# EN12663과 prEN15227에 따른 객차의 구조적 요구사항 검토

# An overview of the structural requirements of passenger carrying rolling stock according to EN12663 and prEN15227

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## ABSTRACT

As the South Korean rolling stock industry is developing designs for full compliance with the European Standards, it is fitting to take a look at these two core standards.

The paper presents an overview of the load cases and structural requirements developed in Europe for the design of safe and compatible rolling stock vehicles. These load cases and structural requirements have been compiled into two standards namely EN12663 and EN15227.

Standard EN12663 was developed as a reference design requirements standard. The work was mandated and sponsored by the European Committee for Standardization and Standard issuing National Institutions.

EN12663 specifies a series of proof and fatigue load cases for European rolling stock regulations compliant vehicle designs. As EN12663 does not address the crashworthiness issue, a dedicated crashworthiness standard, EN15227, was therefore developed in a similar manner through industry wide consultations managed by a Trans-European working group of experienced engineers and specialists. In both standards, the vehicle and/or trains are grouped into categories reflecting the vehicle types and/or their indented operational function.

EN15227, developed to complement EN12663, addresses the "passive" crashworthiness capability of the vehicles and trains. EN15227 specifies reference crash scenarios similar to those found in the Technical Specification for Interoperability (TSI) of high speed trains operating in Europe. The overview also touches on a general comparison with the corresponding British Group Standard (GM/RT2100) and also the UIC leaflet based load cases. The exercise is extended to pertinent design load cases specified by the Federal Railroad Administration (FRA) in the US.

## 1. Introduction

In the present paper an overview of the load cases and structural requirements developed in Europe for the design of safe and compatible rolling stock vehicles, is given. These load cases and structural requirements have been compiled into two standards namely EN12663 and EN15227.

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## 2. Design standard EN12663

European Standard EN12663(1) is applicable to both passenger carrying trains and freight carrying railway vehicles.

(1) "EN12663:2000" is being revised with the intent to re-issue it as a two (or more) parts documents :

<u>Proposal</u> :

Part 1 -> Dedicated to non-freight carrying vehicles,

Part 2 -> Dedicated to freight wagons.

The discussion in this paper concentrates on the passenger carrying rolling stock types and in particular the bodyshell design load cases.

### 2.1 Bodyshell design categories

EN12663 stipulates a set of structural requirements to be met, as a minimum, by all railway vehicles. These structural requirements are based on proven experience and well established and documented rolling stock design best practices. They are required to ensure that any given railway vehicle design complies with specified structural criteria. These structural criteria were defined to confirm the structural integrity of vehicle against every day operational loading requirements, exceptional loading scenario and typical service load spectrums a vehicle is likely to encounter over its entire life.

The vehicles, carriages and locomotives/power units, are grouped into specified categories according to their structural requirement needs and design specifications. Six(2) categories have been identified as follows:

(2) According to the EN12663-1 latest draft proposal.

Table 1 : Vehicle categories

| Category | Vehicle types |
|---|---|
| L | Locomotives and power heads/units |
| P-I | Carriages not destined to operate in a permanent formation |
| P-II | Fixed units and carriages operating in a permanent formation |
| P-III | Underground, rapid transit vehicles and light railcars |
| P-IV | Light duty metro and heavy duty tramway vehicles |
| P-V | Tramway vehicles |

### 2.2 Specified design load cases

EN12663 specifies static load cases a vehicle must be able to sustain without permanent deformation under the specified proof load context and that there are no potential risk of catastrophic failure under the ultimate loading conditions. The proof(3) load context is quantified by the requirement for a minimum reserve factor of 1.15 against the yield or proof strength of the material used. Similarly, a minimum reserve factor of 1.5 against the ultimate strength of the material used must be recorded for compliance with the ultimate(3) loading conditions.

(3) - Alternatively within a linear analysis and/or measurement processing a proof load factor of 1.15 and an ultimate load factor of 1.5 may be used with minimum reserve factors of unity against both the yield/proof strength and the ultimate strength of the material.

The standard also lists fatigue load cases that the vehicle may experiences over its specified design life.

### 2.2.1 Longitudinal proof loads

Longitudinal forces are specified to ensure that the bodyshell structure can react safely without any risk of premature collapse resulting from high longitudinal forces that may arise during rough shunts and minor to medium collision. The specified basic design compressive and tensile forces scenarios are as follows :

Load case ① : Compressive force at buffer/anti-climber height and/or coupler height
Load case ② : Tensile force on coupler mounting plate
Load case ③ : Compressive force 150mm above body-end floor level
Load case ④ : Compressive force at waist rail height
Load case ⑤ : Compressive force at cant rail height
Load case ⑥ : Compressive force applied diagonally at buffer height (If buffers are fitted at both ends of the vehicle)

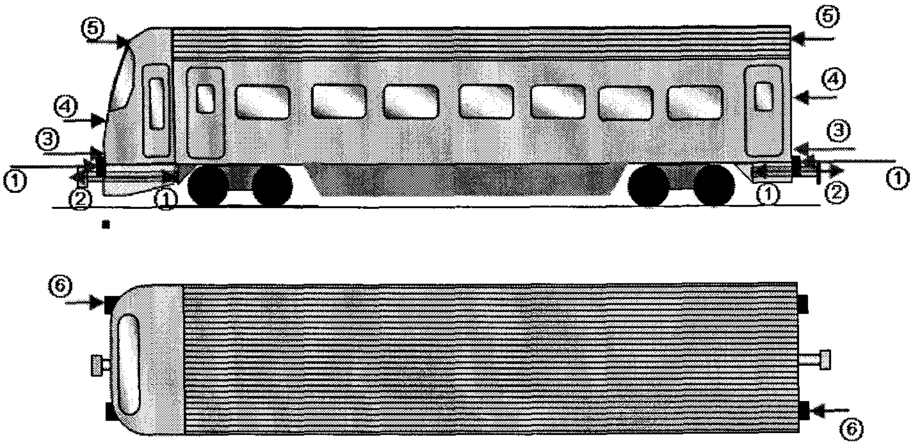


Fig. 1 The Specified basic design scenarios

The magnitudes of the applicable forces are summarised in the following table :

Table 2 : Longitudinal force magnitudes

| | Longitudinal force magnitudes [KN] | | | | | |
|---|---|---|---|---|---|---|
| Category | ① | ② | ③ | ④ | ⑤ | ⑥ |
| L | 2000 | 1000 | 400 | 300 | - | 500 |
| P-I | 2000 | 1000 | 400 | 300 | 300 | 500 |
| P-II | 1500 | 1000 | 400 | 300 | 300 | 500 |
| P-III | 800 | 600 | - | 300 | 150 | - |
| P-IV | 400 | 300 | - | - | - | - |
| P-V | 200 | 150 | - | - | - | - |

The application of the above compressive and tensile forces should be combined with the vehicle in working condition own weight. Load cases ③, ④ and ⑤ should be reacted at the coupler/anti-climber height level at the opposite end.

### 2.2.2 Vertical proof loads

#### 2.2.2.1 Maximum operating load

The bodyshell structure supported at its suspension points should be able to resist the following maximum operating load :

$$F_{vertical} = 1.3 \times g \times M$$

$$\textit{with}$$

$$\begin{cases} \text{Vehicle category L : } M = m_1 \\ \text{Vehicle category P-I, P-II, P-III, P-IV and P-V : } M = m_1 + m_4 \end{cases}$$

$$\textit{where}$$

$$\begin{cases} m_1 = \text{Design mass of the vehicle bodyshell in working order} \\ m_4 = \text{Exceptional payload} \end{cases}$$

#### 2.2.2.2 Lifting load cases

##### 2.2.2.2.1 Lifting at one end

The bodyshell structure when lifted at one end and resting on its suspension at the other end should be able to resist the following vertical load :

$$F_{lift}^{one\ end} = 1.1 \times g \times (m_1 + m_2)$$

$$with\ m_2 = \text{Bogie mass}$$

##### 2.2.2.2.2 Full lift

The bodyshell structure when supported on its purposely design lifting points should be able to resist the following vertical load :

$$F_{lift}^{full} = 1.1 \times g \times (m_1 + 2 \times m_2)$$

##### 2.2.2.2.3 Three point lift

The bodyshell structure when supported on its purposely design lifting points, one of which is out of plane with respect to the other 3, should be able to resist the following vertical load :

$$F_{lift}^{\text{3 point lift}} = 1.1 \times g \times (m_1 + 2 \times m_2)$$

### 2.2.3 Combined vertical and longitudinal proof loads

Passenger carrying vehicles should also be able to resist the combined effects of the coupler/anti-climber loads and an exceptional vertical load as summarised in the following below :

Table 3 : Longitudinal and vertical load case combination force magnitudes

| Category | Longitudinal force [KN] | Vertical load |
|---|---|---|
| L | - | - |
| P-I | Compression: 2000 | $F_{Vertical}^{Combined} = g \times (m_1 + m_4)$ |
| | Tension: 1000 | |
| P-II | Compression: 1500 | |
| | Tension: 1000 | |
| P-III | Compression: 800 | |
| | Tension: 600 | |
| P-IV | Compression: 400 | |
| | Tension: 300 | |
| P-V | Compression: 200 | |
| | Tension: 150 | |

### 3. Design standard prEN15227

Standard prEN15227 is dedicated to the crashworthiness of passenger carrying rolling stock and complements the proof and fatigue requirements, detailed in standard EN 12663. There are four design reference collision scenarios :

Scenario ① : Like to like trains head on collision
Scenario ② : Collision between a train set and a reference railway vehicle
Scenario ③ : Collision with a high sided road vehicle at a level crossing
Scenario ④ : Collision with "small and low" obstacle

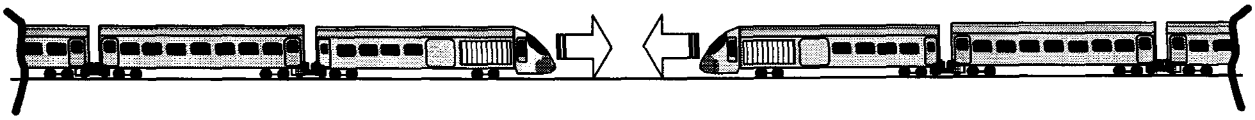
The vehicles, carriages and locomotives/power units, are grouped into specified categories according to the infrastructure they are to run over and the type of operation they are designed to fulfil. Four categories have been identified as follows :

Table 4 : Vehicle categories

| Category | Definition | Vehicle types |
|---|---|---|
| C-I | Vehicles operating on TEN routes, international, national and regional networks with level crossings | Locomotives, coaches & fixed units |
| C-II | Urban vehicles operating only on a dedicated railway infrastructure, with no level crossing | Metro vehicles |
| C-III | Light rail vehicles operating on urban or regional networks with level crossings and in track-sharing operation | Tram trains, peri-urban trams |
| C-IV | Light rail vehicles operating on dedicated urban networks with level crossings | Tramway vehicles |

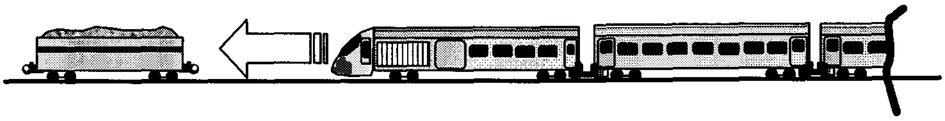
### 3.1 Crash scenario 1 : Like to like head-on collision

The primary crashworthiness design collision scenario consists of a train colliding head on with an identical train.



### 3.2 Crash scenario 2 : Collision between a train set and a reference railway vehicle

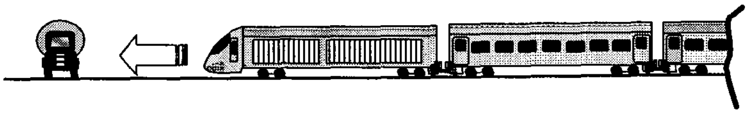
For the C-I and C-III category vehicle types, the impacted reference vehicle is an 80 tonne four-axle freight wagon equipped with side buffers. If a C-III category train is to run into mix traffic with vehicles equipped with central coupler the impacted reference vehicle should be an 129 tonne regional train. Both impacted reference vehicles are defined in the standard in terms of buffer and coupler locations and interacting surface sizes as well as force/displacement characteristic curves.



### 3.3 Crash scenario 3 : Collision with a high sided road vehicle at a level crossing

This collision scenario represents a collision between a train and a high sided road vehicle at a level crossing.

Previously, the 15 tonne road vehicle obstacle was modelled as a rigid mass presenting a vertical surface for impact (conform TSI crash scenario ③). This obstacle was, in away, only good enough to "test" the strength of the underframe of the cab but did very little in terms of its upper structure. However, with the advent of more powerful and user friendlier numerical software, more realistic 'deformable' obstacle models to replace the unrepresentative 15 tonne rigid mass obstacle, have been developed. These models are allowed to roll, realistically, in the train path when struck thus revealing the weaknesses of the upper structure and highlighting a more accurate extent or confinement, as the case may be, of the cab survival space loss. The definition of such a model, representing a lorry tanker, has been included into prEN15227.



A rigid model weighing 3 tonnes is still specified for the C-IV category vehicle type.

### 3.4 Crash scenario 4 : Collision with "small and low" obstacle

A fourth design collision scenario deals with 'small and low obstacle' collision. This collision scenario has been coded as two static load cases applied to the obstacle deflector should one be required. The magnitudes of the forces involved are related to the operational speed of the train under consideration.

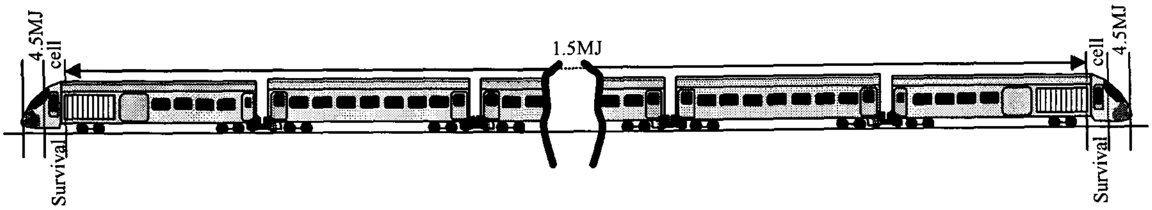
Table 5 : Obstacle deflector load cases

| Operational speed [Km/h] | ≥160 | 140 | 120 | 100 | ≤80 |
|---|---|---|---|---|---|
| Force acting along the centre line [KN] | 300 | 240 | 180 | 120 | 60 |
| Force acting at 750mm from the centre line [KN] | 250 | 200 | 150 | 100 | 50 |

NB: The above forces should be distributed over a 0.5mx0.5m surface

## 4. High speed train TSI considerations

A TSI compliant train should be capable to absorb by controlled collapse of purposely designed sub-structures, 6MJ of crash energy of which 4.5MJ should be absorbed in the front part of the leading vehicle and the remainder down the rake.



The TSI specifies three collision scenarios :

Scenario ① : A 36Km/h like to like trains head on collision

Scenario ② : A 36Km/h head on collision with 4 axle 80 tonne freight wagon

Scenario ③ : A 100Km/h collision with a 15 tonne lorry represented by a rigid mass presenting a vertical surface for impact.

For crash scenario ① no plastic deformations that could undermine the safety of the occupants in the cab and the passenger saloon should take place. For scenario ② and scenario ③ while deformation of the cab may occur, no plastic deformations of the passenger saloon that could affect the safety of the occupants are allowed.

All the vehicles within a train set shall have a consistent level of crashworthiness. The driver and passenger areas should be able to withstand a mean crush load of 1500KN. However, a higher design static buffing load limit is also given in Annexe A of the TSI document, as a load at least 1500KN above the crush force of the crumple zones for all three design main crash scenarios. This load definition for the driver and saloon areas reconciles the TSI with both standards prEN15227 and EN12663. Furthermore, the main text of the TSI calls for the deceleration levels in the passenger and driver areas to be limited to a maximum average of 5g. Annexe A of the TSI, however, also refers to a mean deceleration limit of 5g and thus aligning the TSI with prEN15227 which also specifies a limiting mean deceleration, as far as practicable, of 5g but not exceeding 7.5g.

The standard calls for the provision of anti over-riding capability and/or devices at the vehicle ends. PrEN15227 is more specific than the existing TSI on this subject and specifies that the colliding over-riding constraint systems should be able to engage one another even with a vertical offset of 40mm.

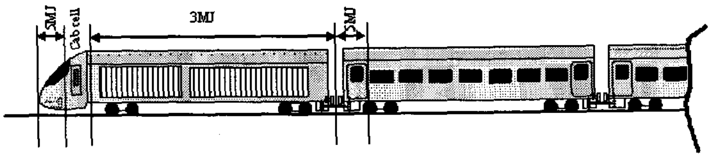
A rigid survival cell at least 750mm long and wide with a residual height of at least 80% of the un-deformed space shall be provided in the or at the rear of the cab for the driver.

### 5. UK rolling stock "existing" design considerations

In the UK, the design load requirements of bodyshells are compiled into Group Standard GM/RT2100. The Group Standard design proof loads are very similar to those listed in the European Standard EN12663. Many of the load cases have been taken from appropriate UIC leaflets. Other load cases have been introduced to reflect British rolling stock operational and design experiences. However a noticeable difference between prEN15227 and GM/RT2100 resides on the crashworthiness front where a higher speed of 60Km/h for the like to like head on collision is stipulated in standard GM/RT2100. As a minimum all vehicles extremities should be able to dissipate 1MJ of energy. However with the advent of higher operational speed (>160Km/h) and the carrying of passengers in the leading vehicles of high speed trains, enhanced crash energy absorption capabilities are required and are typically of the 3MJ order for cab ends and 2MJ per intermediate end modules.

### 6. USA passenger train design considerations

The design collision scenario for a “Tier II” passenger train able to operate at speed of 125mph (200Km/h) and up to 150mph (240Km/h) consists in a 30mph (48Km/h) head on collision with an identical stationary unit. A “Tier II” passenger train should be designed to absorb as a minimum 13MJ by controlled structural collapse of dedicated unoccupied zones. To that effect 5MJ are to be absorbed in front of the cab driver cell, 3MJ between the driver cell and the first trailer car and 5MJ at the end of the first trailer car adjacent to each power car.



The underframe of the cab cell of the power car should be able to resist 9342KN (2,100,000 pounds). Furthermore, the underframe of the occupied volume of the trailer cars should be able to resist a minimum longitudinal static compressive force of 3559KN (800,000 pounds). The underframe of purposely designed collapsible volumes of the power cars and trailer cars should be compatible with the crash energy management adopted and are not subject to the above specified buffing force limits.

No passengers are carried in the leading vehicle/power car. The deceleration of the occupied volumes shall not exceed 8g and a 50th percentile adult male seated anywhere in a trailer car should not impact the back of the seat in front of him at a speed greater than 25mph.

## 7. Conclusion

In the present paper an overview of the European standards for the design of passenger carrying rolling stock bodyshell is given. References are made to existing British and American design standards for information and comparison purposes.

It should be noted that standard EN12663 is being revised with the intention of issuing it as a two part document: one part dedicated to passenger carrying trains and another part covering the design of freight carrying wagons. Standard EN15227 is in the process of being ratified for formal release and as it stands, no major alterations from the latest draft, used as reference material in the present paper, are expected.

## 8. Bibliography

1. BS EN 12663:2000, "Railway applications - Structural requirements of railway vehicle bodies"
2. Draft BS EN 12663-1, "Railway applications - Structural requirements of railway vehicle bodies – Part 1: Railway vehicles other than freight wagons"
3. Draft BS EN 12663-2, "Railway applications - Structural requirements of railway vehicle bodies – Part 2: Freight wagons"
4. Draft prEN15227 (2006-10), "Railway applications – Crashworthiness requirements for railway vehicle bodies"
5. Railway Group Standard GM/RT2100 – Issue 03, "Structural Requirements for Railway Vehicles"
6. UIC Leaflets
7. APTA SS-C&S-034-99 Rev. 1 Standard for the Design and Construction of Passenger Railroad Rolling Stock
8. FRA Code of Federal Regulations 49 CFR, Part 238