 m, the windscreen should be as much as possible in alignment with the streamline and in any event less than 20 cm from the streamline plane.

If $h_{ws} < 1,15 \text{ m} \rightarrow d_{ws} < 20 \text{ cm}$

Recommendations on geometric parameters

It should be noted that the study which was used to define the combinations to be encouraged was carried out with a dummy representing the adult 50th percentile (the size of the pedestrian influences the HIC result) and with discreet values assigned to each geometric parameter (no continuous variation in parameters).

The combinations of the following parameters are used to obtain contact surfaces that deflect the pedestrian to the side while limiting the risk of fatal head injuries. It should be noted that the geometric parameters chosen do not make it possible to entirely define the different impact surfaces. Consequently, certain combinations that are not presented in the table may meet the HIC $15 < 1,000$ criterion.

The objective of HIC $15 > 1,000$ is considered to be achieved when the following parameters are respected for all the possible pedestrian positions on the impact surface.

HIC < 1000	$d_{ws} < 10 \text{ cm}$	$10 \text{ cm} \leq d_{ws} < 20 \text{ cm}$	$d_{ws} \geq 20 \text{ cm}$
$h_{ws} < 1.05 \text{ m}$	$0^\circ \leq \beta_{\text{windscreen}} \leq 30^\circ$	$0^\circ \leq \beta_{\text{windscreen}} \leq 15^\circ$ or $\beta_{\text{streamlining}} \geq 15^\circ$ and $\beta_{\text{windscreen}} \geq 30^\circ$	prohibited
$1.05 \text{ m} \leq h_{ws} < 1.15 \text{ m}$	$\beta_{\text{streamlining}} \leq 30^\circ$	$15^\circ \leq \beta_{\text{streamlining}} \leq 30^\circ$ and $\beta_{\text{windscreen}} \geq 15^\circ$	prohibited
$1.15 \text{ m} \leq h_{ws} \leq 1.2 \text{ m}$			$0^\circ \leq \beta_{\text{streamlining}} \leq 30^\circ$ and $\beta_{\text{windscreen}} \geq 15^\circ$
$h_{ws} > 1.2 \text{ m}$	$0^\circ \leq \beta_{\text{streamlining}} \leq 30^\circ$ and $\beta_{\text{windscreen}} \geq 15^\circ$ Or $0^\circ \leq \beta_{\text{streamlining}} \leq 15^\circ$	$0^\circ \leq \beta_{\text{streamlining}} \leq 30^\circ$ and $\beta_{\text{windscreen}} \geq 15^\circ$	All geometries suit

Table 2: Recommended parameters combination table

3.3. Summary

This section contains no new requirements or recommendations and summarises all the requirements and recommendations of the previous sections concerning a collision with a pedestrian.

3.3.1. Requirements

Zone concerned	Requirement	Objective	
Total external surface of the trainset including between bodies	no possibility of hooking on protruding or external built-in parts	Anti tram surfing	
Total impact surface as defined in 1.1	$\beta_{ws} \geq 0^\circ$	Deflection to the side	
	$h_s \leq 35 \text{ cm}$	Deflection to the side	
	If $h_{ws} < 1,15 \text{ m}$ then $d_{ws} < 20 \text{ cm}$	Minimisation of injuries	
	Covering of flood lights, windscreen wiper motor output shaft, automatic coupling	Sharp edges	
Points accessible by a sphere 100 mm in diameter between 90 and 175 cm high on a width centred on the axis of the trainset that is equal to the width between the pillars at a height of 175 cm	Curve radius $\geq 6 \text{ mm}$ (10 mm recommended)	Sharp edges	
Impact surface located less than 30 cm from a pillar	$\alpha \geq 30^\circ$	Deflection to the side	
Impact surface outside 30 cm wide central zone	α	Deflection to the side	
	β_{ws}		
	$\beta_{streamlining}$		
	$\geq 15^\circ$	$\geq 15^\circ$	-
	$> 20^\circ$	$0^\circ \leq \beta_{windscreen} < 15^\circ$	$\geq 15^\circ$

Table 3: Summary of the requirements for pedestrians by zone

The criteria which relate to the impact surface outside the central zone are read as follows: depending on the value of α , determine which line applies, then ensure that the angles β_{ws} and $\beta_{streamlining}$ meet the requirements.

For example for $\alpha = 22^\circ$, if β_{ws} is higher than 15° , the requirements are met (1st line). If β_{ws} is between 0° and 15° then the second line applies and $\beta_{streamlining}$ must be at least 15° .

3.3.2. Recommendations and requirements

The table below specifies the requirements that apply to the impact surface outside the 30 cm wide central zone merged with the recommendations.

It can be noted that in conformance with § 2.2. an alternative study can be presented as long as proof of the equivalence of safety requirements is provided. Nevertheless, the hypotheses specified in **Appendix 3** should be taken into account.

h_{WS} (m)	$d_{WS} < 10 \text{ cm}$			$10 \text{ cm} \leq d_{WS} < 20 \text{ cm}$			$d_{WS} \geq 20 \text{ cm}$					
	α	β_{WS}	$\beta_{streamlining}$	α	β_{WS}	$\beta_{streamlining}$	α	β_{WS}	$\beta_{streamlining}$			
$h_{WS} < 1.05$	$\geq 15^\circ$	$15^\circ \leq \beta_{WS} \leq 30^\circ$	-	$\geq 15^\circ$	$15^\circ \leq \beta_{WS} \leq 30^\circ$	-	prohibited					
	$> 20^\circ$	$0^\circ \leq \beta_{WS} < 15^\circ$	$\geq 15^\circ$	$\geq 15^\circ$	$\geq 30^\circ$	$\geq 15^\circ$						
$1.05 \leq h_{WS} < 1.15$	$\geq 15^\circ$	$\geq 15^\circ$	$\leq 30^\circ$	$\geq 15^\circ$	$\geq 15^\circ$	$15^\circ \leq \beta_s \leq 30^\circ$						
	$> 20^\circ$	$0^\circ \leq \beta_{WS} < 15^\circ$	$15^\circ \leq \beta_s \leq 30^\circ$	$\geq 15^\circ$	$\geq 15^\circ$	$15^\circ \leq \beta_s \leq 30^\circ$						
$1.15 \leq h_{WS} \leq 1.2$	$\geq 15^\circ$	$\geq 15^\circ$	$\leq 30^\circ$	$\geq 15^\circ$	$\geq 15^\circ$	$15^\circ \leq \beta_s \leq 30^\circ$				$\geq 15^\circ$	$\geq 15^\circ$	$0^\circ \leq \beta_s \leq 30^\circ$
	$> 20^\circ$	$0^\circ \leq \beta_{WS} < 15^\circ$	$15^\circ \leq \beta_s \leq 30^\circ$	$\geq 15^\circ$	$\geq 15^\circ$	$15^\circ \leq \beta_s \leq 30^\circ$				$\geq 15^\circ$	$\geq 15^\circ$	$0^\circ \leq \beta_s \leq 30^\circ$
$h_{WS} > 1.2$	$\geq 15^\circ$	$\geq 15^\circ$	$0^\circ \leq \beta_s \leq 30^\circ$	$\geq 15^\circ$	$\geq 15^\circ$	$0^\circ \leq \beta_s \leq 30^\circ$	$\geq 15^\circ$	$\geq 15^\circ$	-			
	$> 20^\circ$	$0^\circ \leq \beta_{WS} < 15^\circ$	$0^\circ \leq \beta_s \leq 15^\circ$	$\geq 15^\circ$	$\geq 15^\circ$	$0^\circ \leq \beta_s \leq 30^\circ$	$> 20^\circ$	$0^\circ \leq \beta_{WS} < 15^\circ$	$\geq 15^\circ$			

Table 4: Summary of the requirements merged with the recommendations for the impact surface

To use this table, first of all h_{WS} and d_{WS} must be determined, then ensure that the trios $\{\alpha; \beta_{Windscreen}; \beta_{streamlining}\}$ conform to the criteria marked in the box identified.

Example: $h_{WS} = 1 \text{ m}$, $d_{WS} = 12 \text{ cm}$, $a = 22^\circ$, $b_{Windscreen} = 10^\circ$, $b_{streamlining} = 20^\circ$

$\{h_{WS}; d_{WS}\} \rightarrow 1^{st} \text{ line}, 2^{nd} \text{ column}$.

As is the case with $\alpha > 20^\circ$, the triplet $\{\alpha; \beta_{Windscreen}; \beta_{streamline}\}$ must be authorised among the existing triplets for $\alpha \geq 15$ or for $\alpha > 20^\circ$.

Here, the triplet $\{22^\circ; 10^\circ; 20^\circ\}$ is authorised by the triplet $\{>20^\circ; 0^\circ \leq \beta_{WS} < 15^\circ; \geq 15^\circ\}$.

3.4. Pedestrian anti-crush mechanism (DAEP)

3.4.1. Definition

The rolling stock must be fitted with one or more mechanisms to protect against the risks of crushing (tyre tramways) and a limb severing (rail tramway). The pedestrian (dummy) must never come into contact with the bogie's wheels.

For these mechanisms to play their role in full, no protruding elements under the chassis must injure the pedestrian or jam them before reaching the mechanism. In the same way, the pedestrian must not be jammed under the chassis before reaching the mechanism.

This type of mechanism is named the "Pedestrian anti-crush mechanism" (DAEP).

A cowcatcher (static mechanism, permanent) and a body catcher (dynamic mechanism that needs to be activated) are DAEP.

3.4.2. Objectives

The DAEP must:

- Present a shape which is not aggressive and which is designed not to deviate up or down.
- Have a lower clearance line as close as possible to the rail plane as the vehicle's movements allow.
- Cover the whole width of the bogie/axle.

The achievement of these objectives will be validated by the success of the tests described in the protocol in **Appendix 4** in this guide.

The track profile issue was considered as having little influence for the validation of the DAEP.

In the case of a dynamic DAEP which requires to be activated, the activation mechanism must achieve a high level of reliability.

3.4.3. Role of the streamlining

The car's streamlining may be considered as a DAEP once its ground clearance is low enough to avoid any intrusion by a pedestrian under the body frame (to be checked using the test protocol in the appendix).

The streamlining may act as a DAEP for an adult (DAEP status validated after tests according to the protocol in **Appendix 4** with the adult dummy) but not for a child. In this case, the rolling stock must be equipped with a second mechanism to cover the risk of crushing or severing of the limb of a child.

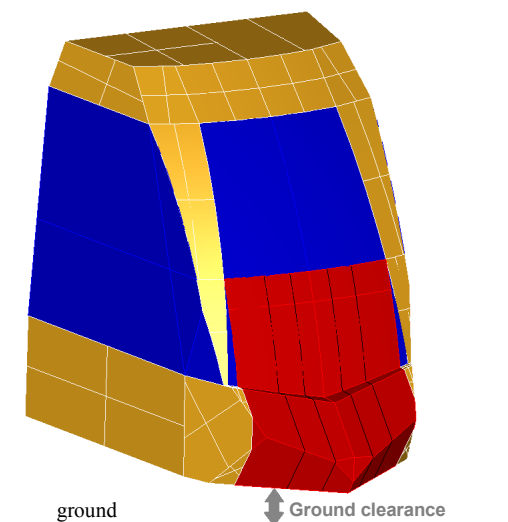


Illustration 7: ground clearance definition

The ground clearance must be as low as possible (space between the rail level and the bottom of the driving cab) to limit the intrusion of a pedestrian under the train set and to constitute a first safety barrier. This space will be sized to prevent a pedestrian from becoming jammed if they intrude under the body frame.

4. Collision with an LV

4.1. Feared event

According to feedback analysis, the feared event is collision with a light vehicle (LV) such as a sedan. The LV is in simple crossing (impact perpendicular to the tramway, with the impact point such that the lengthwise axis of the LV tangents the furthest forward point on the tramway's front end streamlining). The tramway is running at a speed of 30 km/h.

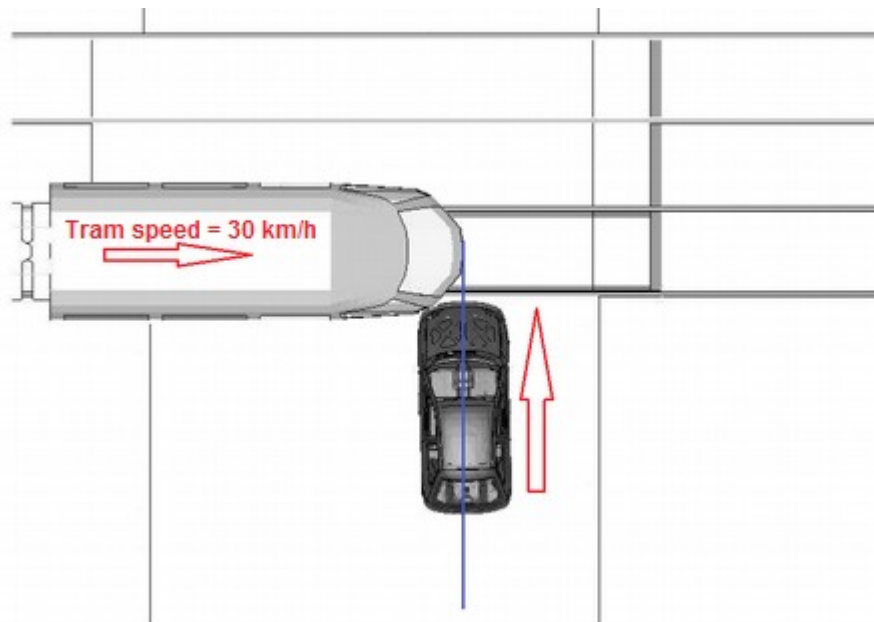


Illustration 8: Collision with an LV scenario

4.2. Severity reduction measures

4.2.1. Tramway structure

The rolling stock structure must be sized according to collision scenario 3 defined in standard NF EN 15 227 in its 2011 version for category IV concerning trams and C-III concerning tram-trains.

4.2.2. Impact surface on the LV

The impact surface must be defined in accordance with the characteristics of road vehicles, in particular for side impacts (impact below the windows).

Note: the windows start at a height of 895 mm in relation to the ground for a city car and 1090 mm for a family sedan.

4.2.3. Derailment sensitivity indicator

Reference rolling stock definition

To guarantee that derailment sensitivity is not aggravated following a collision with a light vehicle (LV) when new rolling stock is designed, each manufacturer will define a rolling stock for reference.

This reference rolling stock must be unique and be an existing one operated on the driving by line-of-sight principle in France. This choice must be justified and accepted by STRMTG.

If the indicator calculation is necessary

For the reference rolling stock, the manufacturer will determine the LV's speed from which the tramway is derailed (see methodology described below).

The derailment sensitivity indicator is determined by comparing the LV's speed from which the new design tramway is derailed or the reference tramway is derailed. It must be determined iteratively.

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As the derailment sensitivity indicator is used relatively in relation to the reference equipment, **it is not intended to reflect reality** but to demonstrate that there is no regression.

This indicator must be determined once a development in the rolling stock's design in relation to the reference tramway may affect the derailment sensitivity. All new rolling stock acquisition projects will therefore identify the discrepancies in the reference rolling stock retained for this indicator. Each of these discrepancies will be analysed in relation to their impact on their ability to derail.

Examples of design changes that require the indicator to be calculated for new rolling stock:

- Extension by at least 10% of the length of the overhand taken at the axis of the 1st bogie (rail tramway) / axle (tyre tramway)
- Or reduction in load on the end axle by at least 10%
- Or modification of the kinematic link between the vehicle body and the bogie/axle
- Or use of a new wheel profile/guide system

Modelling

A two-stage modelling process must be carried out to determine the indicator.

Phase 1: LV - tramway impact

Software to be used:

- crash test software

Input data:

- LV modelling by an impactor defined below
- modelling of the tramway considered empty in working order with new wheels/new guide system

Impactor (see **Appendix 5**):

The AE-MDB barrier intended to be used in crash test software for side impacts on LV is adapted as follows:

- The barrier's geometry is conserved
- The barrier is guided to apply only a purely transverse effort
- The barrier is modelled in a unique block
- The barrier is associated with a weight of 1.3 t

Tramway:

- Tramway structure modelling in detail up to and including at least the structure of the driver's cab.
- Modelling of the mechanisms specifically designed to recover the efforts in the event of a collision, where applicable (for example, the streamlining does not need to be modelled if it is not specifically designed to be involved in passive safety).

It is acceptable to model of half of the train set in relation to the lengthwise axis if the structure is symmetrical.

Each manufacturer will specify clearly the modelling hypotheses in order to guarantee that the new design rolling stock is modelled under the same hypotheses as the reference rolling stock.

Methodology:

The scenario considered is the scenario in the Feared event section, except for the tramway speed which is considered zero for modelling requirements.

The force transmitted by the LV shall be the result of the collision simulation with the adapted 1.3 t AE-MDB barrier defined in **Appendix 5**; simulation carried out using an explicit calculation code

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generally used to simulate structures in a crash. The point of application of the collision force is the first point of impact on the resistant structure when the central axis of the impactor is aligned on the most advanced point of the streamline.

The methodology must be applied first of all to the reference equipment then to the rolling stock concerned by the design development.

Output data:

Effort curve applied to the reference rolling stock and the rolling stock concerned by the design development.

Note: This first phase can be simplified by defining a single set of force curves for the 2 rolling stocks, notably when the change in the design does not concern the resistant structure.

Phase 2: Derailment

Software to be used:

- modelling software which manages the contact between the rail and the wheel/the guide system

Input data:

- Effort curve applied to the rolling stock determined in phase 1
- modelling for the whole tramway, in particular the contact between the rail and the wheel/the guide system, the bogies and their kinematic links, the dampers body-bogie et body-body.

Methodology:

The scenario considered is the scenario which is described in the Feared event section (the tramway is running at 30 km/h).

The effort curve obtained in the 1st phase is integrated into modelling software which integrates in particular the contact between the rail and the wheel/the guide system.

Reference rolling stock:

The following speed steps are proposed to determine the reference rolling stock's derailment sensitivity indicator:

- If no derailment is observed, restart from phase 1 with an impactor speed increased by 5 km/h
- If derailment is observed, restart from phase 1 with an impactor speed reduced by 1 km/h

Output data:

LV speed from which the tramway is derailed for the reference rolling stock and for the rolling stock concerned by the design development.

Summary

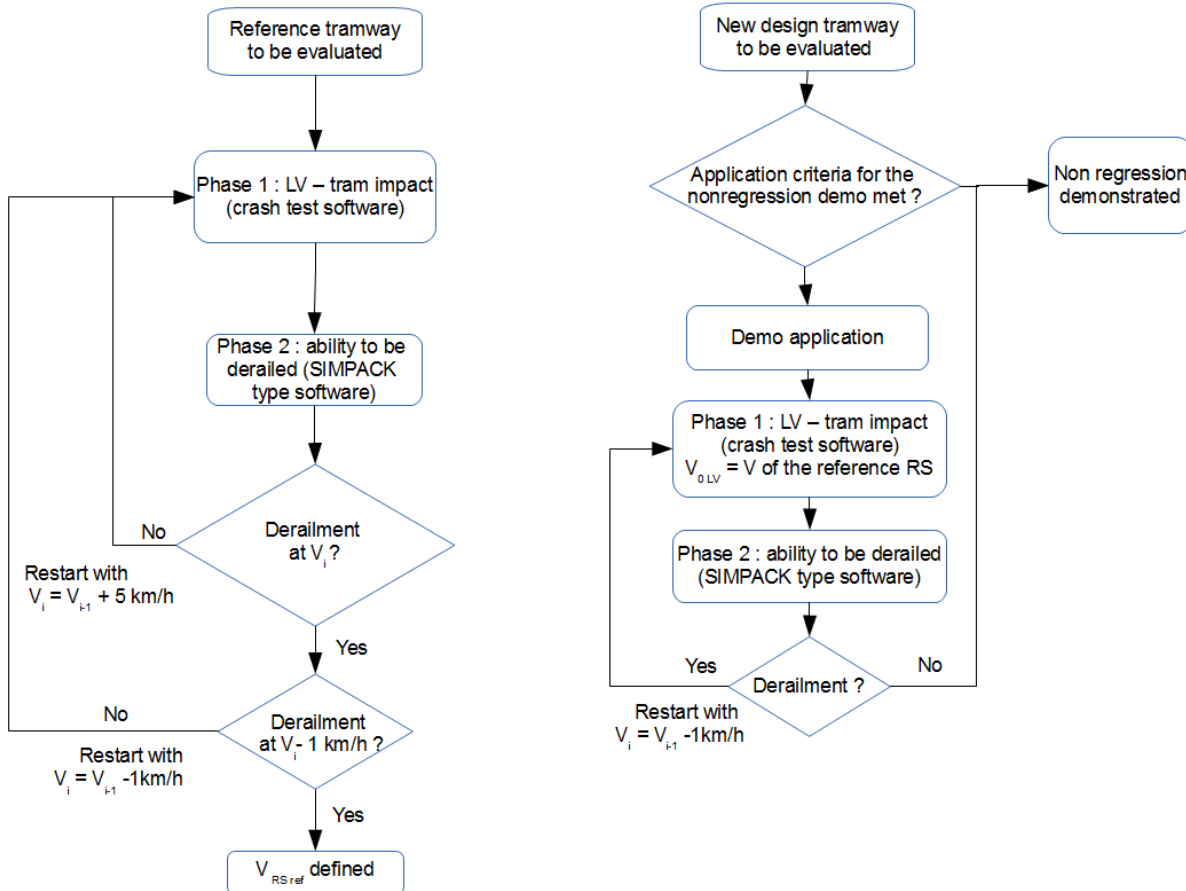


Table 5: Derailment sensitivity determination indicator logical diagram

5. Collision with another train set

5.1. Feared event

The collision scenario to be applied for tramway is scenario 1 defined in standard NF EN 15 227 in its version of 2011 for category C-IV.

The collision scenario to be applied for tram-trains is scenario 1 defined in Standard NF EN 15 227 in its version of 2011 for category C-III.

5.2. Mixed circulation

In the event of mixed circulation between two types of rolling stock, an analysis of the consequences for the people being transported is expected according to scenario 1 in standard NF EN 15 227 (speed, impact direction) in its version of 2011.

6. Feedback enhancement: front camera

The insertion of tramways into urban environments is a strong theme in the analysis and feedback from tramway accidents. STRMTG would like it to be possible to use onboard video systems, with which some rolling stock is already equipped (front camera targeting the public highway) to carry out accident analysis, share feedback and raise awareness of tramway hazards. This STRMTG position is in keeping with the recommendations of the BEA-TT following the investigations into the collisions of 4/06/2007 and 25/06/2011⁴.

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While the installation of a front camera is not compulsory, STRMTG still encourages AOT to equip their rolling stock with this mechanism.

It should be noted that the authorisation to use these cameras is covered by video-protection regulations.

If the rolling stock is equipped with a front camera, the definition of the field of vision objective expected from these cameras is proposed.

Readers are reminded that the main objective of these cameras is to analyse events; consequently, they are not used in real time. The recording depth must enable the sequence that corresponds to an accident to be extracted (at least the maximum duration of the journey by a train set returning to the depot).

The camera's field of vision must enable the platform to be seen, as well its immediate surrounding areas to identify the origin that third parties involved in a collision come from, the condition of the signals and the visibility conditions when the accident occurred (night, fog, rain, etc.).

Ideally, the camera's field of vision must enable the following to be seen:

- The tramway's R17 when it is crossed (R17 height: 3 m)
- The ground 1.5 m away from the tramway's front end (collision with pedestrian)

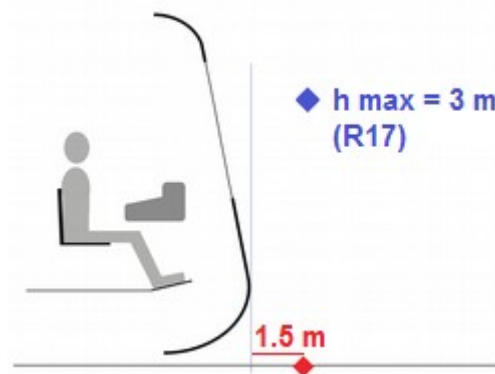


Illustration 9: Front camera field of vision - sagittal plane

- The origin of a third party 20 m in front of the intersection (emergency stopping distance at 30 km/h) in the most restrictive platform side layout configuration (visibility up to at least 24 m on the side, i.e. 100° degree opening horizontally for a camera centred on the train set's axis). The area covered by the camera will therefore be close to the driver's own field of vision.

To avoid any interference with privacy, the resolution expected is not fine: the need is to be able to recognise the category of third party (pedestrian, cyclist, light vehicle, etc.), without being able to identify them, and the status of the signal sent to the tramway.

ANNEXE 1. List of working group members

Name	Company
FOURNEAU David	ALSTOM
LE CORRE Dominique	ALSTOM
POLA José Ignacio	CAF
ROUQUETTE Frédéric	CAF
HAAB Matthieu	NTL
NARDIN Pascal	NTL
FOREST Yannick	RATP
GADEAU Cristina	RATP
MOUGEL Yannick	RATP
JUMIN Patrick	SNCF
LEPAGE Pascal	SNCF
CHAPPELIN Laurent	STRMTG
DE LABONNEFON Valérie	STRMTG
GUESSET Alexandra	STRMTG

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ANNEXE 2. Glossary

AE-MDB	Advance European Mobile Deformable Barrier
AOT	Transport organising authority
BEA-TT	Bureau d'Enquête sur les Accidents de Transport Terrestre - Land Transport Accident Investigation Bureau
DAEP	Dispositif Anti-Ecrasement d'un Piéton - Pedestrian Anti-Crush Mechanism
DPS	Dossier Préliminaire de Sécurité – Safety Preliminary Case (French authorisation process)
EN15227	Crashworthiness requirements for railway vehicle bodies
LV	Light Vehicle
RS	Rolling Stock (tramway)
S	Streamlining
STRMTG	Service Technique des Remontées Mécaniques et des Transports Guidés – Technical Agency for ropeways and guided transports systems
WS	Windscreen

ANNEXE 3. Modelling hypotheses for a pedestrian – tram collision

The dummy to be used must meet the following criteria:

- biofidelity of dummy verified
- adult dummies that represent the 50th percentile male and a six-year-old child. With the child dummy, it must be possible to verify whether the results obtained with the adult dummy do not result in fatal injuries for the child.

The tram travels at a constant speed of 20 km/h. The dummy is hit on the side. 3 points of impact are to be considered:

- the end of the central zone of 30 cm
- the inner edge of a pillar
- a point located midway between the 2 previous points

The tram must be modelled so that it represents the shapes, masses, and stiffness in the zones of impact with the dummy. Each impact zone that is modelled should be sufficiently wide (a minimum of 1 m) and high to cover the complete kinematics of the dummy at the time of the collision.

If the tram impact zone is discretised in longitudinally mobile horizontal bands, at a minimum, the following are recommended:

- the impact zone must consist of at least 5 horizontal subdivisions
- all the subdivisions are at the same height (approximately 40 cm)
- each subdivision must be guided by a slide rail connection perpendicular to the surface of the subdivision
- the stiffness of each subdivision is represented by a spring
- a thickness and density are associated with each link
- the model does not use ellipsoids in order to avoid discontinuities

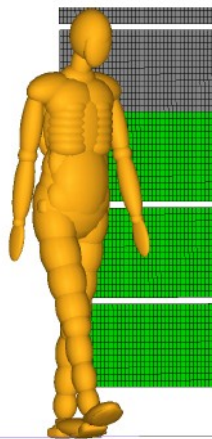


Illustration 10: as an indication, modelling in horizontal bands

The gridding of the modelled tram zone should be sufficiently thin. As an indication, a grid size of less than 25mm is recommended.

The criteria for success are obtaining $HIC_{15} < 1,000$ and obtaining a deflection to the side of at least 80 cm. These criteria are to be achieved for the 3 points of impact.

To calculate the d_y , the simulation is stopped 15 ms after the end of contacts between the dummy and the tram and between the dummy and the ground. The positions and speed vectors of the centres of gravity for each limb of the dummy then enable the definition of the global position of the centre of gravity and its speed vector. It is then considered that the centre of gravity has a parabolic trajectory.

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ANNEXE 4. DAEP validation tests

A) Test objectives

The objectives of these tests are to verify the DAEP's capacities during a collision with a person, represented by dummies whose characteristics are described below, to:

- Stop a body before the first axle on the first bogie.
- Not jam the person at their thighs, chest or head.
- Not sever one of the person's limbs: The dummy must remain intact.
- Push the person away so that they do not come into contact with the wheels.
- Not project any debris or break on impact with the person (risk of aggravating injuries).

B) Test conditions

Vehicle:

- Empty vehicle in running order
- Vehicle equipped with new wheels

Test track:

- The tests must be carried out on a section of track that corresponds to an urban configuration (rails in concrete or tarmac track exclusively)
- The impact zone must be in a straight line.
- The test zone will be as flat as possible. A ramp test will not be accepted in any circumstances.
- The section of track must be long enough to enable the required speed of 25 km/h to be achieved and to stop following braking.
- Any change in weather conditions during the tests must be noted (dry rail, wet rail, etc.)

Dummies used:

The dummies enable representation of the pedestrian to protect against the risks of crushing and their limbs being severed.

- Articulated land rescue dummies made up of a rigid skeleton will be used. These dummies guarantee the representative nature of the distribution of the lengths, volumes and weights as well as the main joints (hips and shoulders) of a human being.
- "Adult" dummy: 1.83 m, 75 kg
- "Child" dummy: 1.22 m, 17 kg

C) Tests to be carried out

4 tests must be carried out with the "adult" dummy:

- Test 1: transverse to the rail, centred
- Test 2: transverse to the rail, off centre (hip on the track rail)
- Test 3: lengthwise on the rail, centred
- Test 4: lengthwise on the rail, off centre (hip on the track rail)

4 tests must be carried out with the "child" dummy:

- Test 1: transverse to the rail, centred
- Test 2: transverse to the rail, off centre (hip on the track rail)
- Test 3: lengthwise on the rail, centred
- Test 4: lengthwise on the rail, off centre (hip on the track rail)

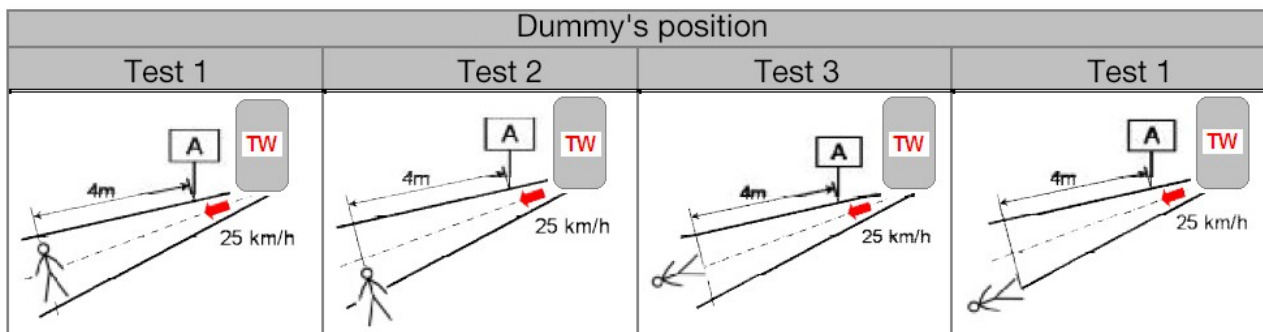


Illustration 11: off centre lengthwise test



Illustration 12: off centre transverse test

To verify the "Push the person back so that they do not come into contact with the wheels" objective, a non contact verification fuse mechanisms may be positioned just in front of the wheels during the tests.



Descriptive diagrams for the different tests:

The 8 tests (4 with the adult and 4 with the child) cover the most credible cases of falling onto the track, as well as the possible positions following impact with the tramway.

Test chronology:

1. The vehicle's reference stopping distance in emergency braking must be measured just before the crash tests with the dummies.
2. The emergency braking activation point [A] is positioned on the track.
3. The dummy ("adult" or "child") is placed on the track 4 metres after the point marked [A] (in the direction of travel). The dummy is positioned lying on its back, with its legs together and its arms (free) down its body.
4. The vehicle travels at a constant speed of 25 km/h (regardless of the length between the front end and the DAEP). When the vehicle's front end reaches point [A], the driver activates emergency braking until the train set comes to a complete stop.

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D) Documents to be provided

Document 1 "DAEP description":

- Plan(s) with dimensions of the DAEP (in particular the altimeter profile of the lower clearance line in relation to the running plane, height, width, etc.)
- Type of fixing to the rolling stock structure
- Materials used

Document 2 "DAEP test protocol report table":

The report framework below must be duly completed along with the associated illustrating photos and videos.

The report table must seek to describe precisely, for each of the 8 tests, the consequences of the impact with the dummy.

For each of the 8 tests, provide:

- Photos of sufficient quality and dimensions, illustrating:
 - The position of the dummy before the impact with the rolling stock: 1 overview photo (track, emergency brake activation point and dummy)
 - The position of the dummy after the impact: 2 photos taken at ground level and under 2 different angles to view the grouping of the dummy and the parts of the rolling stock with which it remains in contact or not following the impact.
- A video of sufficient quality and dimensions of the full sequence taken at a suitable angle to view the dynamic of the impact of the dummy with the DAEP.

Document 3: Conclusion

For each of the 8 tests, the conclusion must indicate whether the DAEP meets the objectives in paragraph A.

DAEP test protocol report table

OLE object: double-click to edit

		Test scope description				
Test dates Test track location Track characteristics Type of rolling stock Tramway emergency braking reference stopping distance (in m) Empty rolling stock in running order with new wheels DAEP ground clearance: Note the highest point and the lowest point in relation to the running plane (in mm) Before the impact Characteristics of the dummy	Slope: in % Manufacturer: in m Highest point (in mm): Lowest point (in mm): Model:	Rail: Wet - Dry Model: Articulated: Yes - No	Train set number: Size: in m Weight: in kg	Highest point (in mm): Lowest point (in mm):	Highest point (in mm): Lowest point (in mm):	
Name of the test Position of the dummy in relation to the track Test description diagram	Test "1" Dummy centred Dummy on the rail 	Test "2" Dummy off centre Dummy on the rail 	Test "3" Dummy centred Lengthwise to the rail 	Test "4" Dummy off centre Lengthwise to the rail 	Train set kinematic description	
Tramway speed during emergency braking (in km/h) Tramway stopping distance after activation of the emergency brake (in m)						
Description of the position and condition of the dummy after the impact during the different tests Fill in the corresponding line with the result obtained during the test (relative position in relation to the train set and the deterioration of the dummy)						
The dummy is thrown away from the area covered by the rolling stock. No part of the dummy remains under the rolling stock (either before or after the DAEP)	Position and condition of the dummy at: The head: The chest: The legs: The arms:	Position and condition of the dummy at: The head: The chest: The legs: The arms:	Position and condition of the dummy at: The head: The chest: The legs: The arms:	Position and condition of the dummy at: The head: The chest: The legs: The arms:	Position and condition of the dummy at: The head: The chest: The legs: The arms:	
The dummy does not cross the DAEP No part of the dummy remain jammed in or under the DAEP	Position and condition of the dummy at: The head: The chest: The legs: The arms:	Position and condition of the dummy at: The head: The chest: The legs: The arms:	Position and condition of the dummy at: The head: The chest: The legs: The arms:	Position and condition of the dummy at: The head: The chest: The legs: The arms:	Position and condition of the dummy at: The head: The chest: The legs: The arms:	
The dummy does not cross the DAEP Parts of the dummy remain jammed in or under the DAEP	Position and condition of the dummy at: The head: The chest: The legs: The arms:	Position and condition of the dummy at: The head: The chest: The legs: The arms:	Position and condition of the dummy at: The head: The chest: The legs: The arms:	Position and condition of the dummy at: The head: The chest: The legs: The arms:	Position and condition of the dummy at: The head: The chest: The legs: The arms:	
The dummy pivots around the DAEP and passes under the train set No part of the dummy hits the bogie and the wheels	Position and condition of the dummy at: The head: The chest: The legs: The arms:	Position and condition of the dummy at: The head: The chest: The legs: The arms:	Position and condition of the dummy at: The head: The chest: The legs: The arms:	Position and condition of the dummy at: The head: The chest: The legs: The arms:	Position and condition of the dummy at: The head: The chest: The legs: The arms:	
The dummy pivots around the DAEP and passes under the train set Parts of the dummy hit the bogie and the wheels	Position and condition of the dummy at: The head: The chest: The legs: The arms:	Position and condition of the dummy at: The head: The chest: The legs: The arms:	Position and condition of the dummy at: The head: The chest: The legs: The arms:	Position and condition of the dummy at: The head: The chest: The legs: The arms:	Position and condition of the dummy at: The head: The chest: The legs: The arms:	
For each test: Provide: Photos of sufficient quality and dimensions taken at a suitable angle, illustrating: - The position of the dummy before the impact with the rolling stock: 1 overview photo (track, emergency brake activation point and dummy) - The position of the dummy after the impact: 2 photos taken at ground level and under 2 different angles to view the grouping of the dummy and the parts of the rolling stock with which it remains in contact or not following the impact. A video of sufficient quality and dimensions of the full sequence taken at a suitable angle to view the dynamic of the impact of the dummy with the DAEP.	Description of the condition of the DAEP after the impact					
For each of the tests, if the DAEP is deformed after the impact: Note the lowest point and the highest point in relation to the running plane (in mm)	Deformation Yes-No	Ground clearance Highest point (in mm): Lowest point (in mm):	Deformation Yes-No	Ground clearance Highest point (in mm): Lowest point (in mm):	Deformation Yes-No	Ground clearance Highest point (in mm): Lowest point (in mm):
For each test: Provide: At least 1 photo of sufficient quality and dimensions taken at a suitable angle, illustrating: The position and condition of the DAEP						

ANNEXE 5. Adapted AE-MDB barrier

The digital model of the impactor that represents the LV is comprised of three parts:

- A rigid non-deforming envelope with the external dimensions of the AE-MDB barrier (Illustrations 15 and 16) and a null or very low mass.
- A lumped mass of 1,300 kg that could be represented either by a volume or by a point.
- A one-dimensional element that connects the rigid envelope to the lumped mass and for which the irreversible force-crushing characteristic is presented in Illustration 17 and Table 6 (please note that under no circumstances can the impactor exceed approximately 375 mm of crushing).

The overall impactor is presented in illustrations 13 and 14.

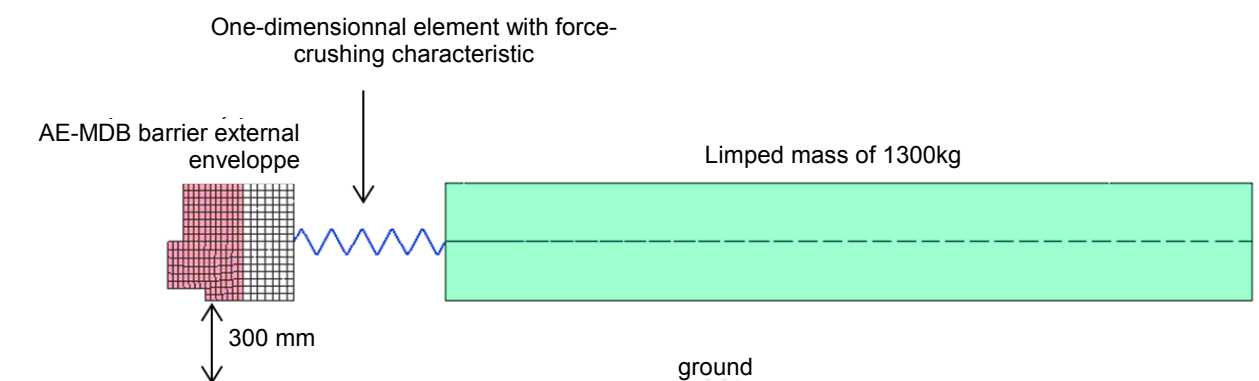


Illustration 13: general view of the digital model of the LV impactor

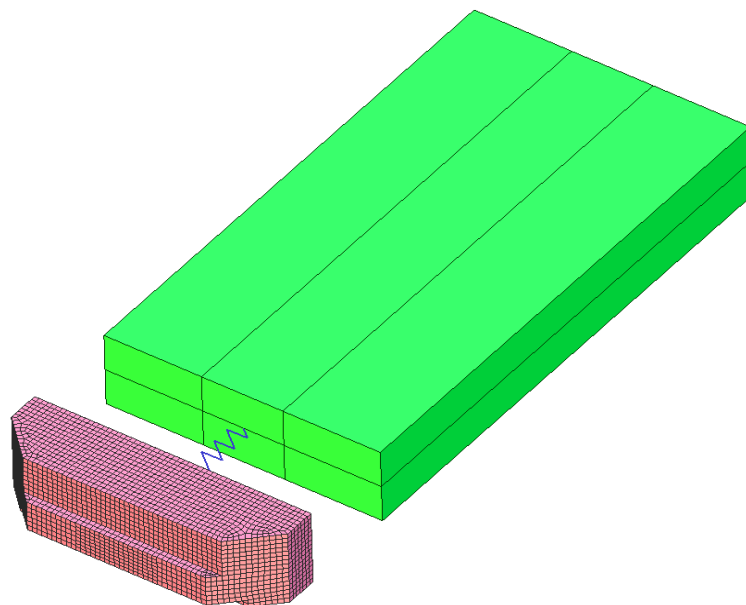


Illustration 14: General perspective view of the digital model of the LV impactor

The three previously listed parts have an initial speed V_i and are guided in translation.

The impactor is positioned so that the lower part of the envelope of the AE-MDB barrier is located 300 mm from the ground and longitudinally, on contact with the modelled tram. A null friction could be considered between the impactor and the tram.

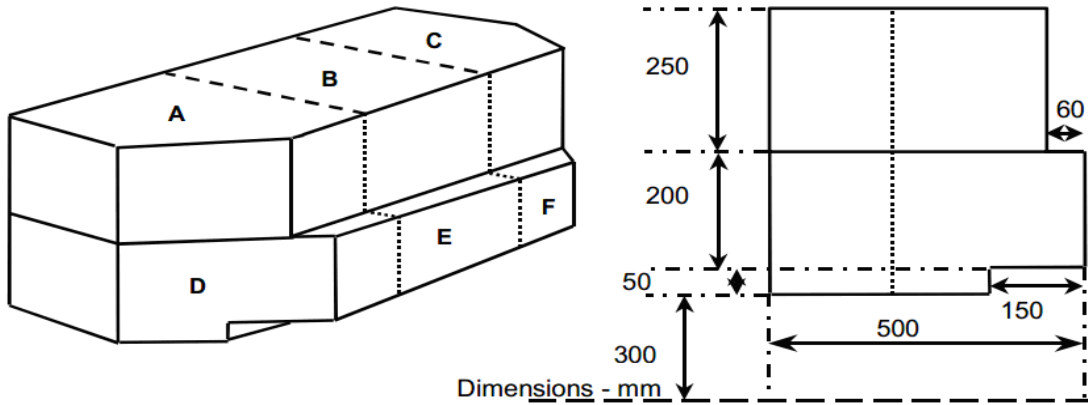


Illustration 15: Dimension of the AE-MDB barrier from a side view

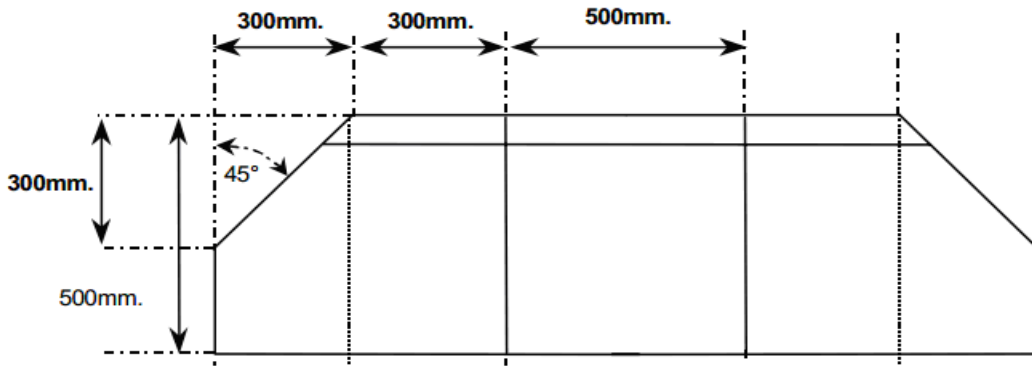


Illustration 16: Dimension of the AE-MDB barrier from a top view

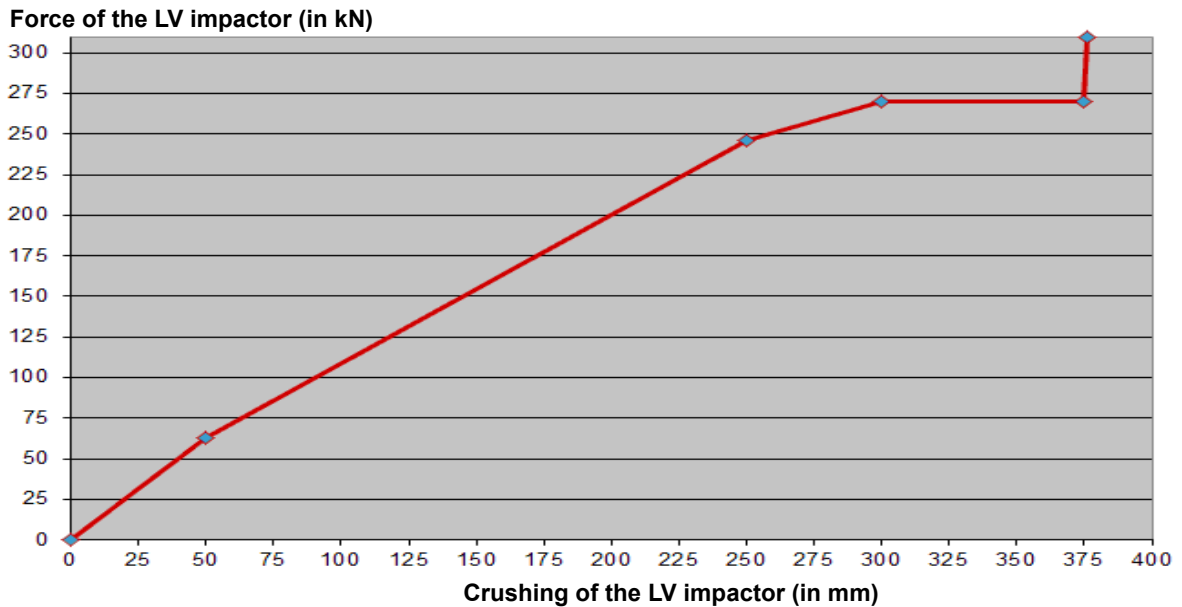


Illustration 17: Force-crushing characteristic of the LV impactor

Crushing (in mm)	Force (in kN)
0	0
50	63
250	246
300	270
375	270
376	310

Table 6: Coordinates of the points that characterise the force-crushing curve of the LV impactor

For each LV speed, the force curves according to time can be filtered for use in phase 2.

The technical guides

Directorate General
for Infrastructure,
Transports
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Technical Agency
for Ropeways and
Guided Transport Systems

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