C4R
Capacity for Rail

Towards an affordable, resilient, innovative and high-capacity European Railway System for 2030/2050

Design requirements, concepts and prototype test results (final)

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Executive Summary

This report is the third deliverable for Work Package 1.1 under Sub-Project1 (SP1) of the Capacity4Rail (C4R) project.

The aim of this deliverable is to present the 2 new slab track concepts that address the general objectives of the project, i.e. an affordable, adaptable, automated, resilient and high capacity railway infrastructure. To that extent, the deliverable documents the structural and functional design, describes the developed installation and maintenance procedures and presents the results of the studied business cases.

Additionally, as both concepts were prototyped, installed full-scale in the CEDEX railway section testing facilities and tested, the deliverable strives to describe the unexpected difficulties and conclusions related to the installation procedure extracted from the prototype construction, record the parameters and particularities of the tests performed on the prototypes and present the analysis of the data recovered during the testing.

In Section 3, the deliverable recaps the general requirements for designing an innovative slab track concept. These requirements are mainly based on the feedbacks from current operated slab track systems. A special attention is paid for construction costs and maintenance costs requirements in order to design a financially more attractive product.

Section 4 provides a detailed geometric description of both slab track concepts, as well as a general overview of the structural and functional design process, including the most relevant features of the FE models and a general approach to the results

Section 5 and 6 describe the component fabrication process, system installation procedure and foreseen maintenance operations

Sections 7 documents the installation, testing procedure and data analysis performed of the two concept prototypes

Sections 8 and 9 document the Life Cycle Cost and studied business cases and their most relevant conclusions.

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Abbreviations and acronyms

Abbreviation / Accronym	Description
3MB	Multi Moulded Modular Slab Track : 1^{st} slab track concept
L-Track	Name of the 2^{nd} slab track concept
RAMS	Reliability Availability Maintainability Safety
LCC	Life Cycle Cost

1 Introduction

The overall objective of *SP1 – WP1.1 Modular integrated design of new concepts for infrastructures* is to design, develop and test new concepts for railway track, adapted to mixed traffic and eventually adaptable to very high speed, with the following particular distinct features:

- Cost and RAMS oriented design.
- Modular design in order to enable "Plug&Play" for rapid construction or maintenance.
- Adaptability of existing infrastructure to new freight requirements.
- Energy provision, telecommunications and signalling will be incorporated, whenever possible.

The main goal of the second task on T1.1.2 is to invent and then design 2 new slab track concepts in agreement with requirements defined in previous task (T1.1.1). The main goal of T1.1.3 is to achieve the fabrication, installation and testing of prototypes for the previously mentioned concepts.

2 Objectives

The objective of this deliverable is to present the results of the development and design process that lead to the two novel slab track concepts, including the insights obtained during the prototyping and testing of the concepts.

To achieve the aforementioned objective, the following secondary goals were fulfilled:

- Definition of design requirements
- Geometric and functional design
- Static and dynamic calculation of the structural elements
- Element fabrication, system installation and maintenance procedures
- Prototyping and testing
- Life Cycle Cost analysis and business cases

3 Requirements

The design requirements have been analysed in the task WP11.1 of the project and are specified in detail in the deliverable D11.1. This section recovers the main conclusions of said deliverable, as they were recapped in D11.2.

3.1 Geometrical requirements

The geometrical requirements of the track focus on 6 specifics points:

- **Cost-Effective track and layout parameters :**
  Because of its better resistance, slab track allows narrower curve with high superelevation and higher cant deficiency. This advantages permit to have a layout with better adaptability to topographical constrains. Therefore the cost of infrastructure may be decreased compared to ballasted track.

- **Reduced height and weight :**
  Low overall track height has significant impact in tunnel because it allows to reduce the tunnel diameter compared to ballasted track. Moreover, height reduction often means weight reduction, which is very important for bridge design.

- **Integration of signalling systems :**
  Signalling equipment has to be taken into account during the design of the slab in order to avoid operation after slab construction to install such equipment.

- **Earthing of the metallic parts :**
  Optimisation of reinforcement of the concrete elements of the track is very important to avoid voltage difference and possible damages of the structure.

- **Electrical isolation of the rails :**
  A compromise has to be reached between a low bedding resistance for earth current diffusion and a high bedding resistance to preserve signalling equipment.

- **Facilitation of drainage :**
  Drainage of slab tracks is a critical requirement, as it is source of many maintenance problems. The evacuation of water between the rails and between parallel tracks may require additional drainage channels than for ballasted track.

3.2 Mechanical requirements

The mechanical requirements of the track focus on 6 specifics points:

- **Non-setting subsoil :**
  In slab track systems, correction of track geometry can be almost exclusively done by fastenings adjustment. With corrections up to 26mm in vertical position and 5mm in horizontal position only small deformations are possible to counteract. As a consequence to

the small adaptability of slab tracks, any settlement in the embankments must try to be avoided.

- **High quality of supporting structure :**
  Supporting structure is not well defined in term of limits. According to the UIC 719 leaflet it is located between "Track components" and "Earthwork". The supporting structure is in many cases made with a reinforced concrete slab; it can consist of unreinforced concrete or asphalt layer too

- **High quality of earth work :**
  As explained above slab track does not admit important settlement of the soil support. When settlement criteria cannot be achieved, strengthen methods in the subsoil must be applied such as additional reinforcement layers or piles foundation.

- **Adequate track stiffness :**
  Stiffness is still an open point in the standards. The common range of values for stiffness of the overall track structure can be of the order from 50 to 100 kN/mm per sleeper which makes the rails deflects approximately 1mm to 2mm under a 20-t axle load. Such values ensure a good compromise between ride comfort and track components life duration. A minimum spreading of load is ensured and stress or strain in track components keep reasonable.

- **High track resistance :**
  One of the main function of the track is to support the train. The wheelsets transmit vertical, horizontal and longitudinal forces onto the track.
    - Resistance to vertical loads is directly linked to track stiffness
    - Resistance to dynamic horizontal loads due to accelerations not compensated by track cant and also crosswind and bogie yaw effects.
    - Resistance to longitudinal loads takes into account forces from acceleration and breaking and also thermal forces

- **Compatibility with bridge movements :**
  A bridge provides a solid foundation for slab track, but temperature changes and traffic loading can cause longitudinal movements, bend of the spans and to twist over the supports. Therefore the slab track must be able to withstand these movements. Many solutions already exists and a rail-structure interaction analysis is needed to select the best.

3.3 Environmental requirements

The environmental requirements of the track focus on 3 specifics points:

- **Possibility to install noise and vibrations absorbers :**
  Noise emissions reduction is a key issue. Two noise sources are identified:
  - Airborne noise: Can be limited with acoustic panels and rail dampers
  - Vibrations and structure-borne noise: Can be limited with rail dampers and appropriate stiffness levels (rail pad, under-slab pad etc.)

Slab track design could include small acoustic panels close to the wheel-rail contact and noise absorption surfaces.

- **Use of waste materials :**
  The construction and renewal of railway infrastructure has an enormous potential in terms of the use of waste, including that deriving from its own activities and from other sectors. The use in track construction of materials made from recycled waste enables, on the one hand, a reduction in the demand of non-renewable natural resources, and on the other, a reduction in the amount of waste dumped without being used.

- **Non-contaminant leachate :**
  Leachate is a widely used term in the environmental sciences where it has the specific meaning of a liquid that has dissolved or entrained environmentally harmful substances which may then enter the environment. The contaminant ability of any new solid material used for slab track has to be investigate.

3.4 Construction requirements

The environmental requirements of the track focus on 5 specifics points:

- **Low number of construction steps :**
  The simpler or less sensitive the design of a slab track, the easier its construction and he more reliably and cost-effectively a high quality standard can be achieved.

- **Fast construction :**
  The construction performance of a slab track system depends on the number of in-situ works, including the assembly of precast elements and the track alignment. Manufacturing of precast elements can limit the speed of in-situ construction if the production rate is not adapted.

- **Modularity :**
  Besides reduction in cost and flexibility in design, the use of standardised construction elements allows a high degree of prefabrication (independent of building site impacts) and therefore extensive assembly works and assembly quality.

- **Easy transport of precast elements to construction site :**
  In case of prefabricated slab track, the size and total weight of individual slabs are important for the construction phase (transport and installation), and also for the removal and replacement if necessary during maintenance operation. Trucks are able to transport up to 30tn through most of European road network, while the trailer usually have a 12m long and 2,60m width area for placing cargo. Higher weights and dimensions are possible but the road authority shall give a special authorization.

- **Easy alignment of track panels :**
  Common to most of slab track construction procedures is the costly and time consuming process required for the correct positioning of the precast elements. This precise installation is essential for good long-term stability of a slab track system. Geometric imperfections

during the installation stage must be avoided by using techniques adopted for road pavement construction for the track structure and the formation work, coupled with a precise dimensional control of the actual construction process.

3.5 Maintenance requirements

The maintenance requirements of the track focus on 3 specifics points:

- **Low maintenance :**
  The low maintenance needs is one of the common features of slab track systems and should be also shared by the new developed ones.

- **Easy replacement of track components :**
  Due to the long life of slab track systems, it is expected to replace at least one time the track components subjected to the highest stresses, i.e. rails, fasteners and elastomers, so the procedure to exchange this elements shall be considered in the design phase.

- **Friendly repair procedures on unforeseeable events :**
  Repair works for the slab track use to be complicated, cost-intensive and time-consuming. The operation hindrance cost in case of long closures of slab track lines due to unexpected defects are extremely high and can hardly be calculated or predicted today.

These requirements will be achieved through a RAMS oriented design.

3.6 Cost requirements

Total cost of ownership of slab track include construction and maintenance cost. Only this total cost is relevant for economic analysis. The cost requirements of the track focus on 3 specifics points:

- **Low construction costs :**
  Traditionally the construction cost of slab track systems is much bigger than for ballasted track. That is one reason why slab tracks is not very widespread around the world. The construction cost of a slab track system in plain lines consists of manufacturing of precast elements, delivery, assembly and installation of complementary equipment, such as noise absorbers or derailment devices.

- **Low maintenance costs :**
  Economic efficiency of slab track as against ballasted track can be calculated only from the increased maintenance expenses required for ballasted track.

- **Long life cycle :**
  Current life expectancy of slab track systems is about 60 years, while in ballasted tracks it is about 40 years. The most usual problems that lead to the end of life of the system are the following:
  - Fatigue strength of the rail fastening system and its components (intermediate layers, intermediate plates, angular guide plates, rail clamps, sleeper screws and anchor bolts)
  - Fatigue strength of the reinforcement and concrete of the track base layers

- Fatigue strength of the elastic coating
- Fatigue strength of the grouting concrete and the substructure (according to application: concrete subbase, hydraulically bound base layer, anti-frost layer, tunnel floor etc.)
- Ageing of the components mentioned above

These requirements will be achieved through a Life Cycle Cost study of the new concepts.

3.7 OPERATIONAL/SAFETY REQUIREMENTS

The cost operational and safety requirements of the track focus on 5 specifics points:

- **Performances parameters :**
  The Capacity4Rail is focused on the core TEN lines and the new slab track systems will be developed for high-speed and mixed traffic, so the TSI categories of lines to be applied are Category I and Category IV-M.

- **Compatibility with linear eddy current brakes :**
  When a linear eddy current is applied, the rails are heated up and therefore, could diminish track stability. The average rise of rail temperature in typical conditions is approximately 16 ºC, but can amount to up to 25 ºC under extreme operational conditions. In these circumstances and under strong insulation the rail temperatures can rise to over 80ºC and cause additional rail tension due to which the “critical temperature” might be exceeded.

- **Track accessibility to road vehicles :**
  Considering the evacuation of passengers following an incident, it is important to eliminate tripping hazards on the ground. Rescue vehicles are expected to get access to the location of the incident, as well as extinguishing resources in case of fire. As stated in the specific TSI ‘safety in railway tunnels’, the infrastructure facilities shall guarantee the self-rescue evacuation routes as well as the access for rescue services.

- **Integration of derailment devices :**
  The usual arrangement of derailment retention device consists of an auxiliary rail fixed 180 mm outside the outer running rail on a special baseplate with two rail positions, but the elastic rail support points used in slab track make this arrangement unsuitable. The new slab track systems shall allow either the fixing of the auxiliary rail (standard solution) or be provided with integrated derailment protection devices.

- **Electromagnetic compatibility :**
  Slab tracks, with their reinforced concrete layers, have substantial electromagnetic properties. In their development, it is necessary to consider effective measures against lightning and catenary line breakage. These measures involve grounding elements (equipotential bonding).

4 Novel Slab Track concepts

4.1 Concept inception

The process by which the two novel concepts were generated was thoroughly described in D11.2. Thus, only a short summary shall be included in the present document.

Several collaborative workshops were held in Systra and Acciona premises during the project

As a result of the collaborative work performed during the **first workshop**, the following concepts were developed:

Moulded Modular Multi-blocks Slab-Track was generated priming RAMS principles, and consisted of a reinforced concrete base slab in which moulded blocks holding two consecutive rail fasteners were mounted. Blocks were to be connected horizontally by means of cylindrical protrusions from the base slab (stoppers), free to move vertically to allow for the vibration attenuation of an elastomeric base, and restrained by steel fasteners to prevent excessive movement.

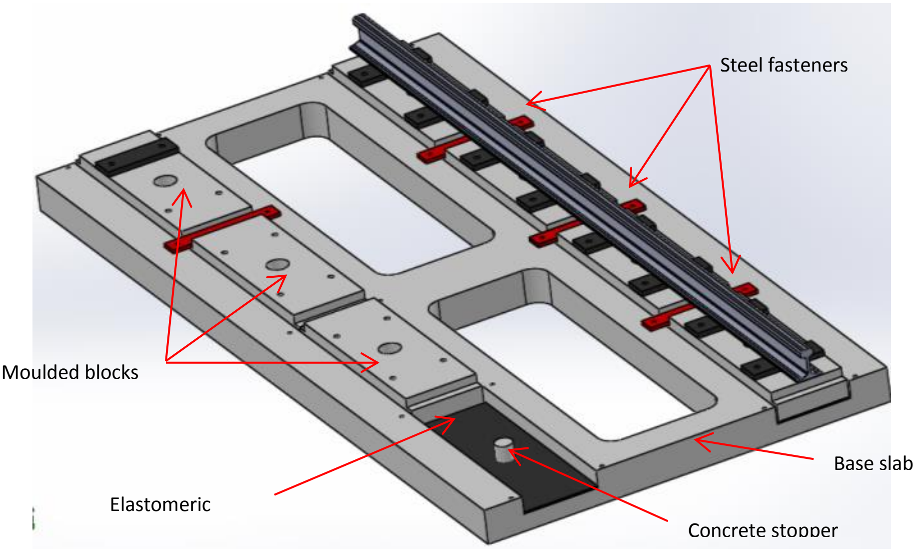


FIGURE 1 : MOULDED MULTI MODULAR BLOCK SLAB TRACK

Vertical alignment was to be obtained through the use of a wide range of blocks with different heights, thus negating the need for precision in the execution of the sub-base

L-Track was designed to be suitable for most subgrade conditions, modular and low-cost.

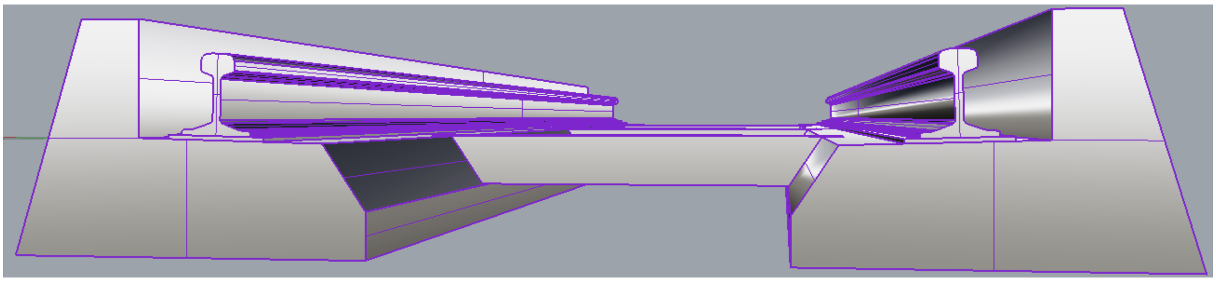


FIGURE 2: L-TRACK SLAB

Modules were to be composed of twin parallel longitudinal concrete beams, linked in situ by transversal sleepers (three per module). Horizontal restraint was to be obtained by means of a central rib in the bituminous sub-base.

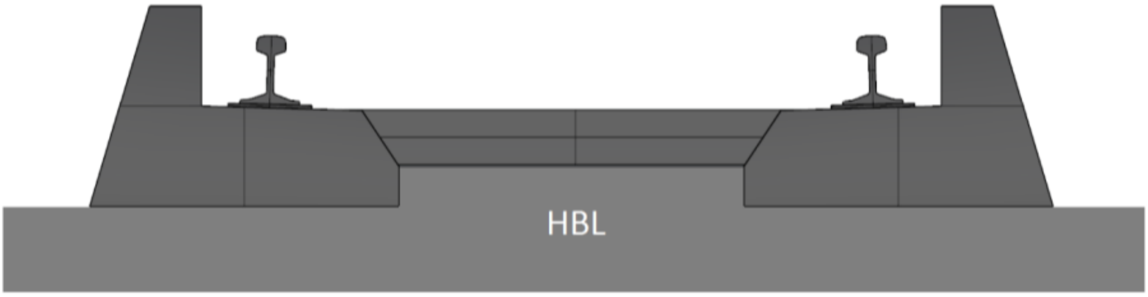


FIGURE 3: L-TRACK FRONT VIEW

Steel Track was designed as an entirely steel 12 m long slab composed of two parallel steel I beams connected by transversal steel tubes. A continuous rubber trim would be responsible of noise and vibration mitigation, and rail support was to be continuous

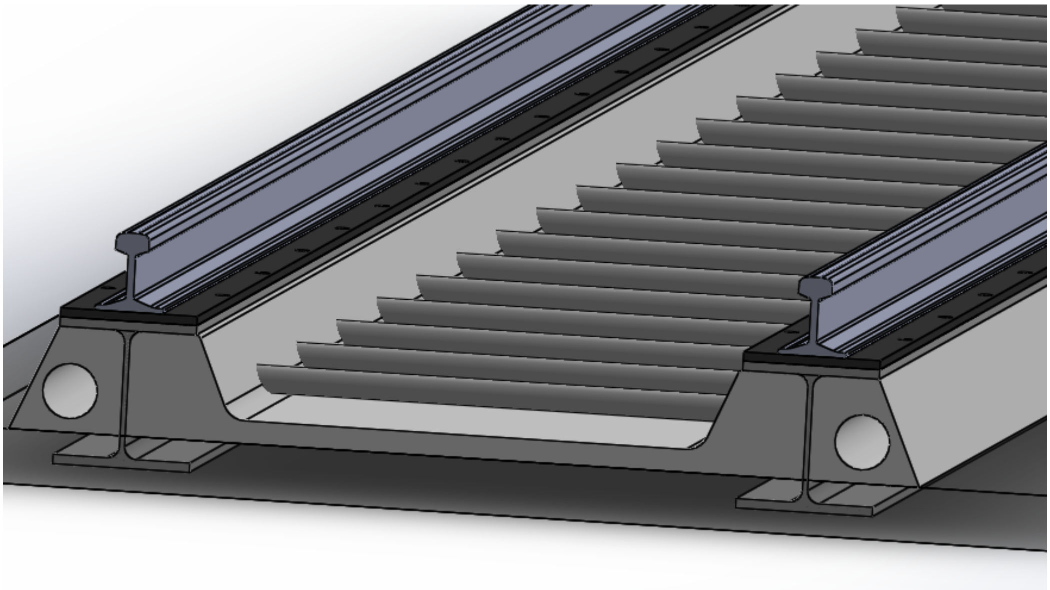


FIGURE 4: STEEL TRACK

The **second workshop** strived to rework and improve the previously developed concepts, as well as define a LCC and RAMS assessment grid in order to evaluate the designed concepts

All three teams reworked the L-track concept, and differed solely on the cross-section of the longitudinal beams, the nature of the transversal sleepers and the horizontal restraint system:

Team A Concept opted for a rectangular cross-section, transversal connection through embedded steel I-beams and horizontal restraint by means of concrete stoppers embedded in the bituminous sub-base and connected to the beams through steel or composite plates

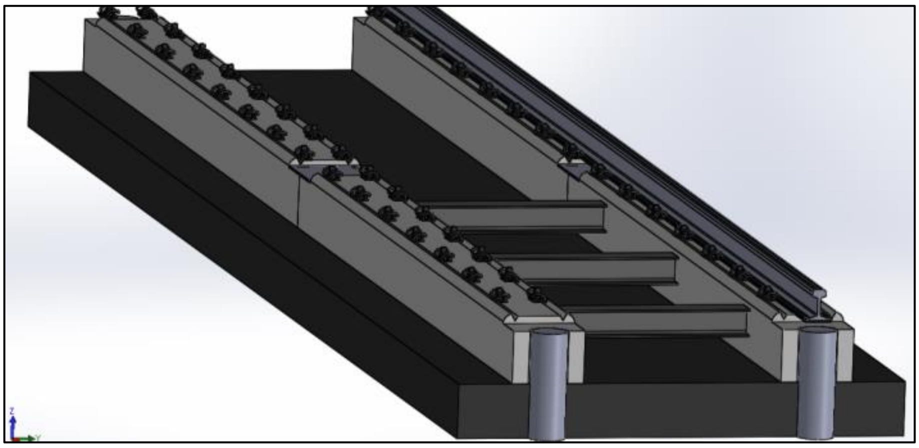


FIGURE 5: GENERAL VIEW OF THE CONCEPT

Team B Concept chose a trapezoidal cross-section, precast concrete sleepers for transversal connection and in situ mortar under the beams to connect them to the sub-base

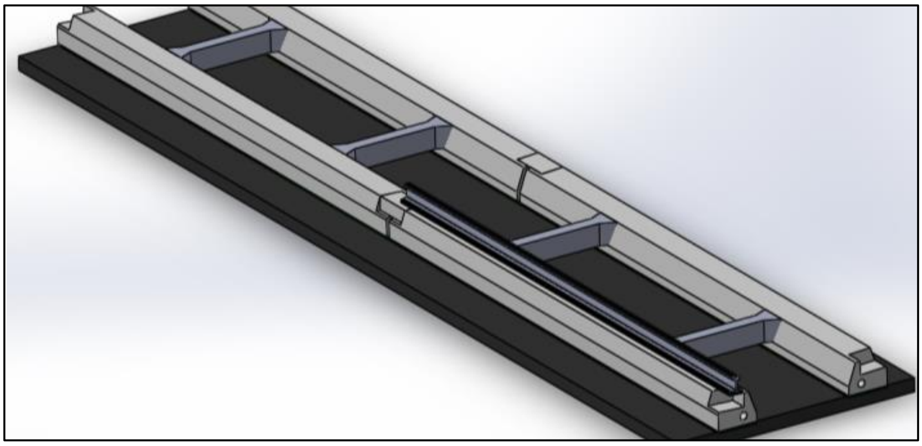


FIGURE 6: GENERAL VIEW OF TEAM B CONCEPT

Team C opted for a rectangular cross-section with lateral noise-barriers, embedded steel T beams for transversal connection and a central bituminous rib for horizontal restraint.

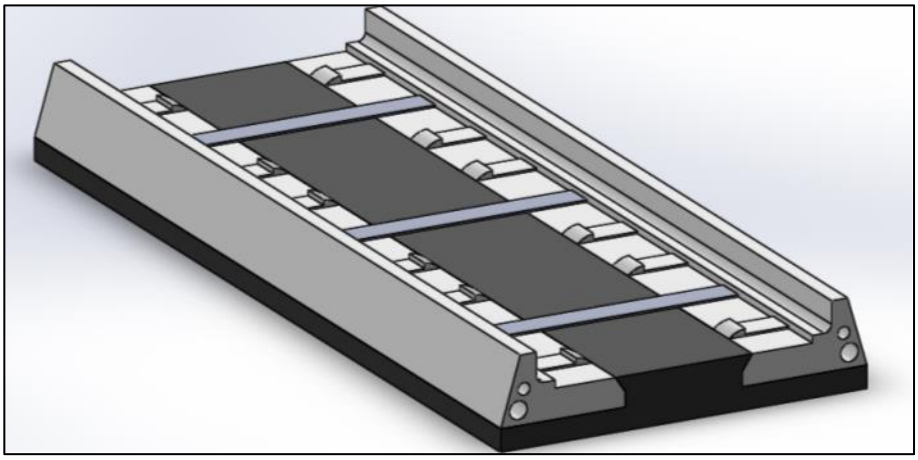


FIGURE 7: GENERAL VIEW OF TEAM C CONCEPT

After evaluating all developed concepts using the LCC and RAMS assessment grid, the **Multi-Moulded Modular Blocks** (**3MB**) slab track and **Team B variation of the Ladder track (L-track)**were selected.

The **third workshop** was held in order to correct and modify the functional flaws and structural weaknesses that had been detected in the concepts after the end of the second workshop.

The **3MB concept** was reworked severely, as original element geometry was impractical for precasting, doubts arose as to the resilience and quality control of proposed concrete stoppers, steel fasteners for vertical restraint could be prone to fatigue and hammering, and vertical alignment based on interchangeable blocks of varying heights was judged to be logistically challenging and troublesome to execute.

The **L-Track concept**, on the other hand, suffered minor modifications and variations mainly due to structural reasons, and alternate designs using discrete and continuous rail support were proposed.

After the end of the third workshop, the final conceptual design was accepted as ready for dimensioning.

4.2 Geometric and functional description

4.2.1 Moulded Multi Modular Block system

The 3MB system is based on the concept of multiple-level modularity and strives to achieve fast and easy maintainability through the use of easily replaceable, precast components.

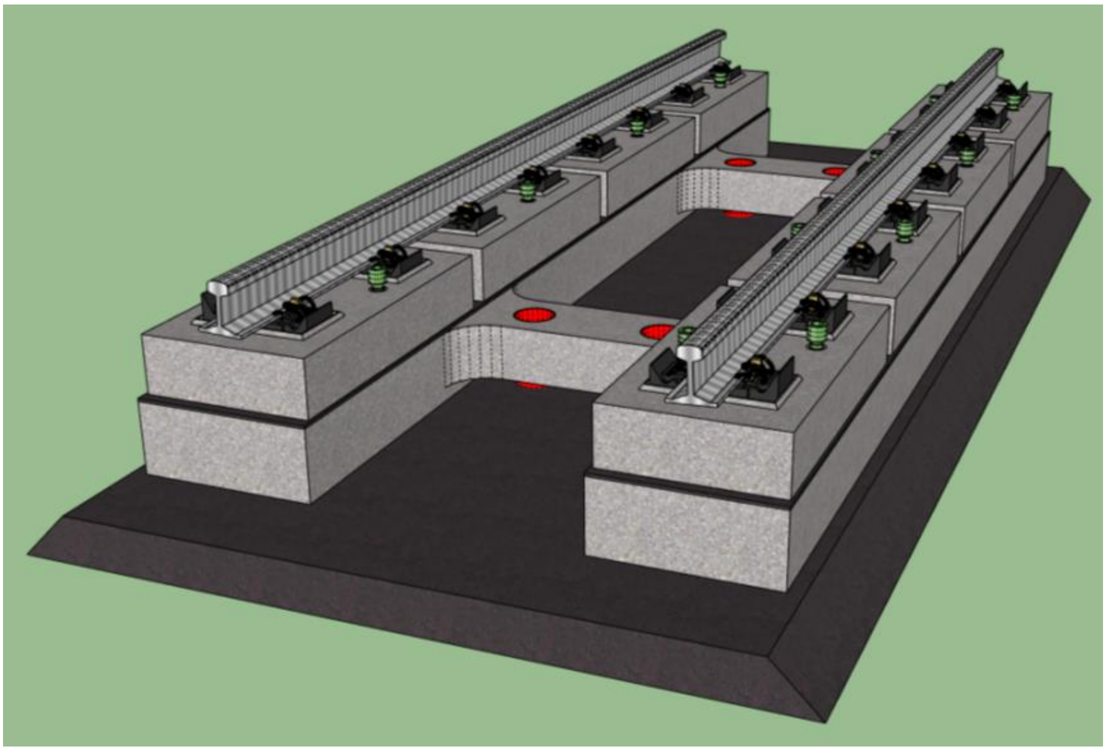


Figure 8: 3MB final design general view

4.2.1.1 Concept description

The system is composed of 4,80 m long modules, each comprising the following elements:

The **base slab** is composed of two longitudinal 600 x 250 x 4780 mm reinforced concrete beams connected by two transversal beams with a 300 x 200 cross section and R150 mm concave chamfers in the intersections with the longitudinal beams.

Additionally, the transversal beams present R75 mm cylindrical through holes for in-situ connection with the bituminous sub-base where needed.

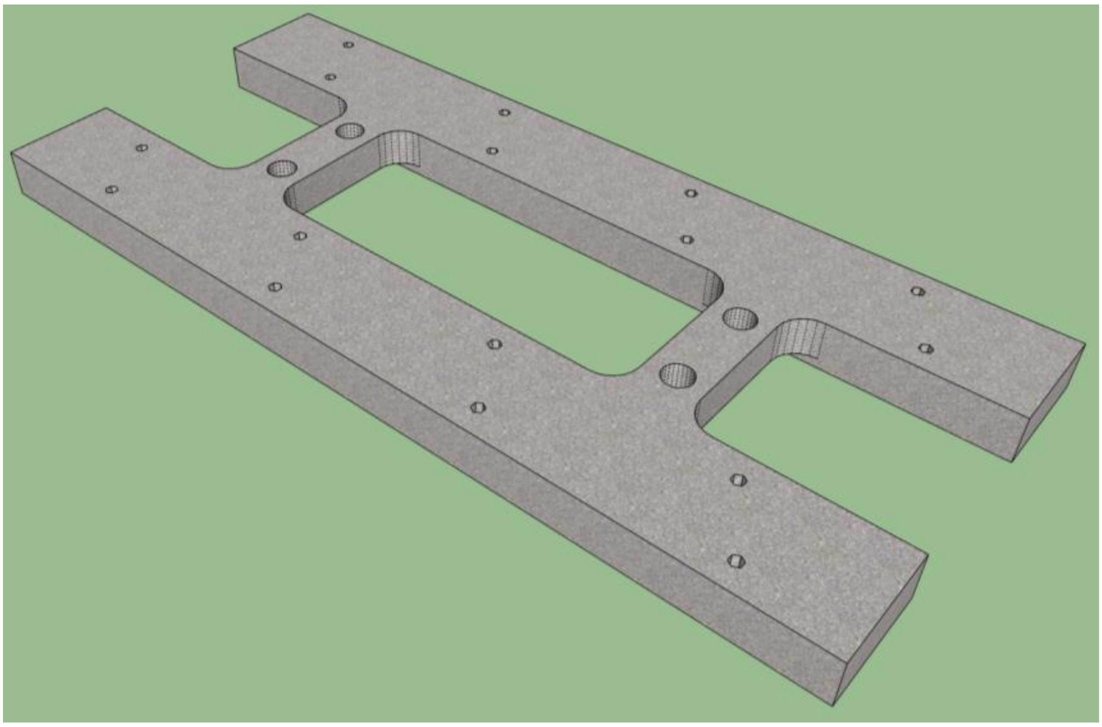


FIGURE 9: 3MB BASE SLAB

Two 10 mm thick TPV+EVA **elastomeric strips** cover the surface of the slab, providing extra vibration attenuation for the system and preventing the hammering of the moulded blocks against the base slab.

The mats present R18 mm cylindrical through holes to allow the passage of the steel pin system connecting moulded blocks and base slab.

FIGURE 10: ELASTOMERIC STRIP

Eight **precast moulded concrete blocks**, four on each longitudinal beam of the base slab, provide support for the fastening system and rail.

The blocks are parallelepipeds 200 mm high, 1120 mm long and 580 mm wide, and present in their top face two 380 x 220 x 140 mm cavities for the levelling adjustment and installation of fasteners, as well as two R30 mm cylindrical through holes to accommodate the steel pin connection to the base slab

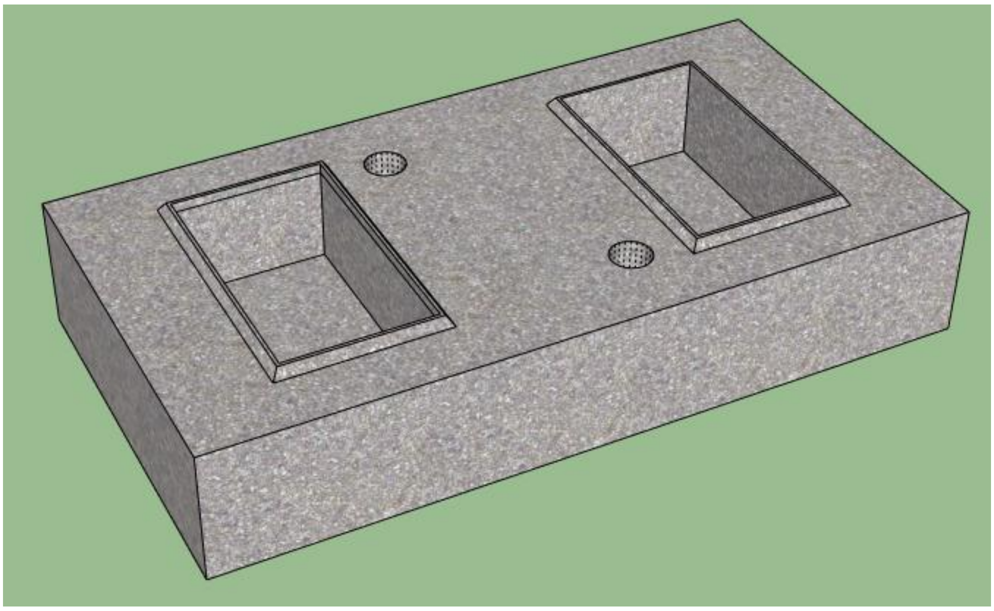


FIG 11: MOULDED PRECAST BLOCKS

In order to restrain the moulded blocks horizontally while allowing unrestrained vertical movement, a **double steel piston system (steel pins)** has been devised.

The system is devised so that the piston is fixed to the base slab while the cylinder is fixed to the through holes in the block, thus allowing the block to move parallel to the piston axis but constraining all other movement.

Each block is restrained by two non-coaxial steel connectors, thus preventing unwanted rotation around the piston axis.

Each of the two steel connectors (or “pins”) are comprised of the following elements:

- A 100 mm long M36 hexagonal steel nut, embedded in the base slab by means of a soldered R40 mm flat washer 8 mm thick
- A 350 mm long M36 partially threaded steel bolt, presenting 100 mm of thread, screwed onto the steel nut
- A 200 mm long R21 steel tube, 3,6 mm thick, Teflon-coated in the inner surface and connected to the moulded block by means of mortar poured *in situ* between the tube and the cylindrical through holes in the block

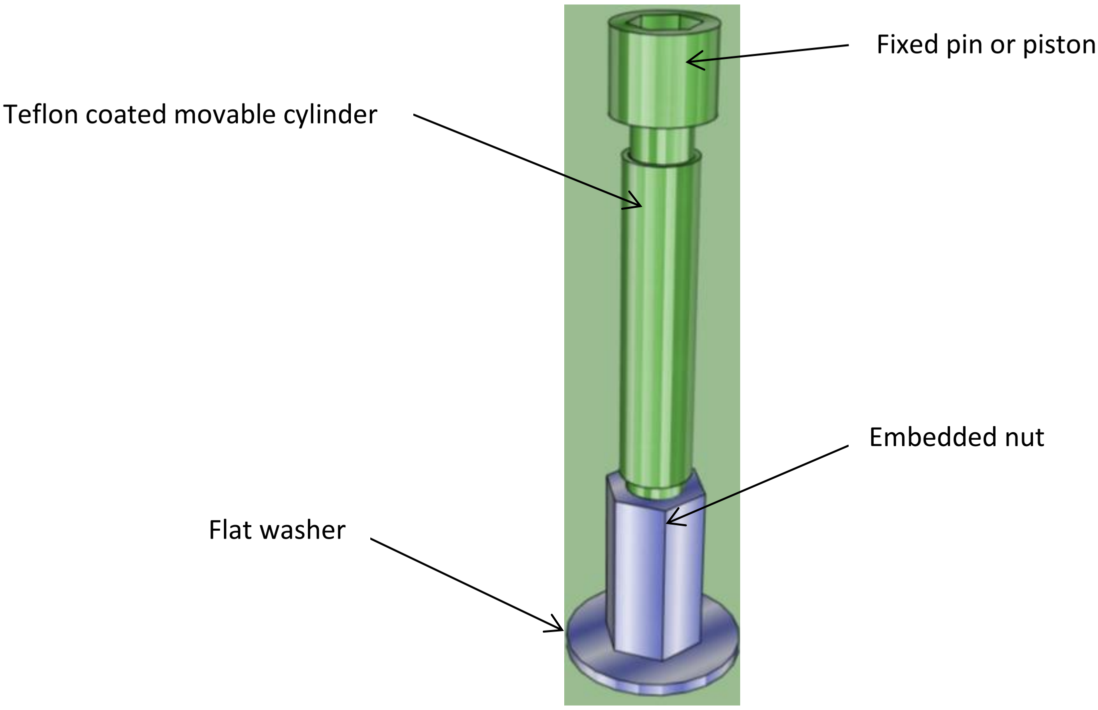


FIG 12: STEEL PIN

The 3MB slab track uses System DFF21 from Vossloh as **rail fastening system**, connected to the moulded blocks through plastic dowels embedded in mortar, poured *in situ* in the rectangular block cavities prepared to that effect.

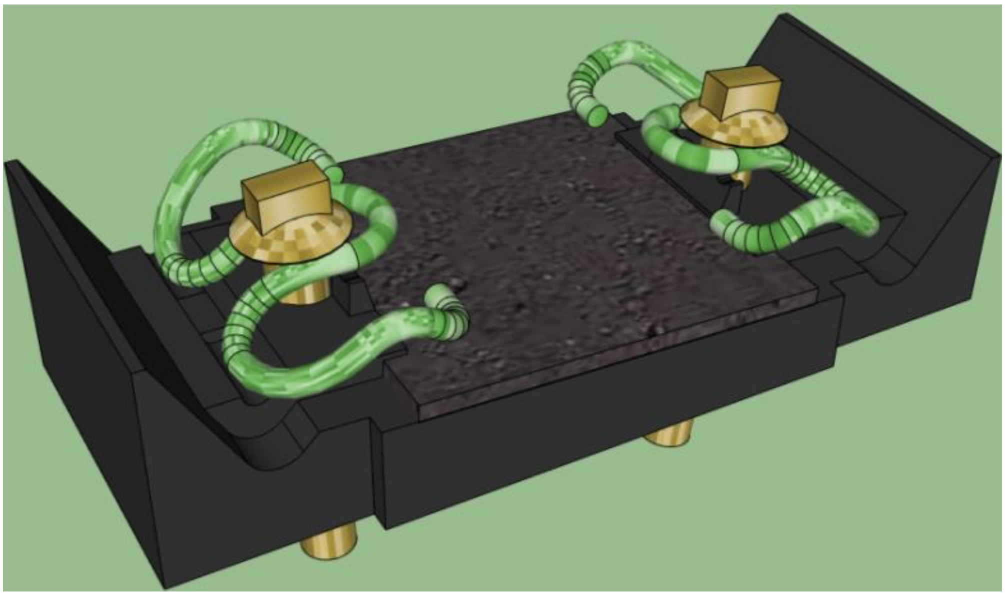


FIG 13: DFF21 FASTENING SYSTEM

4.2.1.2 Functional description

All of the previously described components play a very specific role in the functional model of the track system.

The **bituminous subgrade** provides adaptability to terrain settlements, disperses the loads transferred by the base slab and, where needed, allows the in-situ anchoring of the base slab

The **base slab** supports the moulded blocks, clamps the steel pins and disperses the loads transferred vertically by the blocks and horizontally by the pins. Where needed, it holds the in situ stoppers that connect the system to the sub-base

The **elastomeric strips** provide vibration attenuation and prevent the hammering between base slab and blocks

The **steel pins** restrain the blocks horizontally while allowing the free vertical movement the elastomeric strip requires for dissipating vibrations

The **pin mortar** effectively connects pin cylinders and moulded blocks

The **moulded blocks** provide support (both vertical and horizontal) for the fastening system by means of the in situ mortar poured on the fastener-holding cavities.

The **fastener mortar** provides geometric adaptability, allowing for top-down alignment, and once hardened guarantees track gauge and alignment

The **fastening system** provides elastic support and restraint to the rails

The **rails** provide support and guidance to the train

4.2.1.3 Advantages of the concept

- Thanks to the top-down alignment process, sub-grade precision tolerance is lowered, simplifying the construction process
- Main elements are precast off-site, allowing for mass production, providing enhanced quality control and drastically shortening in situ installation time
- Design is completely modular thanks to standard easily replaceable elements.
- The additional elastic level under the blocks provides vibration attenuation and energy dissipation.
- Blocks are designed to act as a “fuse”, guaranteeing that, in case of structural damage, it shall concentrate on the most easily replaced elements.
- Bituminous sub-base and base slab are designed to adapt to terrain settlements without compromising structural integrity.
- Track realignment after a soil settlement episode does not require base slab replacement.
- Thanks to the unscrewable pin system, blocks may be removed and replaced with minor to no elevation of the rail
- Maintenance and repair operations do not require the use of heavy lifting machinery.

4.2.2 L-Track System

The L-Track system is based on the concept of continuous rail support and industrialization of element fabrication.

Through the use of a specially designed fastening system, standard L-track modules may be used both for straight track and for curves with a radius greater than 300 m, thus benefiting from the scale economy of using standard precast elements for most track segments.

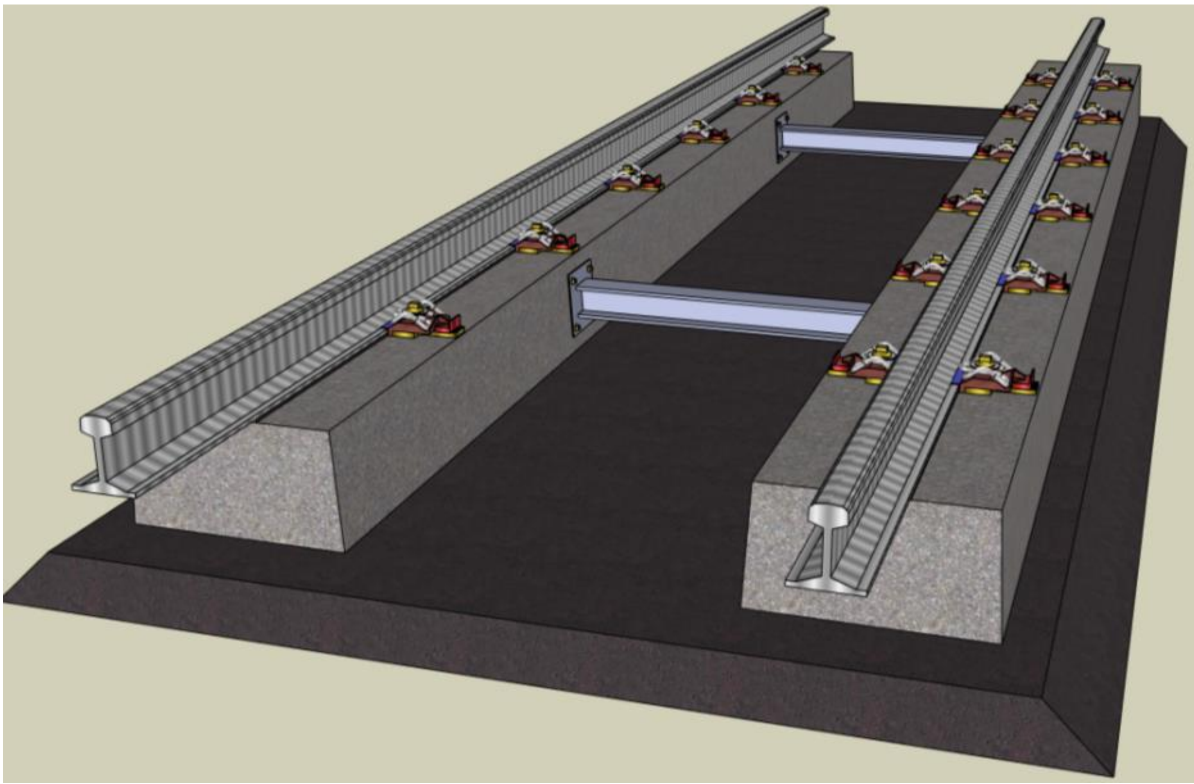


Fig 14: L-track system

4.2.2.1 Concept description

The system is composed of 5,4 m long modules, each comprising the following components:

Longitudinal beams are reinforced concrete elements 5,3 m long presenting a trapezoidal section with 300 mm height, 560 mm bottom width and 540 mm top width.

Both beams present embedded grooves and dowels on the top face, placed with a separation of 900mm between dowel axes and the first and last dowel axis at 400 mm from the beams ends. In curves with a radius under 3000 m, dowel separation is reduced to 600-700 mm to facilitate rail geometry and enhance lateral restraint.

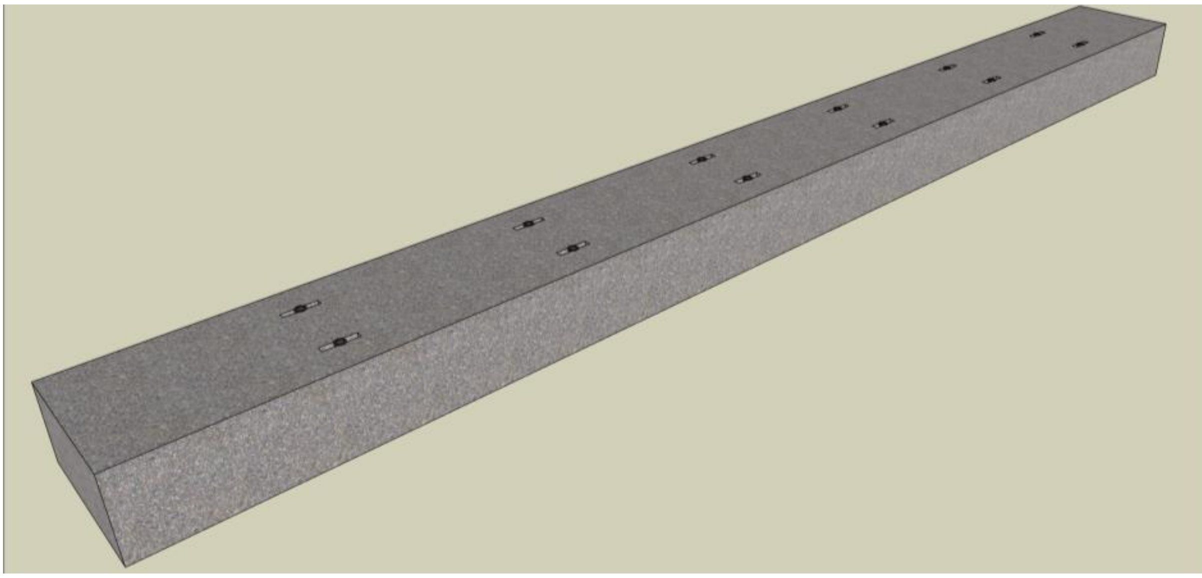


FIG 15: LONGITUDINAL BEAM

In order to guarantee the track gauge and prevent independent movement between longitudinal beams, two **transversal beams** are anchored *in situ* to the inner face of the longitudinal beams.

Said transversal beams present a standard HEB-100 cross-section, 967 mm of length, and end in square steel plates of 200 x 200 x 2 mm, tilted 4 degrees to match the concrete beam inner faces, with 4 symmetric 14 mm diameter cylindrical through holes placed at a 25 mm distance of the plate edges.

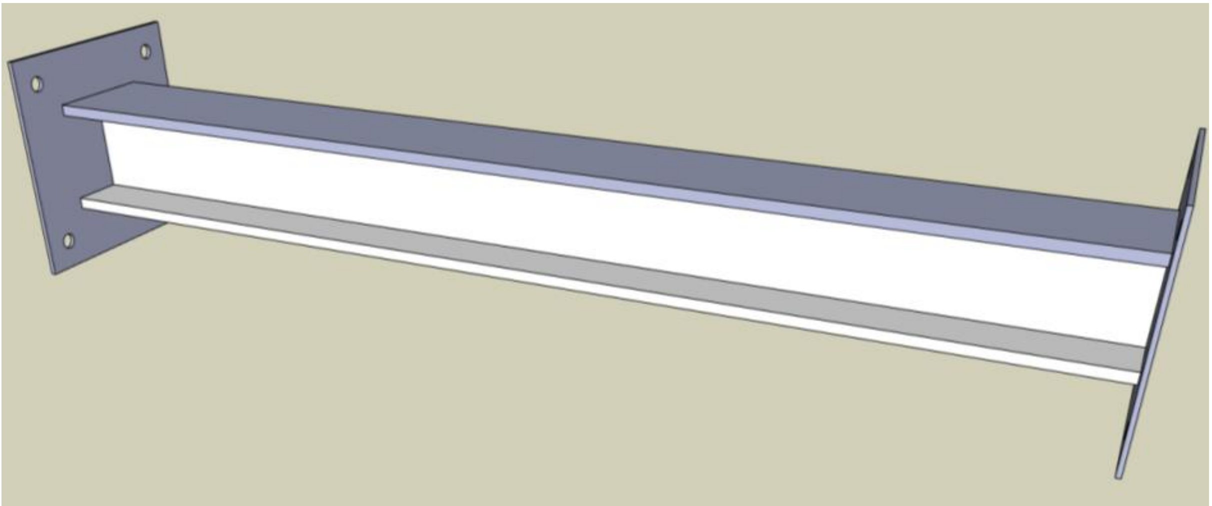


FIG 16: TRANSVERSAL BEAM

In order to provide adequately flexible support for the rail, **continuous elastomeric under rail pads** are used.

Said pads present a width of 170 mm, a thickness of 7 mm and cover the whole length of the longitudinal beams

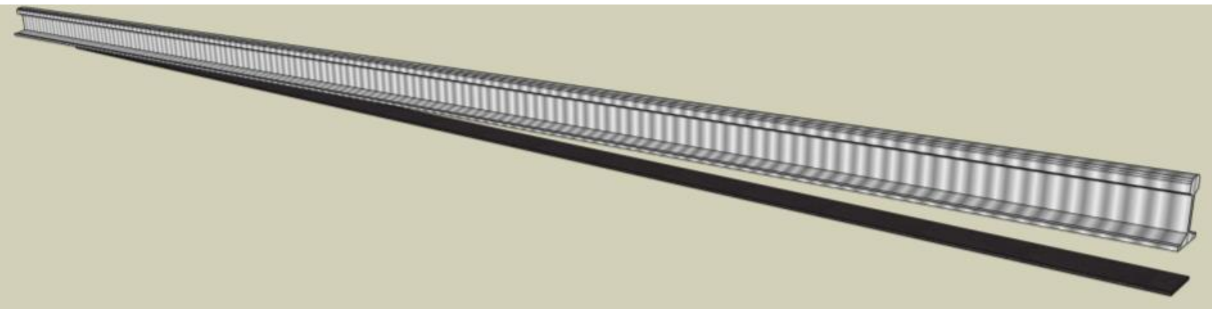


FIG 17: CONTINUOUS RAIL PAD

The core component of the system, the newly developed **adaptable fastening system** from Vossloh is designed to provide +/- 6,5 mm initial horizontal adjustment plus an additional +/- 4 mm adjustment capability for maintenance.

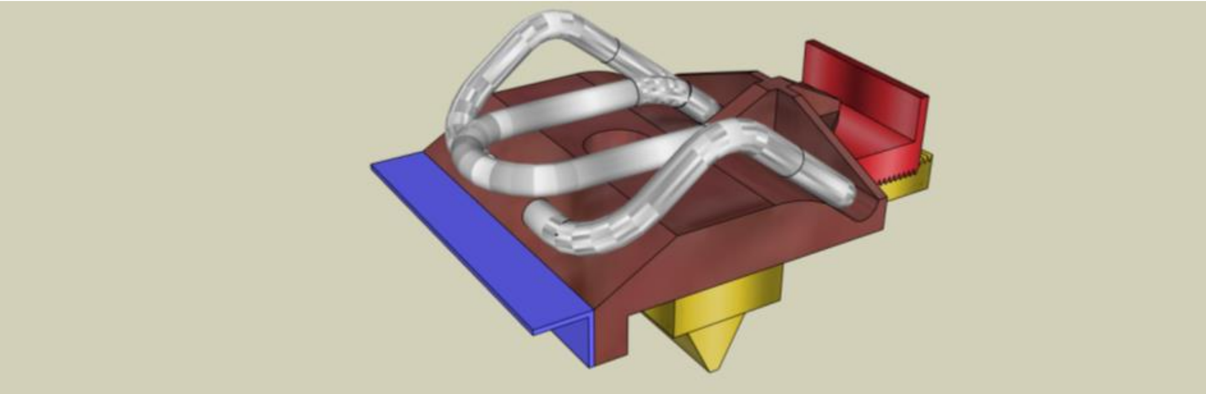


FIG 18: ADAPTABLE FASTENING SYSTEM

It is composed of the following elements:

- Toothed base plate (bronze colored)
- Toothed adjustment plate (red colored
- Spring plate (brown colored
- Fastening spring (silver colored)
- Load distribution plate (blue colored)

4.2.2.2 Functional description

All of the previously described components play a very specific role in the functional model of the track system.

The **bituminous subgrade** provides adaptability to terrain settlements and disperses the loads transferred by the longitudinal beams

The **levelling mortar** provides connection to the subgrade and fine top-down track geometry adjustment.

The **Longitudinal beams** provide support for the rail and anchoring for the adaptable fastening system while dispersing the loads transferred vertically by the rail and horizontally by the fasteners.

The **Transversal beams** connect the longitudinal beams in order to maintain track gauge, guarantee the relative position of longitudinal beams and prevent differential settlements.

The **continuous under rail pad** provides elastic support for the rail, reduces the system vertical stiffness and attenuates the noise and vibration emission from the rail

Within the **adaptable fastening system**, each component provides also different functionalities:

- The **toothed base plate** provides general horizontal restraint by means of the metallic insert placed inside the concrete beam grooves
- The **toothed adjustment plate** connected to the base plate through their intertwined teeth, restrains the spring plate horizontally. Provides the horizontal adjustment, as several positions relative to the base plate are available
- The **spring plate** provides restraint for the spring. Its horizontal position is fixed through the contact of its back ridge with the toothed adjustment plate
- The **fastening spring** provides vertical elastic restraint for the rail
- The **load distribution plate** distributes the fastening loads in the rail foot

The **rails** provide support and guidance to the train

4.2.2.3 Advantages of the concept

- There is no need to have a precise subgrade layer levelling and as a result a precise positioning of the slab because final track alignment is achieved by top-down adjustment.
- Design is completely modular thanks to standard elements.
- Slab is easy to make thanks to its simple design.
- Fastener design provides superior lateral adaptability in both construction and maintenance phases
- Continuous support greatly reduces rail stress

4.3 Detailed design of the selected concepts

Two working sessions were held in Madrid (December 2015) then Paris (February 2016) in order to do the detailed design of the two concepts. Since these meetings complementary studies were done by each partners.

Main results of the calculation and modelling of both concepts is shown in the following paragraphs.

4.3.1 DESIGN AND DIMENSIONING OF THE 3MB CONCEPT

4.3.1.1 Static calculation

In order to determine the necessary dimension of all structural elements, so that expectable and extraordinary loads may be resisted with a negligible risk of failure, static calculations were performed.

4.3.1.1.1 STRUCTURAL MODEL

To perform the structural calculations of all elements, a 3d numerical model was developed using ANSYS Mechanical v.17 software.

Concrete elements, elastomers, fastening plates and rails were modelled using 3D finite elements, while reinforcement bars within concrete, bolts and elastic clips were modelled as beams.

Contacts prone to separation (such as the ones between blocks and elastomer, rail and railpad, rail and fastenning plates) were modelled as non-linear.

In order to reduce computing time, existing symmetries were used to represent an indefinitely long section of track by modelling only half a module.

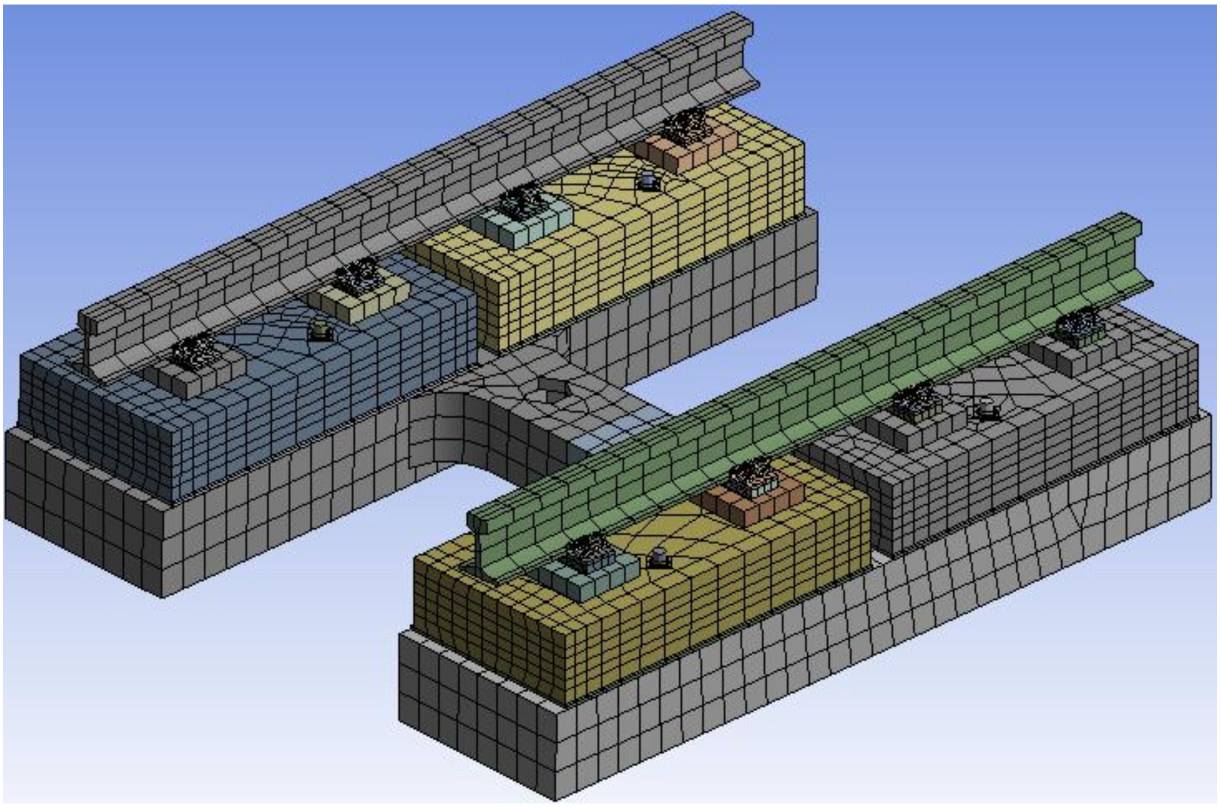


FIGURE 19 : 3D FE MODEL

4.3.1.1.2 Mechanical properties of materials

The mechanical properties of materials used in the calculation are shown in the table below.

Table 1. Mechanical properties

Parameter	Value	Units
Steel (Rail, Pins, rebar, etc)		
mass density	7849.62	kg/m^3
Young's modulus	2.1e+11	N/m^2
poisson ratio	0.3	
C35 concrete (Slab, blocks)		
mass density	2300	kg/m^3
Young's modulus	3e+10	N/m^2
poisson ratio	0.2	
Railpad		
mass density	1200	kg/m^3
Young's modulus	3.9e+7	N/m^2
poisson ratio	0	
Blockpad		
mass density	1200	kg/m^3
Young's modulus	6,16e+5	N/m^2
poisson ratio	0,45	
Mortar		
mass density	2300	kg/m^3
Young's modulus	3e+10	N/m^2
poisson ratio	0.2	
Fastening plates		
mass density	1130	kg/m^3
Young's modulus	3.3e+9	N/m^2
poisson ratio	0.39	
Bituminous sub-base		
Subsoil stiffness, k_f	50e+6	(N/m)/m

4.3.1.1.3 Applied loads

In order to envelope most pessimistic loading situations, vertical loads to consider have been selected based on the UIC71 load model shown below, multiplied by the following factors:

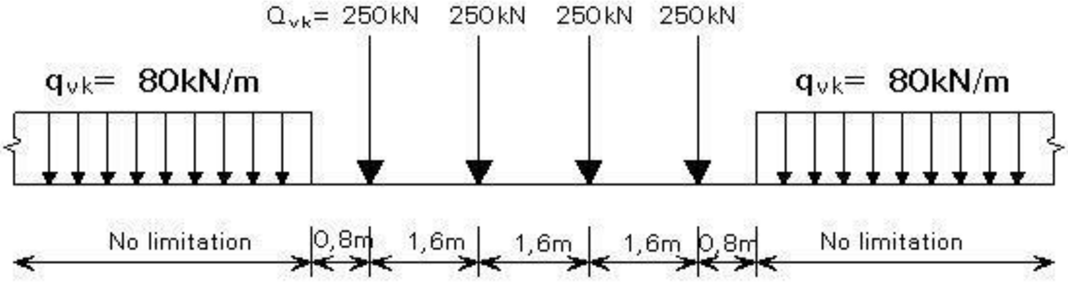


Figure 20 : UIC71 load model

- **Track load class multiplier α**: said parameter is used to cover the possibility of heavy freight traffic. In order to cover this eventuality, allowing the use of 3MB for mixed traffic lines, **α=1.21** has been selected.
- **Dynamic impact coefficient ϕ**: this coefficient is obtained from the quotient between the maximal dynamic stresses caused by all potential train configurations and the static stresses caused by the UIC71 load model. In order to consider both heavy traffic (225 kN/axle) at low speed (v < 120 km/h) and light traffic (170 kN/axle) at high speed (v ~ 360 km/h), **ϕ= 1.2** has been selected
- **Dynamic vibration unloading coefficient ϕ^-**: this coefficient represents the fact that, due to the vibratory nature of dynamic loads, vertical static loads may not only be amplified, but also partially reduced. Φ^- is obtained as twice the quotient between the maximal static stresses caused by all potential train configurations and the static stresses caused by the UIC71 load model, minus the dynamic impact coefficient Φ. Thus, **Φ^- = 0.7** has been selected.

As for horizontal loads, two kinds of horizontal loads have been considered:

- **Centrifugal force:** in order to represent centrifugal force, a maximum speed of 360 km/h and a minimum radius of 1500 m have been considered. Additionally, when applying centrifugal forces, a cant of 145 mm has been considered in order to partially compensate the centrifugal force. Thus, the centrifugal force is expressed as 0,68 times the UIC71 loads (affected by the α multiplier, but not by impact coefficients) minus 0,091 times the concomitantly applied vertical loads
- **Hunting forces:** hunting forces represent the effect on the tracks caused by the lateral oscillation of bogies due to the coning action. In order to represent said forces, a single 100 kN force (affected by the α multiplier, but not by impact coefficients) is placed in the point where it causes most stresses.

Both forces are applied simultaneously for worst case scenario effect.

Two load positions have been considered in the calculations, attending to worst case scenario for concrete elements and horizontal stability (load centered on the module) or maximum stresses in the rail (load centered between two modules).

4.3.1.1.4 Load combinations for ULS

In ULS, variable load groups are affected with a safety multiplier ϒv=1,5 if they contribute to a worst case scenario, and ϒv=0 otherwise. Permanent loads, similarly, are affected with ϒp=1,35 or 1,0.

Thus, the following combinations have been applied to the model:

Table 2. Load combinations for ULS

Combination	Position	Vertical		Horizontal		Hunting
		Axle	Distributed	Axle	Distributed	
1	Slab center	544,5 kN	-	-	-	-
2	Slab center	544,5 kN	174,2 kN/m	-	-	-
3	Slab center	541,7 kN	-	259 kN	-	181,5 kN
4	Slab center	541,7 kN	173,5 kN/m	259 kN	82,9 kN/m	181,5 kN
5	Slab center	316 kN	-	279,8 kN	-	181,5 kN
6	Slab center	316 kN	101,6 kN/m	279,8 kN	89,5 kN/m	181,5 kN
7	Slab center	210,7 kN	-	186,5 kN	-	181,5 kN

Combination	Position	Vertical		Horizontal		Hunting
		Axle	Distributed	Axle	Distributed	
8	Slab center	210,7 kN	67,5 kN/m	186,5 kN	59,7 kN/m	181,5 kN
9	Module gap	544,5 kN	-	-	-	-
10	Module gap	544,5 kN	174,2 kN/m	-	-	-
11	Module gap	541,7 kN	-	259 kN	-	181,5 kN
12	Module gap	541,7 kN	173,5 kN/m	259 kN	82,9 kN/m	181,5 kN
13	Module gap	316 kN	-	279,8 kN	-	181,5 kN
14	Module gap	316 kN	101,6 kN/m	279,8 kN	89,5 kN/m	181,5 kN
15	Module gap	210,7 kN	-	186,5 kN	-	181,5 kN
16	Module gap	210,7 kN	67,5 kN/m	186,5 kN	59,7 kN/m	181,5 kN

4.3.1.1.5 Load combinations for SLS

In SLS, variable load groups are affected with a safety multiplier ϒv=1 if they contribute to a worst case scenario, and ϒv=0 otherwise. Permanent loads, similarly, are affected with ϒp= 1,0.

Additionally, deformation SLS considers characteristic load values, while concrete fissuration SLS considers quasipermanent load values. However, given that quasipermanent combination factor for rail traffic is 0, frequent combination factor of 0,8 has been considered.

Thus, the following combinations have been applied to the model:

Table 3. Load combinations for SLS

Combination	Position	Vertical		Horizontal		Hunting
		Axle	Distributed	Axle	Distributed	
1	Slab center	363 kN	-	-	-	-
2	Slab center	363 kN	116,1 kN/m	-	-	-
3	Slab center	361,1 kN	-	192,7 kN	-	181,5 kN
4	Slab center	361,1 kN	115,6 kN/m	192,7 kN	61,7 kN/m	181,5 kN
5	Slab center					
6	Slab center					
7	Slab center	210,7 kN	-	143,7 kN	-	181,5 kN
8	Slab center	210,7 kN	67,5 kN/m	143,7 kN	46 kN/m	181,5 kN
9	Module gap	290,4 kN	-	-	-	-
10	Module gap	290,4 kN	174,2 kN/m	-	-	-
11	Module gap	541,7 kN	-	192,7 kN	-	181,5 kN
12	Module gap	541,7 kN	173,5 kN/m	192,7 kN	61,7 kN/m	181,5 kN
13	Module gap	316 kN	-	215,6 kN	-	181,5 kN
14	Module gap	316 kN	101,6 kN/m	215,6 kN	54,9 kN/m	181,5 kN
15	Module gap	210,7 kN	-	143,7 kN	-	181,5 kN
16	Module gap	210,7 kN	67,5 kN/m	143,7 kN	46 kN/m	181,5 kN

4.3.1.1.6 ULS results

In order to guarantee structural safety of steel and concrete elements during operation, standard Eurocode calculations were applied to the different critical elements.

Moulded blocks were calculated assuming their dimensions and load distribution cause them to behave as D-regions. Thus, their structural integrity was checked by ensuring all concrete struts were subject to acceptable compressions, while steel rebar within ties presented acceptable tensions.

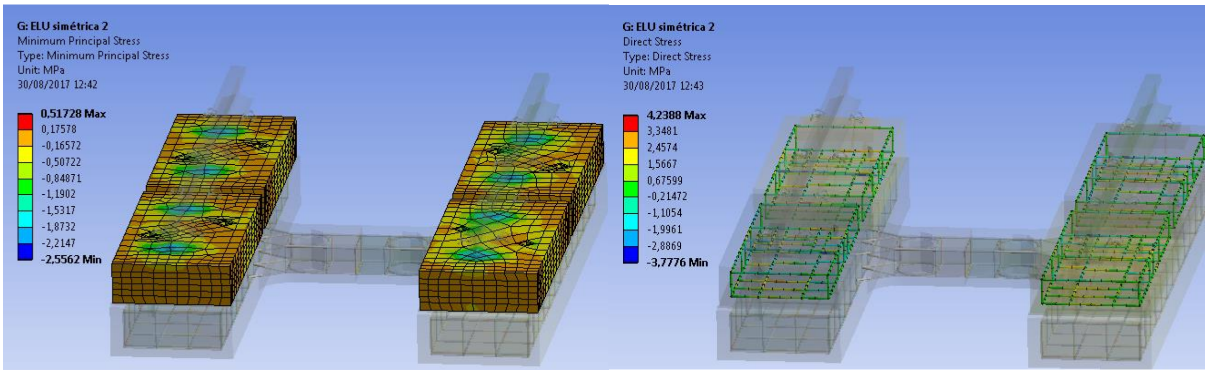


FIGURE 21 : MINIMUM PRINCIPAL STRESSES IN BLOCKS AND STRESS IN BLOCK REBAR

Results from calculation show that minimum principal stress in the concrete is 2,52 MPa, well below its ultimate resistance, while maximum stress in the steel rebar is 4,23 MPa, once again insignificant compared to rebar yield strength.

Base slab longitudinal and transversal beams were calculated as reinforced concrete beams, extracting section forces from the 3D model and applying Eurocode 2 formulation to the beams cross-sections and worst section force combinations.

Worst-case combinations for the longitudinal beams may be seen in the following table:

TABLE 4. WORST-CASE SECTION FORCES IN LONGITUDINAL BEAMS

Combinations	Vx (kN)	Vy (kN)	Fz (kN)	Mx (kN·m)	My (kN·m)	Tz (kN·m)
VxMAX	13,02	3,84	8,25	11,04	4,77	6,19
VxMIN	-21,99	-5,17	13,57	20,01	0,72	-9,67
VyMAX	-8,49	65,69	-3,72	-0,46	-2,17	-19,10
VyMIN	8,43	-60,64	6,35	6,16	-0,46	18,65
FzMAX	8,56	-4,56	27,65	26,55	1,45	15,90
FzMIN	-0,12	6,85	-12,68	-8,88	-1,49	-0,47
MxMAX	2,76	-8,48	27,00	27,02	1,62	11,37
MxMIN	-0,12	6,85	-12,68	-8,88	-1,49	-0,47
MyMAX	5,02	1,29	11,53	13,07	5,95	0,34
MYMIN	-6,34	31,54	-9,14	11,88	-6,54	-9,28
TzMAX	8,43	-60,64	6,35	6,16	-0,46	18,65
TzMIN	-8,49	65,69	-3,72	-0,46	-2,17	-19,10

Section force envelopes may be seen in the following diagrams:

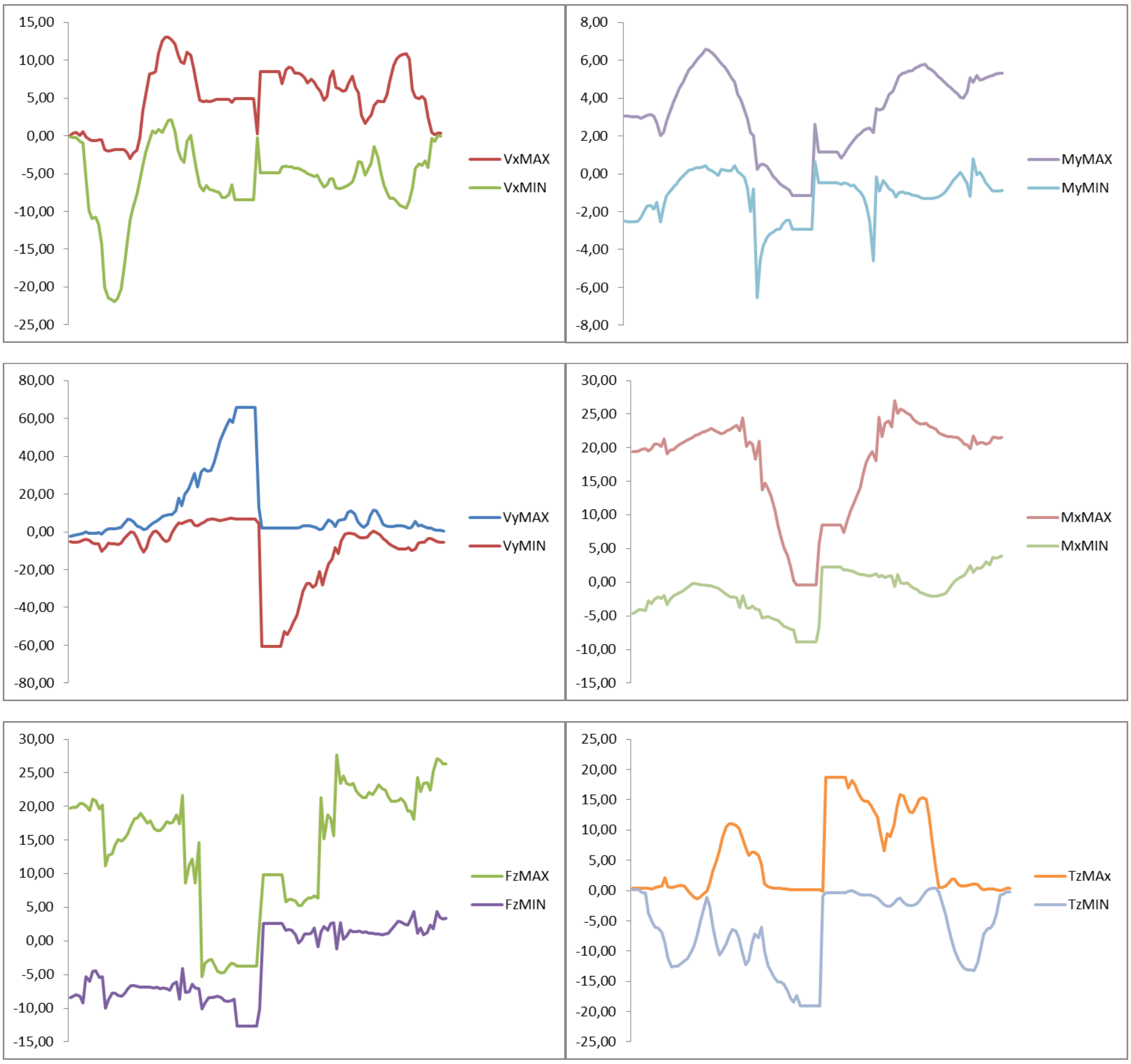


Figure 22 : Section forces envelopes for longitudinal beams

Section analysis was performed using the software *Prontuario informático del Hormigón 3.0*, which implements automatic calculation of concrete cross-sections following the Spanish EHE-08 code, which in turn is a transposition of Eurocode 2.

The following figure shows the **composite flexure** interaction diagram for the beam cross section, considering the most adverse tension force (27 kN), with all load combinations falling well within the safety area. In fact, minimum safety factor for composite flexure is 3,5.

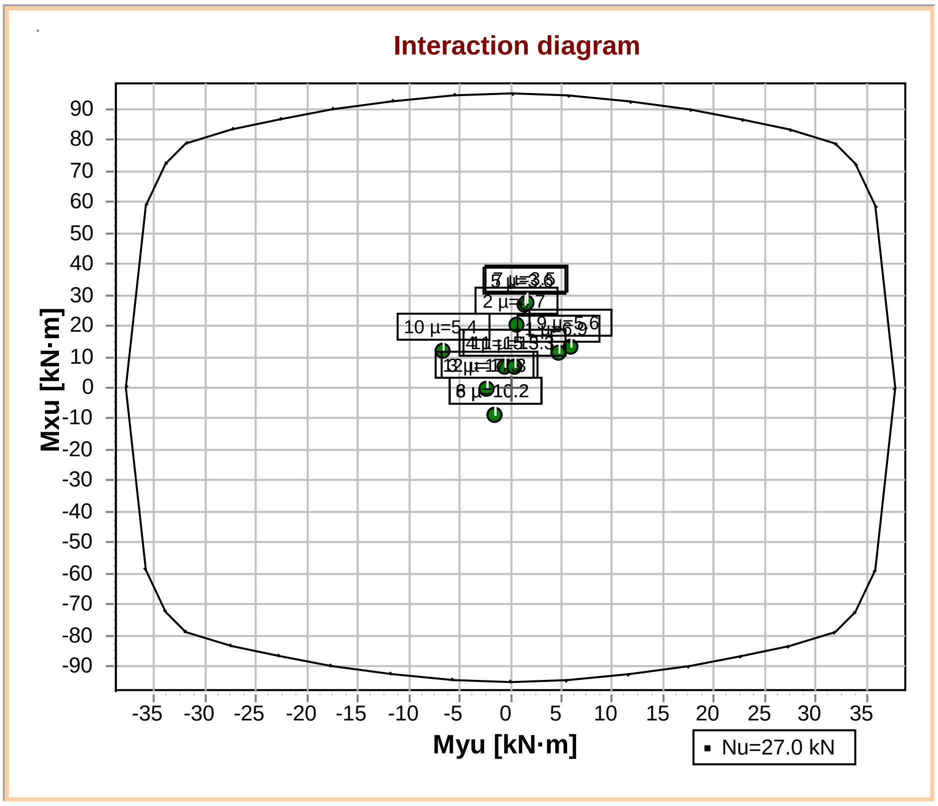


FIGURE 23 : LONGITUDINAL BEAM INTERACTION DIAGRAM

As for **shear** calculation, ULS resistance of the longitudinal beam cross-section is 114,6 kN for Vx and 295,6 kN for Vy, which guarantees a minimum safety factor of 5 and 4,5 respectively.

Finally, **torsion** calculation was performed considering worst case flexural rebar strain (30%), thus considering only 70% of longitudinal rebar is available for torsion. Under said assumption, ultimate torsional resistance is 33,3 kN·m, which provides a minimum safety factor of 1,74

Base slab transversal beams were calculated as reinforced concrete beams, extracting section forces from the 3D model and applying Eurocode 2 formulation to the beams cross-sections and worst section force combinations.

Worst-case combinations for the longitudinal beams may be seen in the following table:

TABLE 5. WORST-CASE SECTION FORCES IN TRANSVERSAL BEAMS

Combinations	Distance	Vx (kN)	Vy (kN)	Fz (kN)	Mx (kN·m)	My (kN·m)	Tz (kN·m)
VxMAX	800,35	5,63	26,50	-24,13	-7,42	-0,67	-0,09
VxMIN	693,63	-4,28	1,40	-22,92	1,58	0,82	1,07
VyMAX	907,06	-3,25	40,92	-32,66	2,12	1,63	0,93
VyMIN	907,06	-2,21	-20,67	-15,15	8,58	1,55	1,07
FzMAX	800,35	2,71	25,71	22,98	-6,68	-0,77	0,01
FzMIN	586,92	-3,47	4,24	-33,22	2,66	0,54	1,22
MxMAX	0,00	-2,46	-0,70	-31,95	13,31	-1,58	1,19
MxMIN	907,06	-3,25	1,49	-32,66	-12,63	1,63	0,93

Combinations	Distance	Vx (kN)	Vy (kN)	Fz (kN)	Mx (kN·m)	My (kN·m)	Tz (kN·m)
MyMAX	0,00	0,85	23,04	-16,67	9,33	2,78	-0,35
MYMIN	907,06	2,61	25,97	-19,96	-7,38	-1,78	-0,69
TzMAX	907,06	-3,25	1,49	-32,66	2,12	1,63	1,87
TzMIN	907,06	2,91	34,63	-17,97	-9,62	-1,40	-0,88

Section force envelopes for each of the two transversal beams may be seen in the following diagrams:

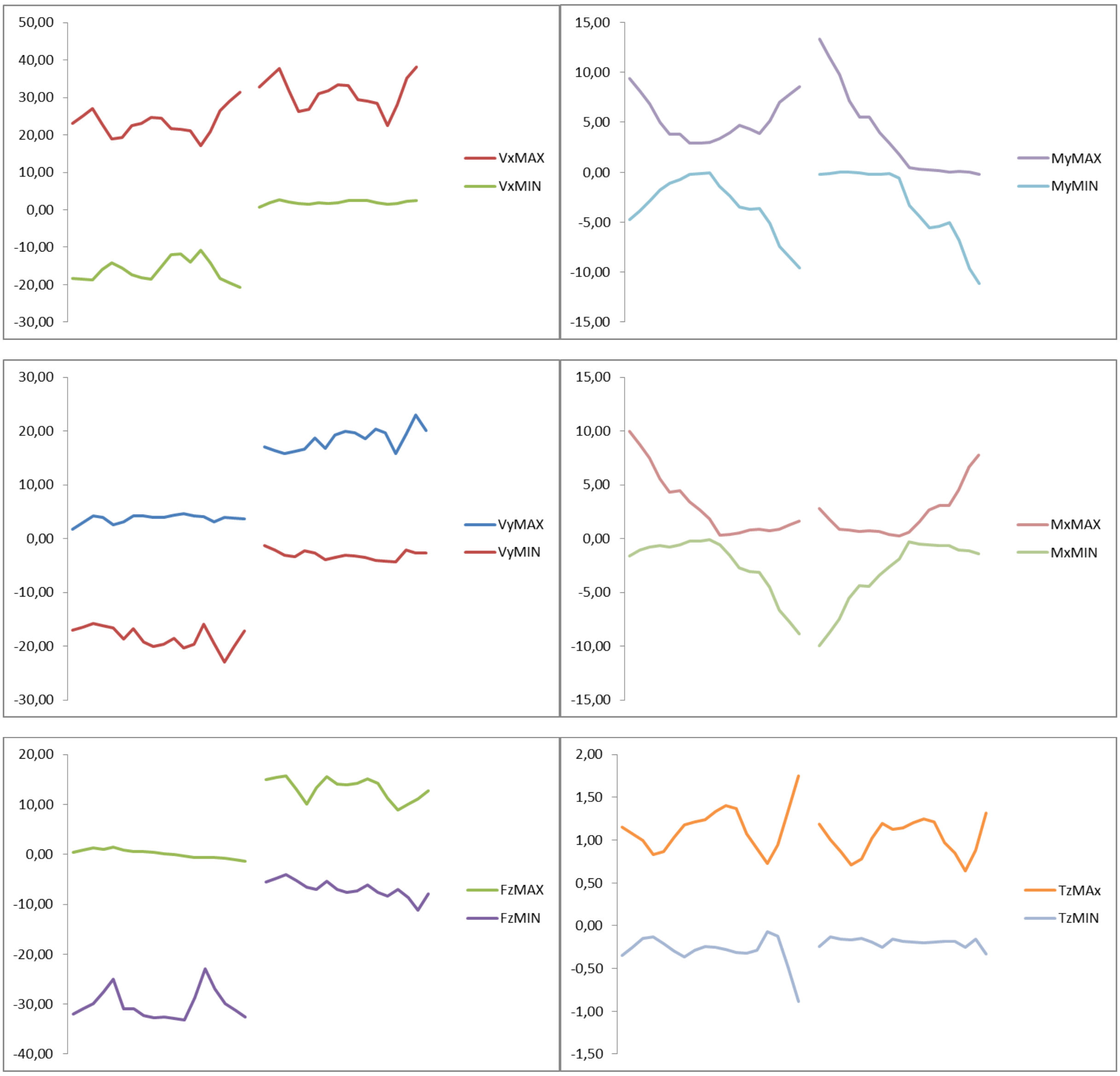


FIGURE 24 : SECTION FORCES ENVELOPES FOR TRANSVERSAL BEAMS

The following figure shows the **composite flexure** interaction diagram for the standard beam cross section, considering the most adverse tension forces (23 kN), with all load combinations falling within the safety area. Minimum safety factor for composite flexure is 1,1.

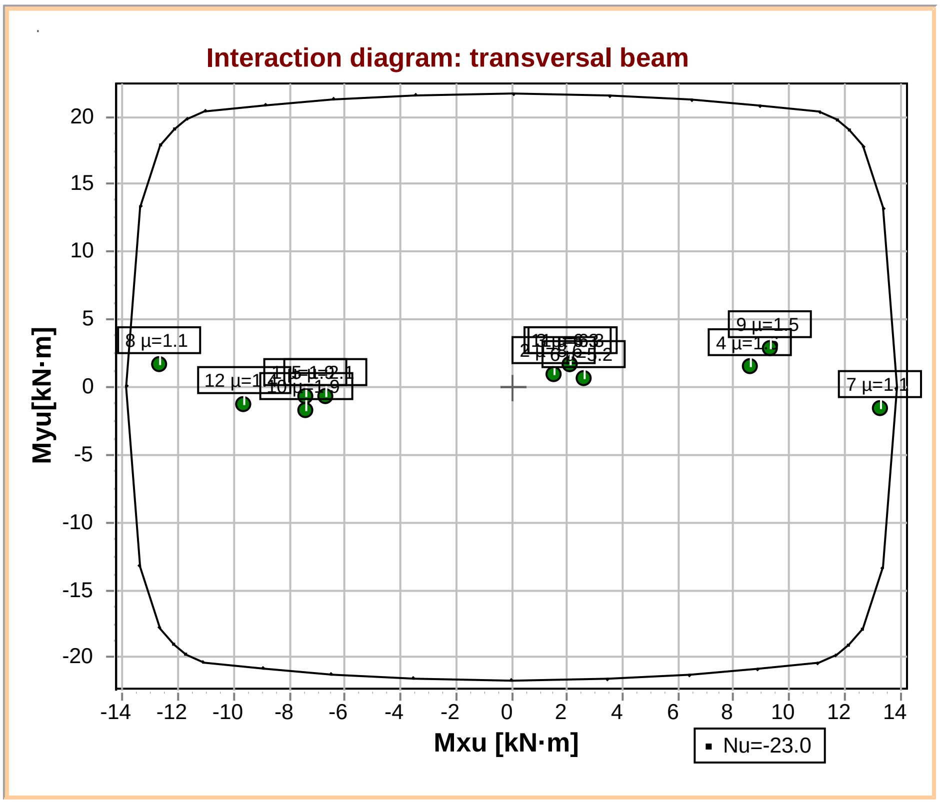


FIGURE 25 : TRANSVERSAL BEAM INTERACTION DIAGRAMS

As for **shear** calculation, ULS resistance of the full transversal beam cross-section is 217,9 kN for Vx and 138,4 kN for Vy, which guarantees a minimum safety factor of 5,3 and 24,5 respectively.

Finally, **torsion** calculation was performed considering worst case flexural rebar strain (90%), thus considering only 10% of longitudinal rebar is available for torsion. Under said assumption, ultimate torsional resistance is 10,2 kN·m, which provides a minimum safety factor of 5,45.

The through-hole section of the beam was analysed as two parallel beams, clamped at the full section, with torsion causing bimoment and thus increasing both vertical shear and flexural bending Mx, and flexural bending My causing a pair of tension-compression forces.

Thus, worst combinations for the critical sections (at a distance of 211 and 696,6 mm) shall be checked:

TABLE 6. WORST COMBINATIONS IN THE TRANSVERSAL BEAM

Combinations	Vx (kN)	Vy (kN)	Fz (kN)	Mx (kN·m)	My (kN·m)	Tz (kN·m)
VxMAX	4,08	17,15	-15,92	-3,63	-0,59	-0,28
VxMIN	-4,28	22,48	-6,90	-4,65	0,76	0,85
VyMAX	-1,81	26,31	-6,05	5,50	-1,35	0,76
VyMIN	-2,20	-14,23	-8,80	-1,14	-0,81	0,87

Combinations	Vx (kN)	Vy (kN)	Fz (kN)	Mx (kN·m)	My (kN·m)	Tz (kN·m)
FzMAX	2,32	21,51	16,63	-4,34	1,42	-0,10
FzMIN	-2,28	-0,12	-25,00	2,09	-0,27	0,77
MxMAX	-1,81	26,31	-6,05	5,50	-1,35	0,76
MxMIN	-0,10	18,33	-2,35	-5,03	-0,62	0,18
MyMAX	2,32	18,66	-16,63	4,34	1,42	-0,10
MYMIN	-1,81	26,31	-6,05	5,50	-1,35	0,76
TzMAX	-3,98	-10,86	-7,20	3,87	0,84	0,90
TzMIN	4,08	17,15	-15,92	-3,63	-0,59	-0,28

Worst-case combination in the demi-sections can be seen below:

TABLE 7. WORST COMBINATIONS IN THE CRITICAL DEMI-SECTIONS

Combinations	Vy (kN)	Fz (kN)	Mx (kN·m)
VxMAX	17,15	-15,92	-3,63
VxMIN	22,48	-6,90	-4,65
VyMAX	26,31	-6,05	5,50
VyMIN	-14,23	-8,80	-1,14
FzMAX	21,51	16,63	-4,34
FzMIN	-0,12	-25,00	2,09
MxMAX	26,31	-6,05	5,50
MxMIN	18,33	-2,35	-5,03
MyMAX	18,66	-16,63	4,34
MYMIN	26,31	-6,05	5,50
TzMAX	-10,86	-7,20	3,87
TzMIN	17,15	-15,92	-3,63

The following figure shows the **composite flexure** interaction diagram for the demi-cross section, with all load combinations falling within the safety area. Minimum safety factor for composite flexure is 2.

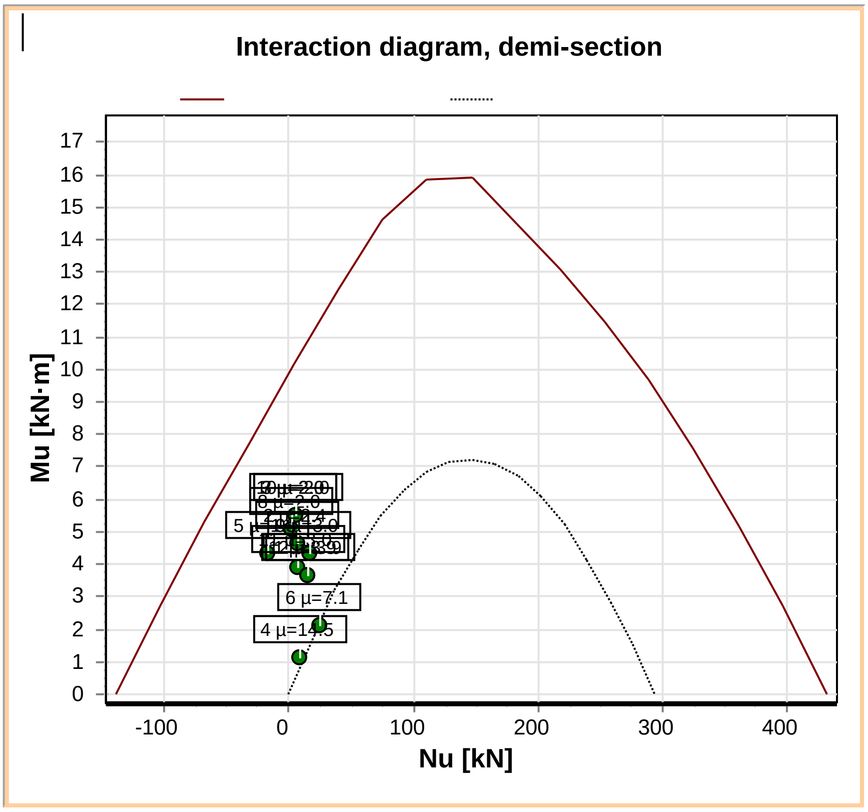


Figure 26 : Demi-section interaction diagrams

As for **shear** calculation, ULS resistance of the demi-section is 63,5 kN, which guarantees a minimum safety factor of 2,4.

4.3.1.2 Stiffness level calculation

The vibrations induced by rail is an important source of annoyance. Today, an increased attention is bring to this problematic. These vibrations are due to relative displacements between the wheels and the rails. These displacements are created by surface irregularities of the wheels and rails, namely the roughness.

The way commonly used to mitigate these vibrations is to put a resilient material into the track. This material is designed as a carpet whose Young module is adapted to the need of mitigation.

Within the 3MB concept, such a material is planned between the slabs and the blocks. An optimized value of the Young modulus of this material is searched in study (Annex I).

The results show that the very small values of the Young's modulus give a high mitigation of the vibration transmitted by the track. Nevertheless, some values can significantly amplify the vibrations. In this configuration, a resilient material of with $E = 9$ MPa generates important amplitudes due to the coincidence of Eigen frequency of the pumping mode of the track and the maximum amplitude of the force.

Consequently, the optimal value of the Young's modulus is the smallest (1MPa).

4.3.1.3 Dynamic calculation

Dynamic effects due to the passage of the vehicles are studied under high speed railway traffic with the following train models:

- HSLM-B from EUROCODE EN 1991-2 : Virtual high-speed trains combination
- Type 4 from EUROCODE EN 1991-2 : Real high-speed passenger train
- Type 11 from EUROCODE EN 1991-2 : Real freight train

The following results from calculations are provided in the relative Annex II:

- Slab displacement under train circulation from 0 to 420 km/h
- Vertical acceleration of the slab
- Vertical acceleration of the block
- Vertical acceleration of the rail
- Vertical car body acceleration with track geometry defects

These calculations results will be compared to experimental tests at CEDEX TrackBox.

In the case of a slab track directly laid on the subsoil, there is no specified recommendation concerning any vertical acceleration limit in the regulations at the moment; the value of 5 m/s² only gives an order of magnitude of acceptable vertical acceleration.

Under high speed railway traffic, rail vertical displacement limit is fixed at 2mm for rail under 20 ton axle according to UIC recommendations. Nevertheless no limit is fixed for blocks and slab, however vertical displacement results are given in order to measure deformation of railway platform subsequently.

4.3.1.4 Fatigue Calculation

Complete fatigue study is part of the Annex II.

Fatigue load model used for fatigue check is the high speed passenger train Type 4:

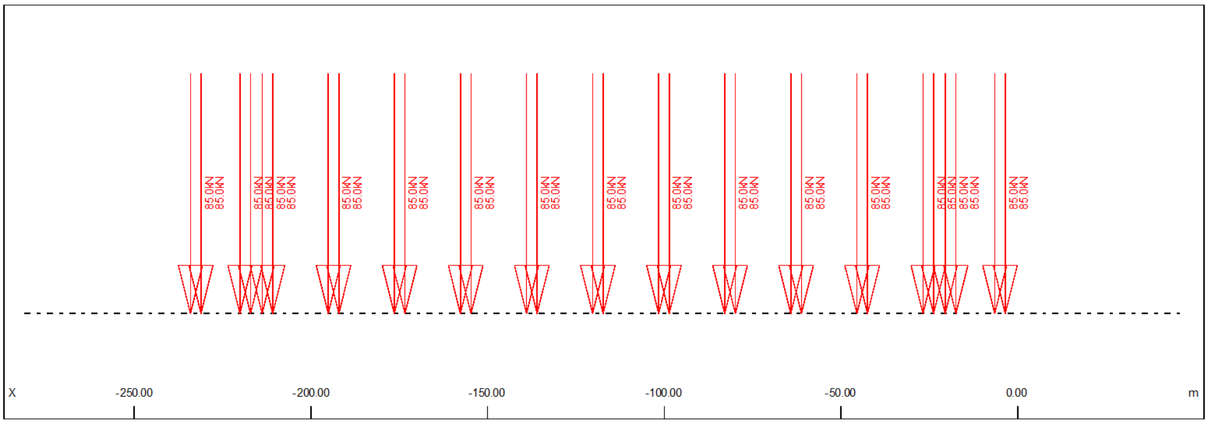


Figure 27 : Load model for fatigue calculation

The cumulative damage method, available in Eurocode, considers the load history; it is used here for fatigue verification as it can be used for reinforced concrete structures subjected to compression, bending and shear.
Train loads are applied on the finite elements model at critical speed, and stresses are calculated in the appropriate critical sections where cumulative damage is analysed.
Analysed active stress results in the considered structural elements are those produced by train load, which constitutes the relevant fatigue load (Q_{fat}).
Stress calculation is done considering cracked sections; area moments of inertia of cracked sections are taken as 65% of those of uncracked sections (this value of 65%, taken as envelope, comes from calculations of cracked section located in lateral beams of the slab, under maximal N and M forces).

The damage calculation follows – as described in Eurocode – two procedures: one for compressed concrete, the other for reinforcement in tension and compression.
In this document, only the damage calculation procedure for reinforcement in tension and compression is done, assuming this constitutes the design case for the slab track fatigue check.

The damage calculation method for the reinforcement bars is described in EC 1992-1-1; it aims to compare active stress range to resistant stress range, which matches the reinforcement bars used.

The Palmgren-Miner's rule is used to calculate the total damage on the reinforcement bars:

$$D = \sum_{i=1}^{m} \frac{n(\Delta\sigma_i)}{N(\Delta\sigma_i)} \leq 1$$

Where:

- *$n(\Delta\sigma_i)$* is the applied number of cycles for a stress range $\Delta\sigma_i$
- *$N(\Delta\sigma_i)$* is the ultimate number of cycles for a stress range $\Delta\sigma_i$.

Applied number of cycles for each active stress range $n(\Delta\sigma_i)$ is obtained using rainflow method on the stress history for one passing train :

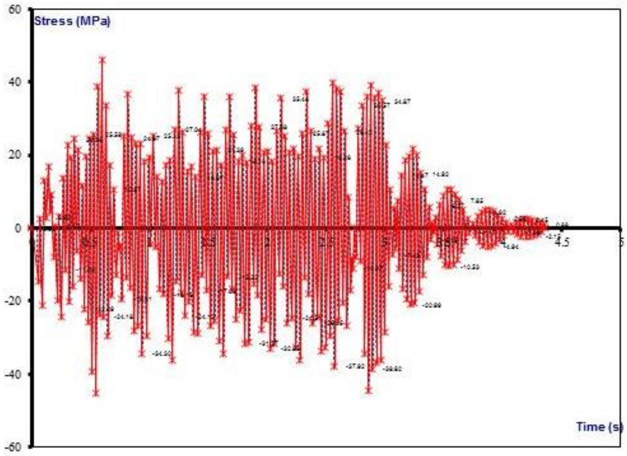


Figure 28 : Stress history for one passing train

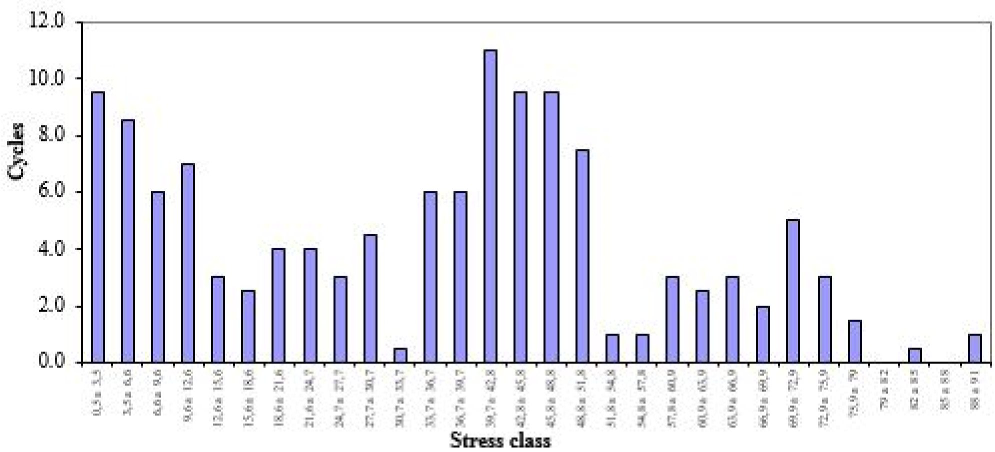


Figure 29 : Applied number of cycles for each stress range, for one passing train

The ultimate number of cycles N(Δσ$_i$) for a given stress range Δσ$_i$ is determined using S-N curve, which shape is shown below :

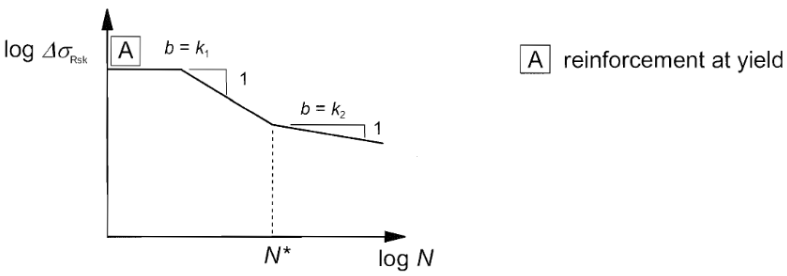


Figure 30 : Shape of the characteristic fatigue strength curve (S-N-curves for reinforcing and prestressing steel) EC 2 1.1 Figure 6.30

Type of reinforcement	N^*	stress exponent		$\Delta\sigma_{Rsk}$ (MPa) at N^* cycles
		k_1	k_2	
Straight and bent bars[1]	10^6	5	9	162,5
Welded bars and wire fabrics	10^7	3	5	58,5
Splicing devices	10^7	3	5	35

Note 1: Values for $\Delta\sigma_{Rsk}$ are those for straight bars. Values for bent bars should be obtained using a reduction factor $\zeta = 0{,}35 + 0{,}026\ D/\phi$.
where:
D diameter of the mandrel
ϕ bar diameter

Figure 31 : Parameters for S-N curves for reinforcing steel EC 2 1.1 Table 6.3

For the slab track study, straight bars are considered:

$$N^*=10^6,\ k_1=5,\ k_2=9 \text{ and } \Delta\sigma_{Rsk} = 162.5 \text{ MPa}$$

Critical sections are those which are subject to the higher load – one section is considered for concrete blocks, and one for the lateral beams of the slab.

Stress results are normal stress results given for top and bottom layer of steel reinforcements in those sections.

4.3.1.5 Fastening selection

The rail fastening system DFF 21 is simple, reliable, safe and does not require any regular maintenance. It fully supports automatic track-laying and is proven on several installations throughout the world. The outer spring arms of the W-shaped tension clamp permanently clamps the rail to the rail pad placed on the rail seat of the base plate. The rail is laterally kept in position by the angled guide plates. The vertical and lateral forces are directly transferred to the slab track via the angled guide plates without any loading of the sleeper screws to bending or shearing. The rail fastening system has an additional secondary stiffness as a result of the middle bend of the tension clamp, which projects above the rail foot (see also characteristic curve or data sheet of the tension clamp). Overloading of the outer spring arms and consequently plastic deformation is therefore not possible. The middle bend also provides protection against rail tilting. Also the special design of the angled guide plate deals as an additional tilting protection.

4.3.1.5.1 Pre-Assembly

The pre-assembly of the Vossloh rail fastening system is an especially economical solution. All the fastening components can be pre-assembled. In this way there is no possibility of losing the components. We recommend using grease e.g. Elaskon, Ferrocoat or similar lubricants, before insertion of the sleeper screw into the dowel. For closed dowels we recommend compressible grease. For detailed information see the installation manual of the system.

4.3.1.5.2 Final-Assembly

If the system is pre-assembled, no components need to be removed on track. The advantages are no loss of material, no confusing with the individual parts lying on the track. Due to the simple installation training costs are minimal. For detailed information of assembly see also the installation manual of your system.

4.3.1.5.3 Tension Clamp Skl 21

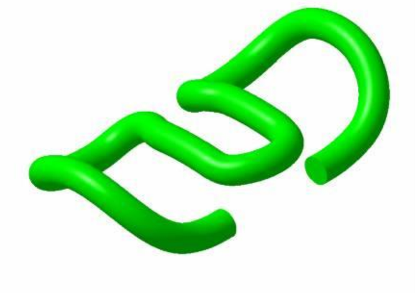


Fig. 32 Tension clamp Skl 21

The tension clamp Skl 21 exerts a permanent spring-actuated force on the rail. The nominal toe load of 10 kN is available at a deflection of approx. 14 mm and is capable of continuous dynamic vertical deflection of 2.5 mm at this deflection. Rail pads with a static stiffness of ≥ 35 kN/mm and an axle load up to 22.5 t can therefore be used in System DFF 21. The middle bend of the tension clamp prevents a plastic deformation of the outer spring arms and over stressing. It also provides protection against rail tilting.

4.3.1.5.4 Angled guide plate Wfp 21 K NT

Fig. 33 Angled guide plate Wfp 21 K

The angled guide plates create a channel for the rail in longitudinal direction. They keep the rail in position and transfer the lateral forces directly into the slab track without bending or shear forces to the sleeper screws. Angled guide plates with different widths make it possible to adjust the gauge or use of a different rail profile. The anti tilting (NT) nose in front of the angled guide plate prevents abrasion and plastic deformation of the rail pad when the rail tilting or vertical deflection of rail (e. g. due to high dynamic forces) is too high. Further the angled guide plates insulate the fastening system electrically.

4.3.1.5.5 Rail Pad Zw (standard)

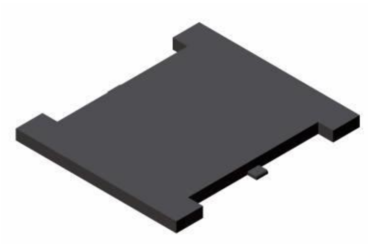


Fig. 34 Rail pad Zw

The rail pad separates the rail from the sleeper. Pre-assembly lips on the sides of the rail pad which reach under the angled guide plates avoid loss of the rail pad during transportation. The rail pad also insulates the fastening system electrically.

4.3.1.5.6 RailPAd Zw AT with Anti-Tilting for tight curves (optional)

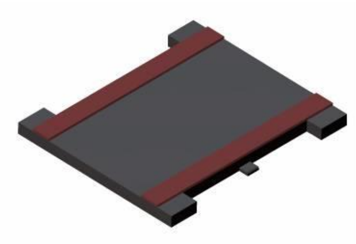


Fig. 35 Rail pad Zw AT

By using rail profiles with a small rail foot or in tight curves the anti tilting (AT) modification of the rail pad with reinforcements at the borders (Fig.) is supporting the anti tilting opportunity of the system additionally and prevents abrasion or plastic deformation of the rail pad when the rail tilting is too high.

4.3.1.5.7 Sleeper screw

The sleeper screw transfers tensile forces directly into the concrete, bending or shearing is avoided by the design of the angle guide plate. Due to the rounded thread of the sleeper screw prevents cutting or cross-threading into the plastic dowel.

Fig. 36 Sleeper screw Ss35 with washer Uls 7

4.3.1.5.8 Plastic Dowel

Fig. 37 Plastic dowel SDü 26

The dowel can be easily installed. The pullout force is very high due to a unique profile which allows more direct transfer of loading to surrounding concrete.

4.3.1.5.9 Height Adjustment plate Apw (optional)

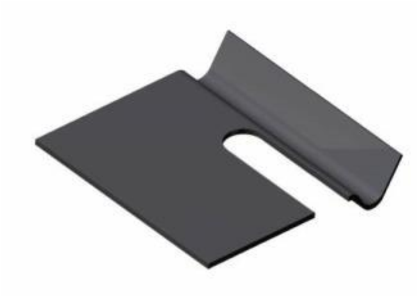


Fig. 38 Adjustment plate Apw

The Vossloh rail fastening system DFF 21 can be adjusted in height by using special plates. This is also referred to as anti-frost wedge fastening in many countries. The adjustment plate offers easy assembly without dismantling the fastening system. For installation of height adjustment plates refer to the instructions in the height regulation manual.

4.3.1.5.10 Base plate ULP

Fig. 39 **Base plate ULP**

The lateral loads of the rail will be transmitted over the angled guide plate and the base plate into the concrete of slab. No bending or shearing forces in the embedded anchoring system arises. High forces are derived by the formed lower surface of the base plate. The sleeper screw / anchor bolt is stressed only on tensile forces. Completely electrically insulating by the embedded plastic dowel or insulated anchor bolt, the rail pad, the angle guide plates and the base plate made of plastic. No additional insulating components between tension clamp and rail foot are required. No danger of out moving or breaking insulators or demolition by steel mounting elements.

4.3.1.5.11 MAINTENANCE

The Vossloh rail fastening system DFF 21 doesn't require any regular maintenance. The two spring arms of the tension clamp exert a permanent spring-actuated force on the rail. The system is simply tightened and loosened by means of a screw. Re-tightening of the sleeper screws is not necessary. In the extreme situation where both spring arms are broken (e. g. derailment) the middle bend acts to prevent the rail leaving the rail seat.

4.3.1.5.12 RAIL CREEP RESISTANCE

The creep resistance of system DFF 21 is > 9 kN per railseat. Dangerous rupture gaps are prevented in CWR-tracks and anti-creep devices are not required. The creep resistance can be reduced if required, e.g. for bridges.

4.3.1.5.13 ELECTRICAL INSULATION

By means of the rail pad, the angled guide plates, base plate and dowels (all made of plastic), the Vossloh rail fastening system DFF 21 is completely electrically insulated. No additional components are required between the tension clamp and the rail base.

4.3.1.5.14 DAMPING

Rail movements caused by pressure from the moving wheels, are elastically cushioned

- transmission of vibration to the concrete
- structure borne noise to the foundations of adjacent buildings

4.3.1.5.15 EXCHANGEABILITY

All wear parts of the rail fastening system are easy to exchange.

4.3.1.5.16 PROTECTION AGAINST RAIL-TILTING

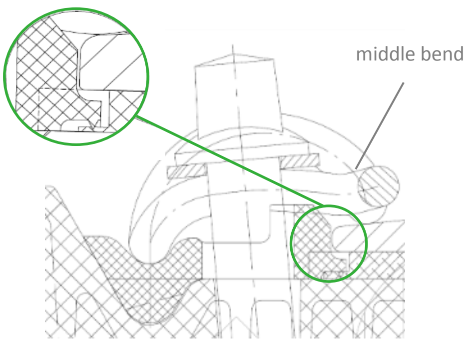


FIG. 40 DETAIL ANTI-TILTING PROTECTION

During tamping and lining of the rails or train passing through tight curves a lift or tilt of the rail is compensated by the middle bend after overcoming the small air gap. A lasting plastic deformation of the fastening clamp is prevented as well. Additional protection against tilting is provided by means of a small nose in the front of the angled guide plate. This is avoids a lasting deformation of the rail pad, too. This protection can be increased by using anti-tilting rail pads with reinforcement at the borders (Fig.9).

4.3.1.5.17 GAUGE ADJUSTMENT

The Vossloh rail fastening system DFF 21 allows in standard a gauge adjustment of ± 10 mm in steps of 2,5 mm by using angled guide plates with different widths (see Appendix, Fig. 12 Table of gauge adjustment). Optionally an adjustment in steps of 1 mm also is possible.

4.3.1.5.18 ADJUSTMENT FOR DIFFERENT RAIL PROFILES

Generally it is possible to change the rail profile on the mounted system while keeping the existing gauge. Therefore only the angled guide plates have to be changed.

4.3.1.5.19 HEIGHT ADJUSTMENT

By means of different adjustment plates for system DFF 21 a regulation of max. +16 mm in steps of 2 mm is possible (see Appendix, Fig. 13 Drawing and table of optionally height adjustment).

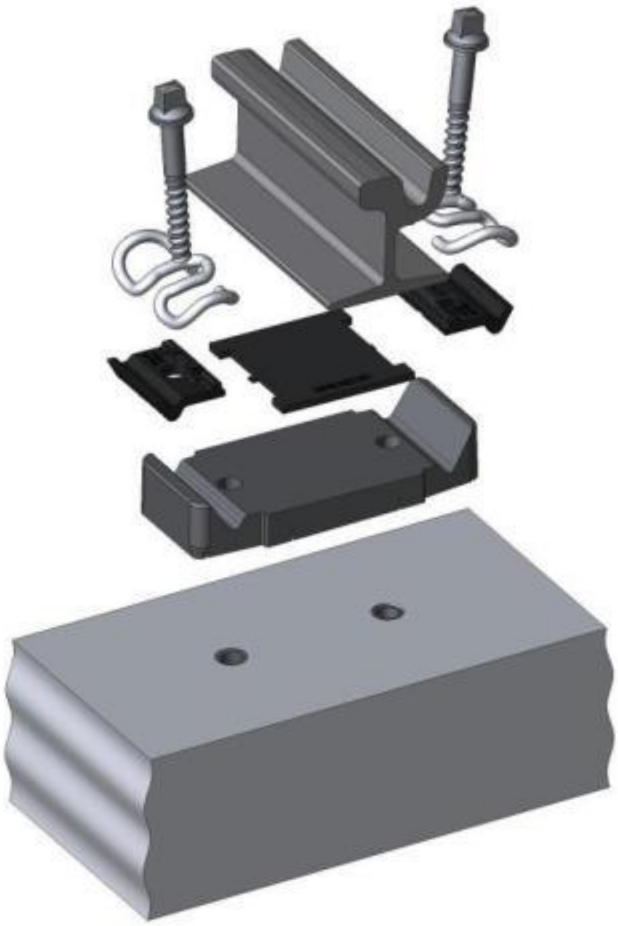
4.3.1.5.20 NEUTRALIZATION/ DISTRESSING

No rail fastening component has to be removed for continuous welded rails (CWR). The sleeper screws have to be loosened, but they don’t need to be removed. The components of the fastening system shouldn’t be exposed to any liquids or corrosive chemicals during storage or installation. Furthermore the fastening system don’t may be exposed to open flame or heat for example by rail welding works.

4.3.1.5.21 System DFF 21

The standard fastening system DFF 21 consists of following components per fastening point:

Pos.	Component	Quantity
1	Tension clamp Skl 21	2
2	Angled guide plate Wfp	2
3	Rail pad Zw	1
4	Plastic dowel Sdü	2
5	Sleeper screw Ss with washer Uls	2
6	Base plate Ulp	1



4.3.1.5.22 APPENDIX

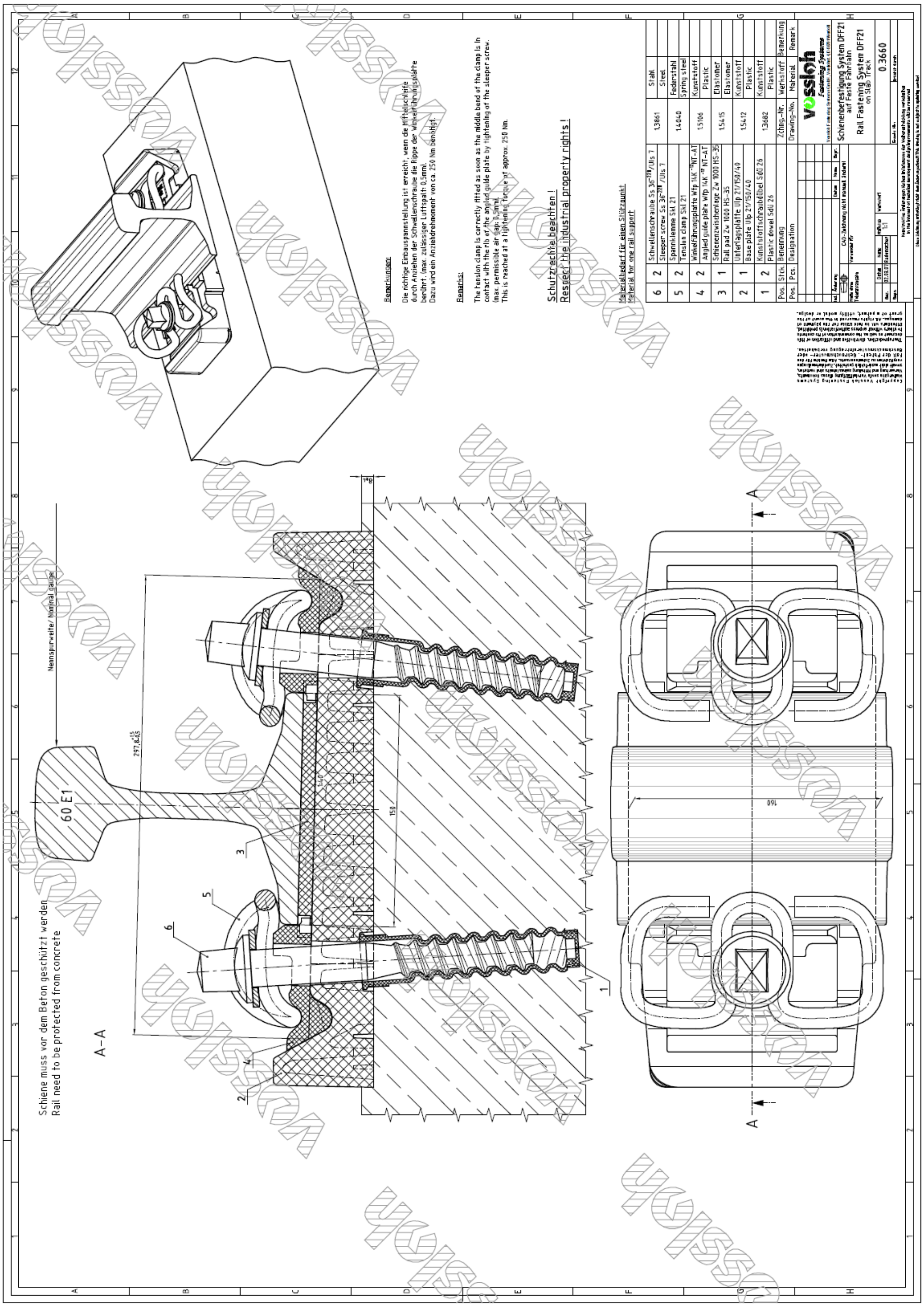


FIGURE 41 : ASSEMBLY

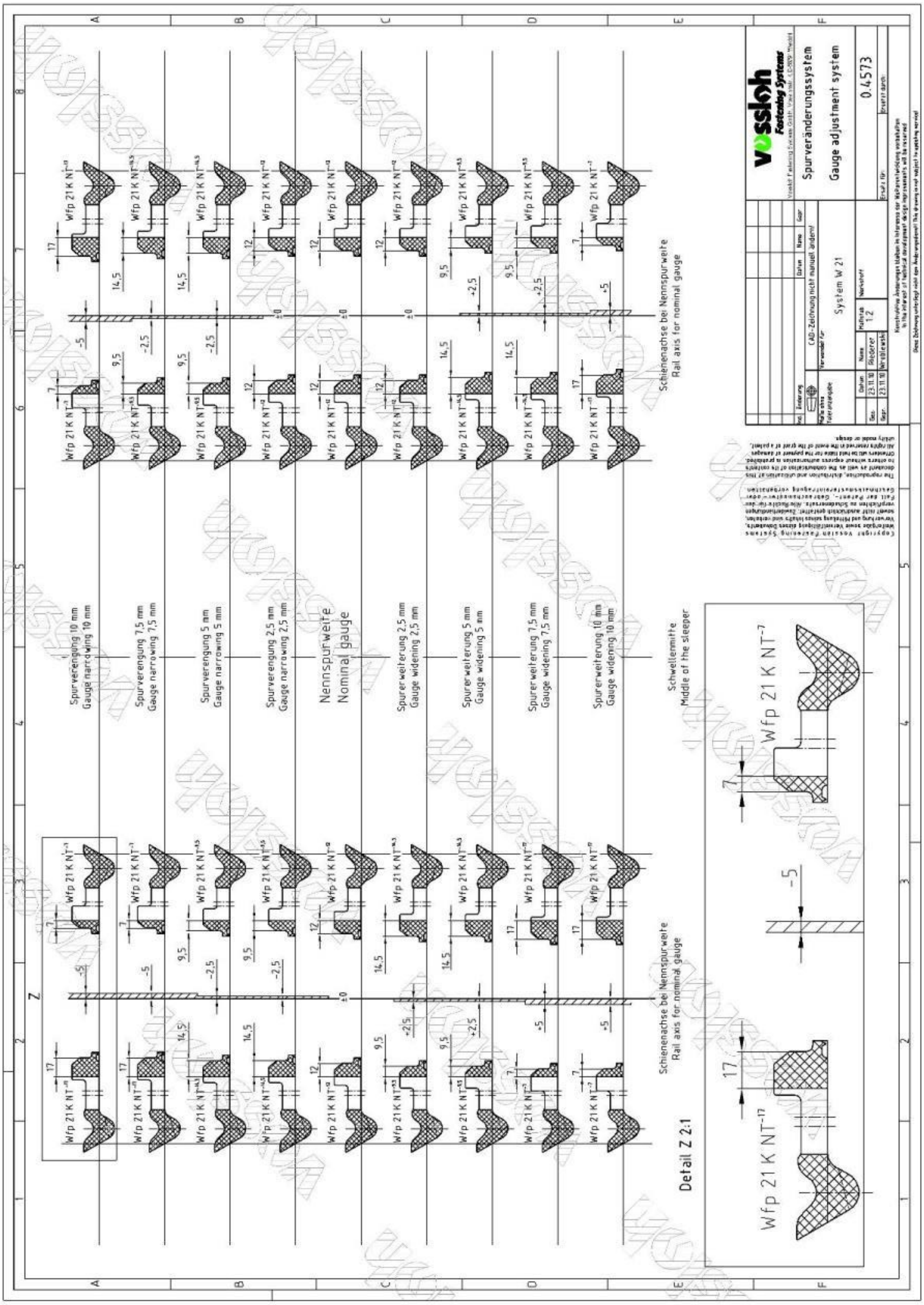


FIG. 42 TABLE OF GAUGE ADJUSTMENT

4.3.1.6 Geotechnical assessment

4.3.1.6.1 Model

A finite element model in Plaxis 2D was implemented to assess the behaviour of the new concept of modular slab track (3MB) developed during the Capacity for Rail project.

The model includes a number of layers which represent the different support layers of the embankment where the slab is placed. In order to obtain a better simulation, different models of behaviour were selected depending on the material.

SYSTRA performed the same calculations with a different software (Plaxis 3D) in order to have independent results. The study is covered by ANNEX VI of this deliverable.

Next table presents the different material along with its parameters and the behaviour model used in the model.

Table 8. Materials parameters used in the model

Component	Material	Behaviour model	Weight (kN/m3)	Young's modulus (MPa)	Poisson coefficient	Internal skid resistance	Cohesion parameter (kN/m2)
Slab	Reinforced concrete	Linear elastic	24	25000	0.25	-	-
Supporting layer	Asphalt	Linear elastic	23	6000	0.35	-	-
Base layer	Unbound granular	Mohr-Coulomb	20	200	0.35	35	0.1
Formation layer	Unbound granular	Mohr-Coulomb	19	200	0.30	35	0.1
Subgrade	QS1	Mohr-Coulomb	19	12.5	0.40	10	15
	QS2	Mohr-Coulomb	19	25	0.30	20	10
	QS3	Mohr-Coulomb	19	80	0.30	35	0.1

The graphic model is shown in the following figure (Figure 43).

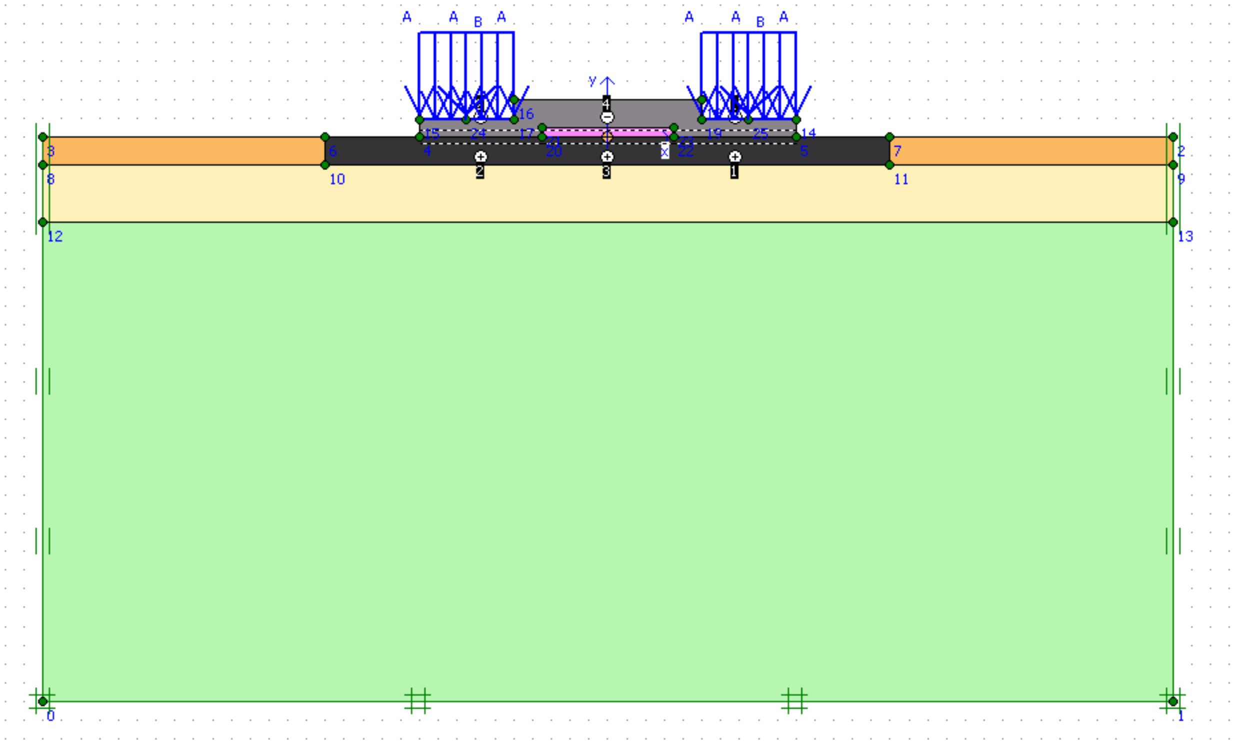


Figure 43. Plaxis 2D Model for the new concept of slab track developed in C4R

The loads considered in the model were calculated based on the Spanish normative for rail bridges (Ministerio de Fomento de España, 2010) as follows:

Table 9. Vertical loads

Load	Value
Wheel load (axle load/2)	112.5 kN
Quasi-static forces (15%)	16.88 kN
Dynamic forces (40%)	45 kN
Total	174.38 Kn

Table 10. Horizontal loads

Load	Value
Quasi-static forces	20 kN
Dynamic forces	40 kN
Total	60 kN

Finally these forces, which has determined for a 3D model, had to be converted in a 2D model. Considering a 2D section with a 1 meter of length, the forces in the model resulted as follows:

TABLE 11. FEM MODEL LOADS CONSIDERED IN THE FEM 2D PLAXIS MODEL

Load	Value
Vertical loads (distributed)	242.19 kN/m2
Horizontal load (linear)	30 kN/m

It is remarkable that in the modelling of the subgrade, different typologies of the same were used. The subsoil typologies chosen were determined in based on the Spanish Rail Normative (Ministerio de Fomento de España, 2015) which established three different kind of subgrade (Qs1, Qs2, and Qs3) depending on the values of its stiffness. Besides, different thickness for the asphalt layer was considered. Together with these considerations, the need for a shoulder was studied too.

As a result, different models were analysed in order to determine the behaviour of whole system.

4.3.1.6.2 RESULTS

A number of calculations have been made in order to cover the whole range of different case of study considered as hypotheses. The different models resulted in different behaviours and results which are collected in the next figures and tables.

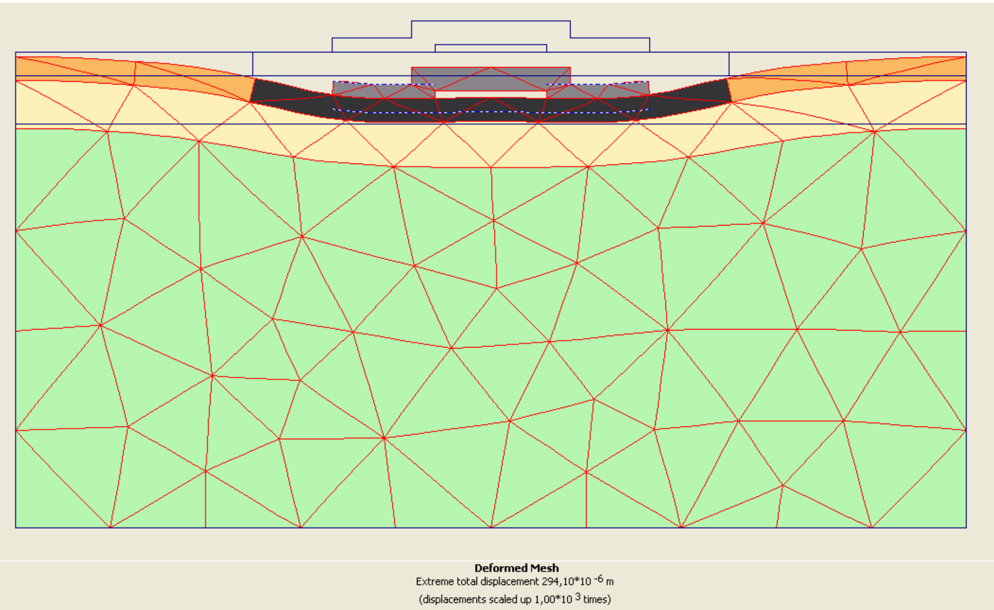


FIGURE 44. DEFORMED MESH

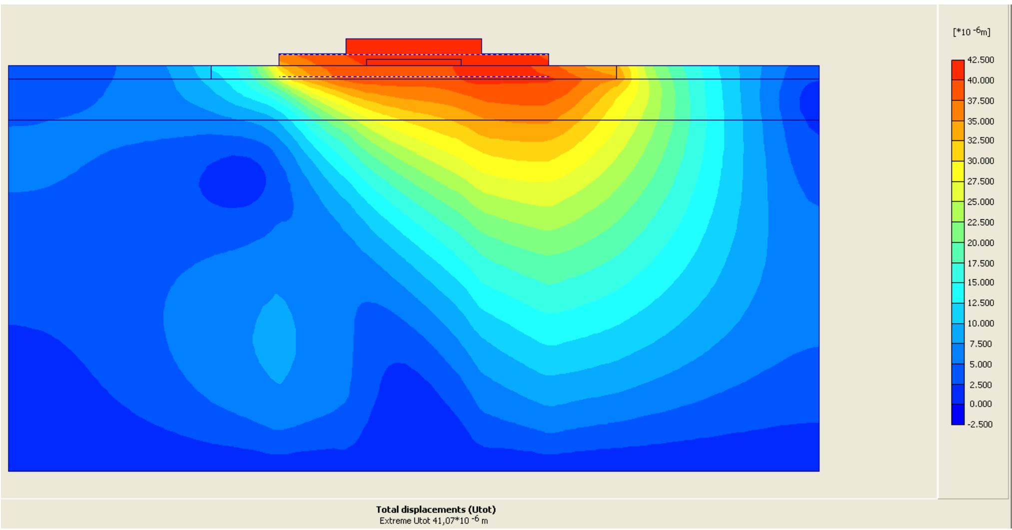


Figure 45. Total displacements obtained from the model

Table 12. Results obtained in the most relevant models

Model	Asphalt thickness (cm)	Shoulder (yes/no)	Formation layer thickness (cm)	Subsoil typology	Load A (distribute vertical) (kN/m2)	Load B (linear) Horizontal (kN/m)	Results
1	10	No	30	Qs3	240	0	Settlement: 2,06 mm
2	15	No	30	Qs3	240	0	Settlement: 1,84 mm
3	20	No	30	Qs3	240	0	Settlement: 1,78 mm
4	10	No	30	Qs3	240	30	Settlement: 2,39 mm

4.3.1.7 Asphalt layer assessment

4.3.1.7.1 Fundamentals

The assessment of the asphalt layer had been performed using the finite element model (FEM) 2D in Plaxis 2D, previously defined. However, in these calculations, the goal was to determine the optimal thickness of the asphalt layer depending of a number of factors such as the Young's modulus and the thickness of the asphalt layer, which in the most of the cases are not well-defined or are unknown.

In order to assess the requirements of the asphalt layer, a sensitivity analysis was performed. In this analysis, different values for the Young's modulus of the asphalt layer were considered along with different thickness of the same. The range of values includes in the different models for the Young's modulus of asphalt and the thickness of the asphalt layer is shown below:

- Asphalt Young's modulus considered (MPa): 1000-2000-3000-4000-5000-6000
- Thickness of asphalt layer (cm): 20-30-35-40

In total, 24 different numerical models were implemented in Plaxis 2D, in order to determine the best and optimal solution for the asphalt layer.

In every one of the model, different parameters could be evaluated such as the vertical strain, horizontal strain, equivalent stresses and displacements and so on.

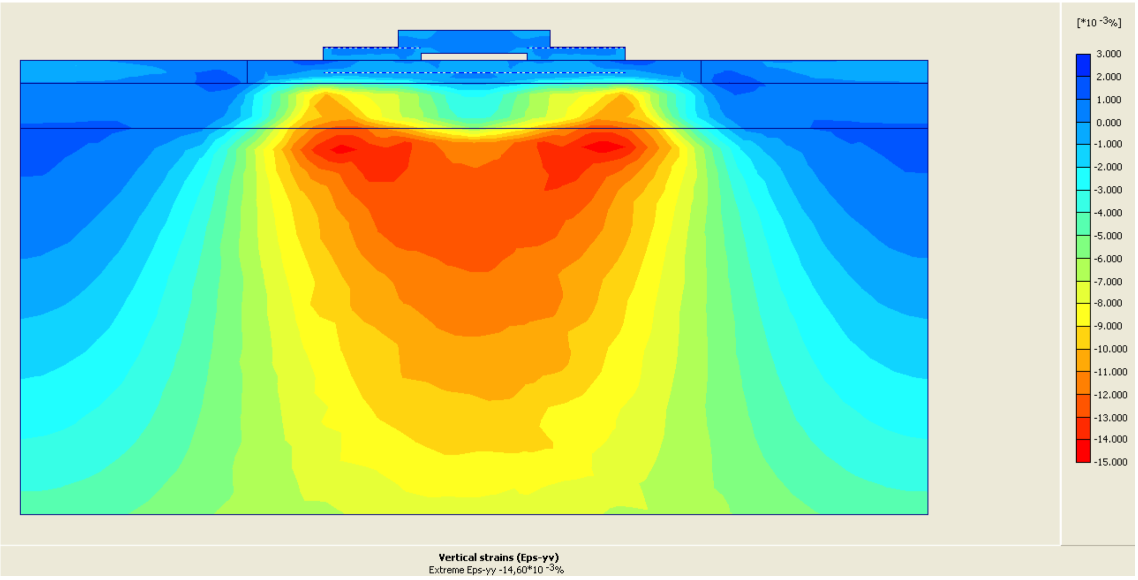


Figure 46. Vertical strains obtained from the model Plaxis 2D

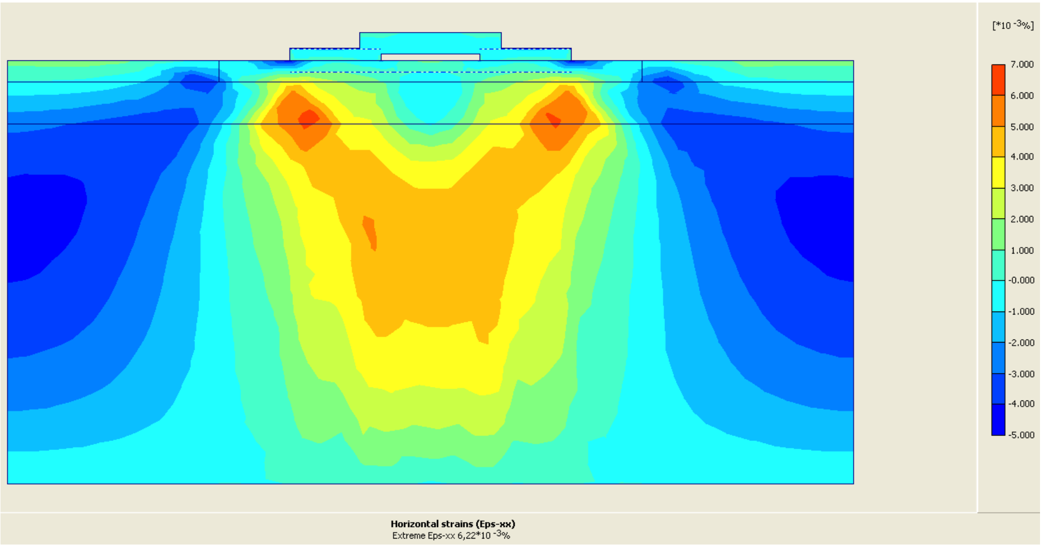


FIGURE 47. HORIZONTAL STRAINS OBTAINED FROM THE MODEL PLAXIS 2D

Once the model allows assessing the values of strain, deformation and stress in the asphalt layer for every model, it was needed to implement a methodology to evaluate the life expectancy taking into account the fatigue behaviour in time. To do that, the following fatigue criterion was used.

$$N = \left({6{,}92 \cdot 10^{-3}}/{\varepsilon_r} \right)^{3{,}67}$$

This is a fatigue criterion which is used in the design of the road pavements in Spain according to the Spanish pavement design prescriptions (Ministerio de Fomento de España, 2003). In order to use this criterion is needed to check the value of the radial strain in the lower face of the asphalt layer (ε_r). The criterion allows calculating the number of cycles which can support the asphalt layer until occurs the failure.

Under the hypothesis of an overloaded railway line, a number between 1.000.000 and 500.000 axles per year were chosen as the value of reference in order to determine the life expectancy of the asphalt layer.

4.3.1.7.2 RESULTS

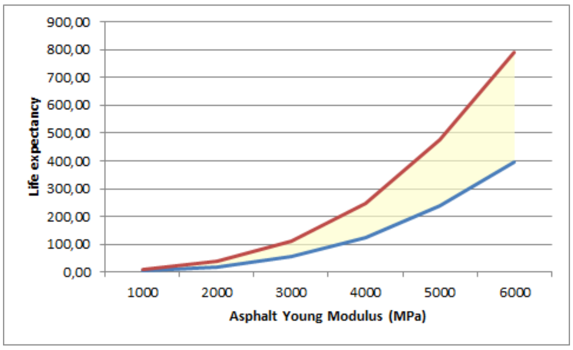
For every model the value of the maximum radial strain in the lower face of the asphalt layer was checked. The obtained values can be found in the following table:

TABLE 13. RESULTS OBTAINED IN THE FEM MODEL

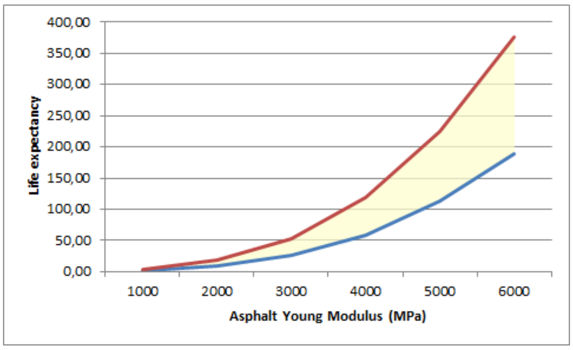
Asphalt Young's Modulus (MPa)	Asphalt layer thickness (cm)			
	20	30	35	40
1000	2.08E-04	1.60E-04	1.35E-04	1.12E-04
2000	1.45E-04	9.93E-05	8.70E-05	7.15E-05
3000	1.15E-04	7.75E-05	6.55E-05	5.36E-05
4000	9.62E-05	6.19E-05	5.28E-05	4.31E-05
5000	8.35E-05	5.25E-05	4.43E-05	3.61E-05
6000	7.39E-05	4.58E-05	3.85E-05	3.15E-05

Applying the fatigue criterion defined above, and considering 1.000.000 – 500.000 axles per year as said above it is possible to build a number of curves which allow the determination of the life expectancy in the different use cases

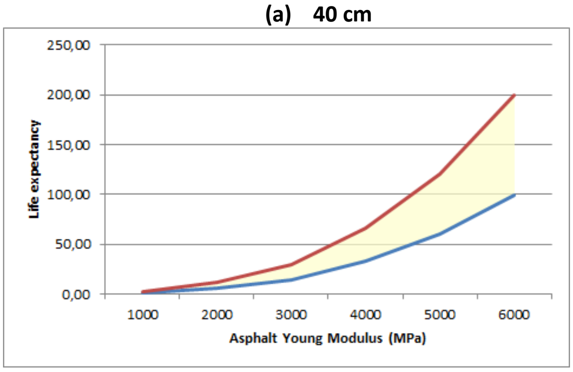
The following figures show the life expectancy for every one of the use cases where the red curve depicts the life expectancy under the hypothesis of 500.000 axles per year and the blue curve depicts the life expectancy under the hypothesis of 1.000.000 axles per year. The yellow area between these curves describes the highest probability area of life expectancy.



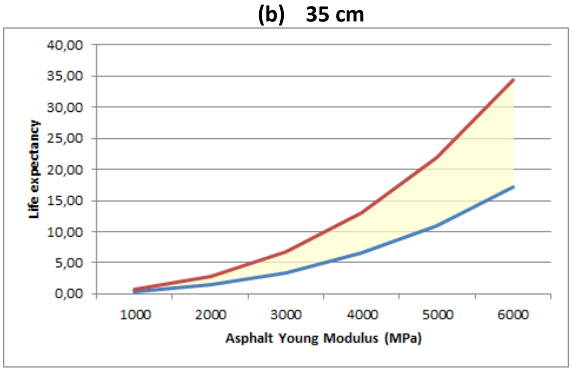
(a) 40 cm



(b) 35 cm



(c) 30 cm



(d) 20 cm

FIGURE 48.LIFE EXPECTANCY IN 3 MB SLAB MODEL FOR THE ASPHALT LAYER IN THE GIVEN USE CASES WITH DIFFERENT THICKNESS

It can be seen the high degree of variability between the different use cases. For the lowest thickness asphalt layer use case, it is obtained that the maximum expected life in the best of the hypothesis (500.000 axles per year) almost achieves the 35 years, far away from the 100 years required in the design phase. However, this figure (100 years of life expectancy) is achieved for the all other use cases.

In order to determine the optimal solutions which allow a life expectancy of 100 years, all the above figures had been merged in one. For that purpose, the hypothesis of 500,000 year per year had to be considered. In the following figure (Figure 49) all the results are shown.

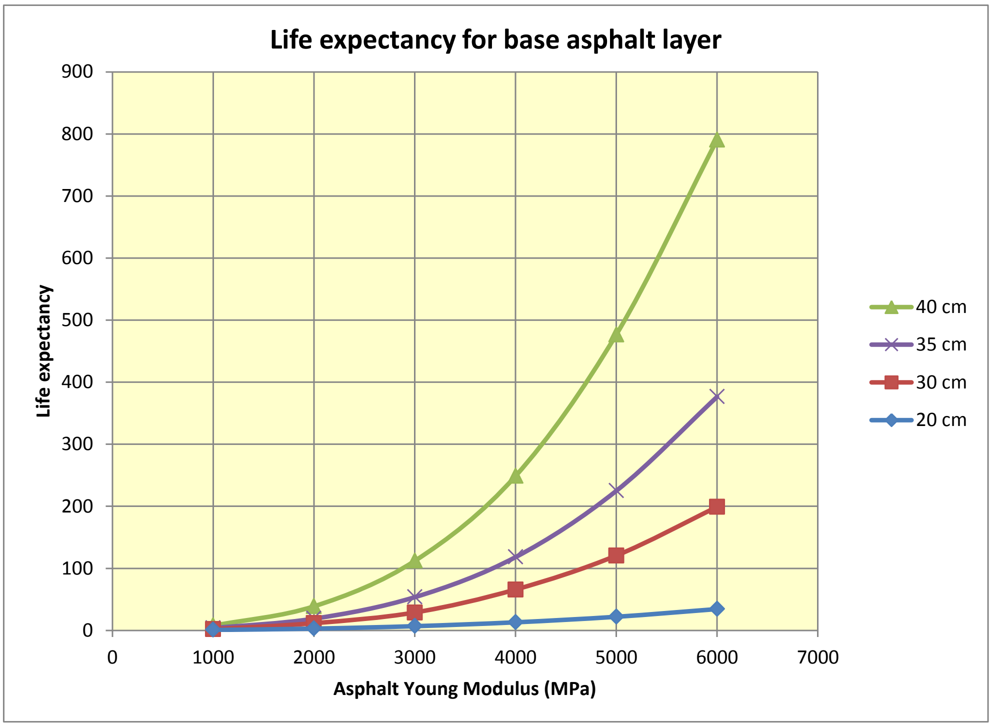


Figure 49. Results in terms of life expectancy for different thickness and Young's modulus of the asphalt layer in 3MB slab track model

Taking into account an expected life of 100 years for the new concept of slab track, it is probed that a layer of 30 cm is required (for common asphalt with a Young's modulus of 5000 MPa).

4.3.1.8 System integration

The outdoor signalling equipment on a passenger dedicated line made with concrete track have a relation to the signalling system chosen to control train movement and speed. This study presents the outdoor signalling equipment that can be found on a railway line fitted with a regular ETCS/ERTMS signalling system in accordance with the latest TSI specification.

The installation constraints regarding the slab track are given for all outdoor signalling equipment: this includes track circuit, axle counter, Eurobalise, EuroLoop and underline cable crossing. Since the signalling systems insure protection of the train based on information received from vehicle monitoring system, installation of these equipment on the slab track is described either; this includes dragging detector, hot box, wheel detector and axle load detector. This installation process applies to both top layer and bottom layer of the slab track.

Different technical solution are proposed in this study and detailed for each signalling equipment. Solutions involve bracket with adjustable plate fixed on the asphalt layer, specific block with reservation for equipment and mounting plate attached to the transversal arm of the slab.

The complete study is covered by Annex III

4.3.2 DESIGN AND DIMENSIONING OF THE L-TRACK CONCEPT

4.3.2.1 Vertical static calculation (ACCIONA)

4.3.2.1.1 SIMPLIFIED VERTICAL MODEL

To perform the structural calculations of elements subject to vertical loads, a 2D numerical model was developed using SAP2000 v.16.1.1 software.

Frame elements were used to represent rails and longitudinal beams, while shell elements were applied to represent the continuous rail pad and sub-base. The sub-base was supported using elastic restraints in the lower nodes of the shells. Elements were assigned a standard length of 0,10 m.

Three consecutive slabs have been modeled.

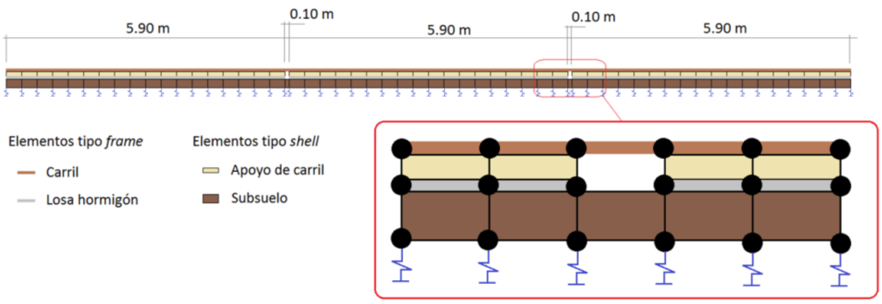


FIGURE 50. SIMPLIFIED VERTICAL MODEL

4.3.2.1.2 MECHANICAL PROPERTIES OF MATERIALS

The mechanical properties of materials used in the calculation are shown in the table below.

TABLE 14. MECHANICAL PROPERTIES

Parameter	Value	Units
Rail (UIC60)		
Rail mass density	7849.62	kg/m^3
Rail Young's modulus	2.1e+11	N/m^2
Rail poisson ratio	0.3	
Rail area	0.007687	m^2
Rail second moment inertia	3.055e-5	m^4
Rail damping ratio	0.005	
Slab (C35 concrete)		
Slab width at the top, w_{b1}	0.52	m
Slab width at the bottom, w_{b2}	0.56	m
Slab height, h_b	0.3	m
Slab length, L_b	5.9	m
Slab longitudinal spacing, L_{bs}	0.1	m
Slab Young's modulus	27e+9	N/m^2
Slab poisson ratio	0.2	
Slab mass density	2300	kg/m^3
Slab damping ratio	0.015	

Parameter	Value	Units
Railpad		
Railpad stiffness, k_p	200e+6	(N/m)/m
Railpad damping ratio	0.125 (beta=1.37e-4)	
Subsoil		
Subsoil stiffness, k_f	40e+6	(N/m)/m
Subsoil damping ratio	0.01/0.125/3 (beta=5.09e5/ 8.22e-4/0.0197)	

4.3.2.1.3 Applied loads

In order to envelope most pessimistic loading situations, vertical loads to consider have been selected based on the UIC71 load model shown below, multiplied by the following factors:

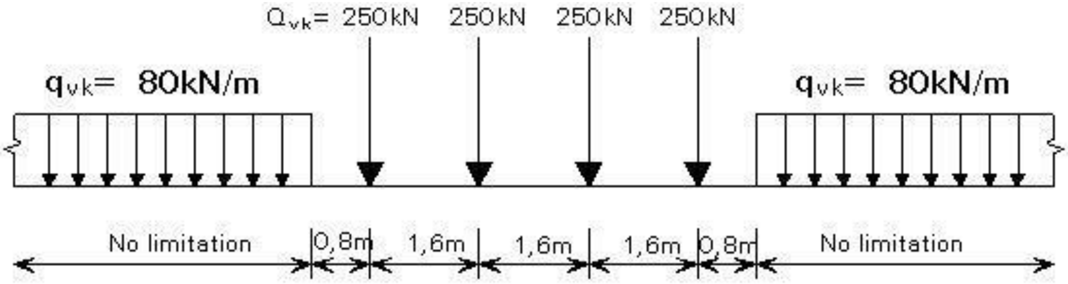


Figure 51 : UIC71 load model

- **Track load class multiplier α**: said parameter is used to cover the possibility of very heavy freight traffic. In order to cover this eventuality, allowing the use of L-track for all kinds of traffic lines, **α=1.33** has been selected.
- **Dynamic impact coefficient ϕ**: this coefficient is obtained from the quotient between the maximal dynamic stresses caused by all potential train configurations and the static stresses caused by the UIC71 load model. To envelop all possible configurations, **ϕ= 1.5** has been selected

four load positions and two combinations for each position have been considered in the calculations, attending to worst case scenario for concrete elements and horizontal stability (load centered on the module) or maximum stresses in the rail (load centered between two modules).

4.3.2.1.4 Load combinations for ULS

In ULS, variable load groups are affected with a safety multiplier Υv=1,5 if they contribute to a worst case scenario, and Υv=0 otherwise. Permanent loads, similarly, are affected with Υp=1,35 or 1,0.

Thus, the following combinations have been applied to the model:

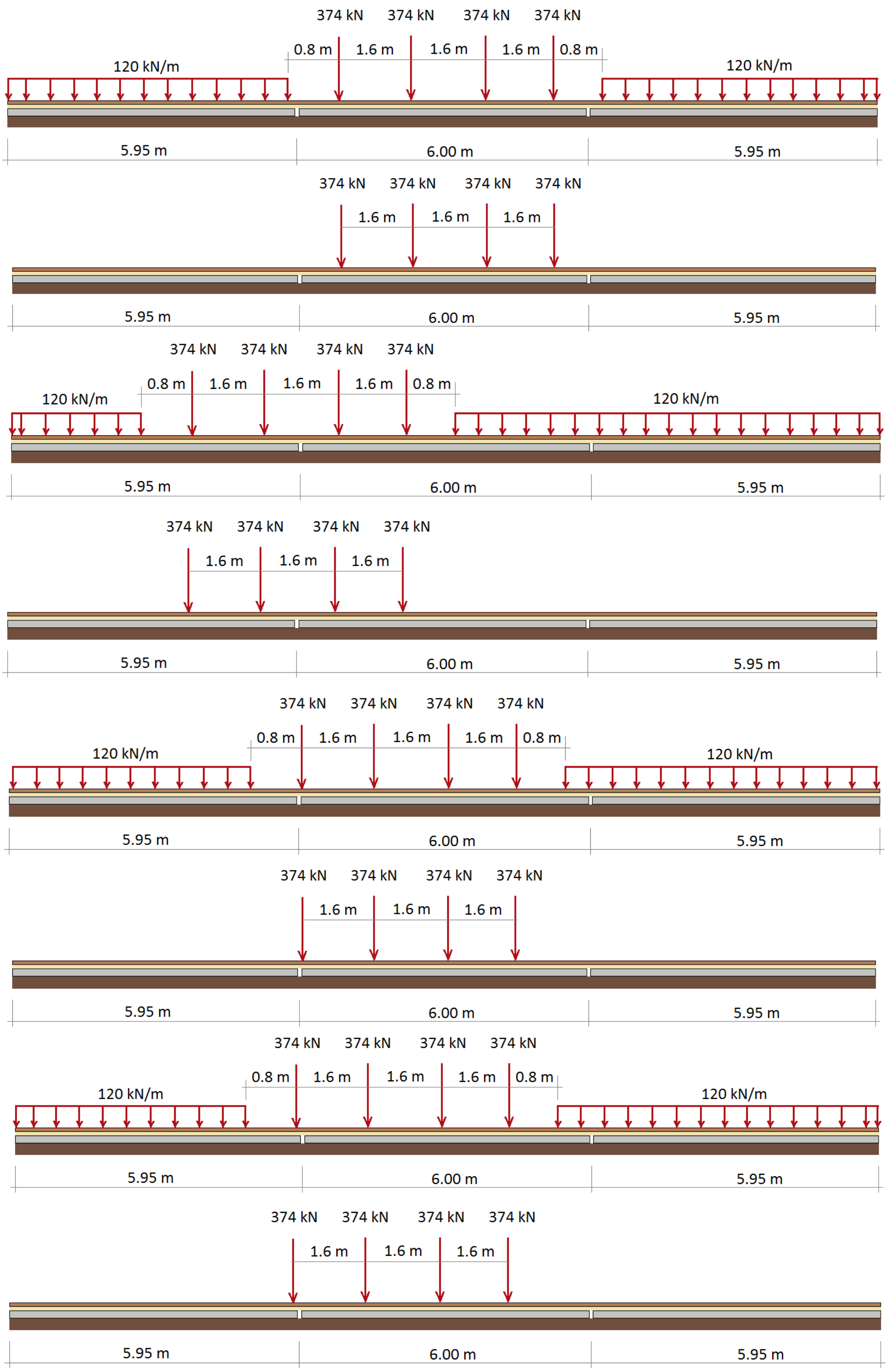


FIGURE 52 : ULS LOAD COMBINATIONS

4.3.2.1.5 ULS RESULTS

In order to guarantee structural safety of steel and concrete elements during operation, standard Eurocode calculations were applied to the longitudinal concrete beams

Worst-case combinations for the longitudinal beams may be seen in the following table:

TABLE 15. WORST-CASE SECTION FORCES IN LONGITUDINAL BEAMS

Combinations	Mmax (kN·m)	Vmax (kN)	Mmin (kN·m)	Vmin (kN)
A1	15.61	27.64	-23.39	-28.13
A2	32.52	49.77	-45.42	-50.27
B1	31.41	46.09	-20.46	-43.72
B2	49.02	69.64	-37.17	-64.74
C1	31.69	41.00	-31.89	-33.00
C2	52.62	63.52	-56.61	-53.22
D1	33.25	39.35	-32.16	-32.37
D2	55.59	61.42	-57.15	-52.09

Thus, pessimal flexural moments appear in load case D2, while pessimal shear forces appear in load case B2.

The resultant steel reinforcement may be seen below:

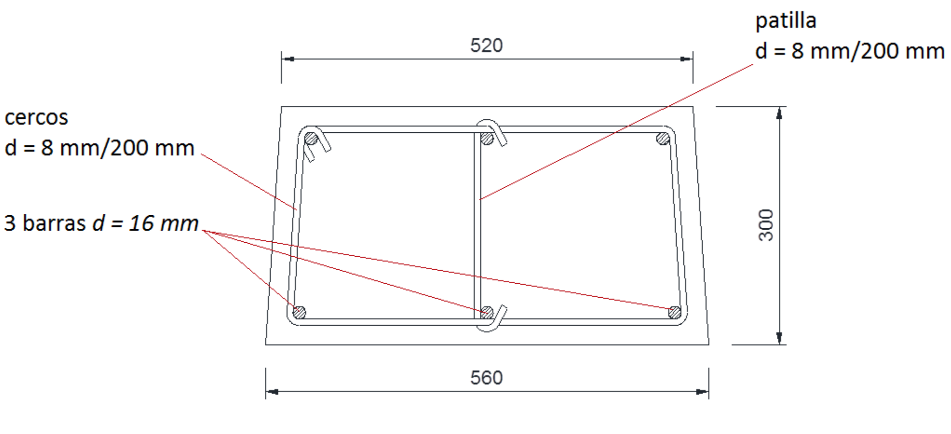


FIGURE 53 : DIMENSIONED REINFORCEMENT

ULS flexural capacity of the cross section is 63,1 kN·m, which guarantees a safety factor of 1,1

ULS shear capacity of the cross section is 105 kN, which guarantees a safety factor of 1,5.

4.3.2.2 Horizontal static calculation (ACCIONA)

In order to study the horizontal stability of the system and dimension the transversal steel beams and their anchoring, a 3D FE model was developed using the software ANSYS v.17

4.3.2.2.1 3D MODEL

Concrete elements, elastomers, fastening plates and rails were modelled using 3D finite elements, while reinforcement bars within concrete, bolts and elastic clips were modelled as beams.

Contacts prone to separation (such as the ones between blocks and elastomer, rail and railpad, rail and fastenning plates) were modelled as non-linear.

In order to reduce computing time, existing symmetries were used to represent an indefinitely long section of track by modelling only half a module.

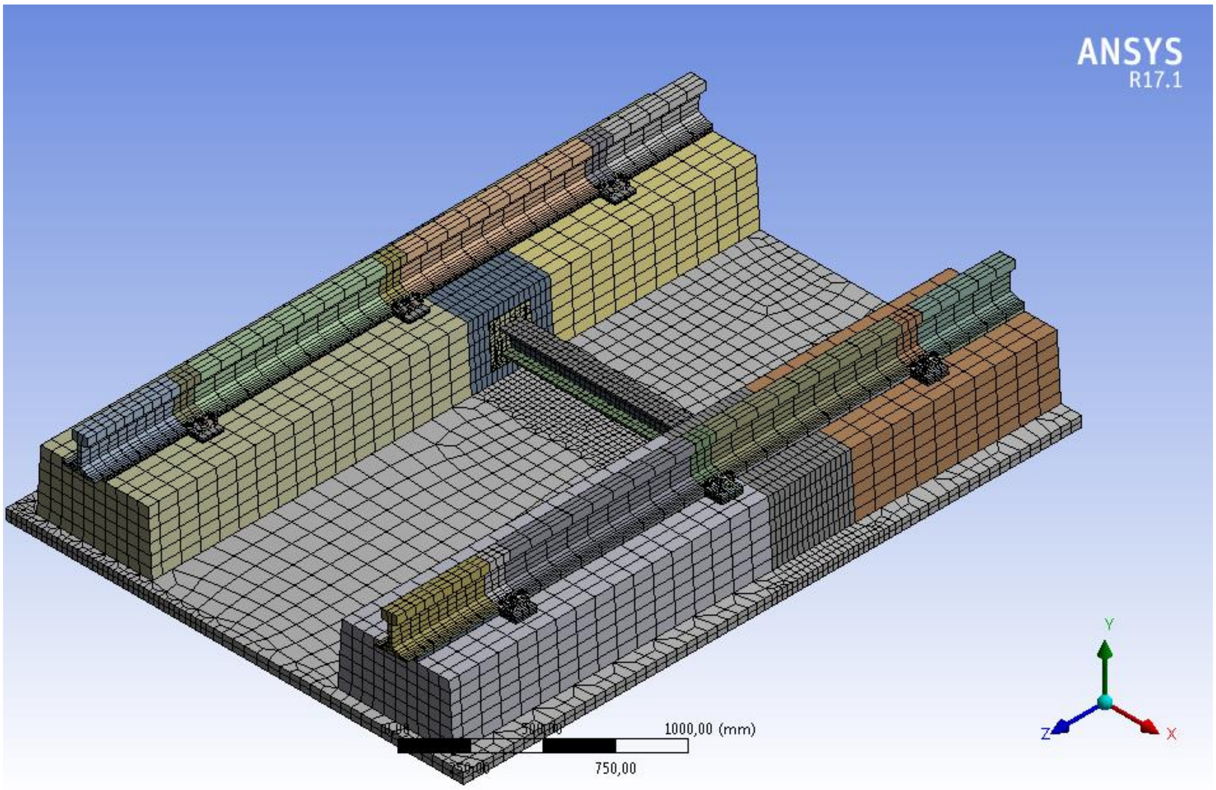


FIGURE 54 : L-TRACK 3D MODEL

4.3.2.2.2 ADDITIONAL LOAD COMBINATIONS IN ULS

In addition to the loads previously described for the vertical model, a single horizontal load of 150 kN representing hunting forces was applied to the active face of the right rail in the intersection of said face and two vertical planes: the module symmetry plane and the transversal beam axial plane.

Thus, the maximal bending moments and tension forces respectively were achieved in both the transversal beams and their anchoring plates.

4.3.2.2.3 Main ULS results for the transversal beams

The following diagram shows the envelope of equivalent stress in the transversal steel beams.

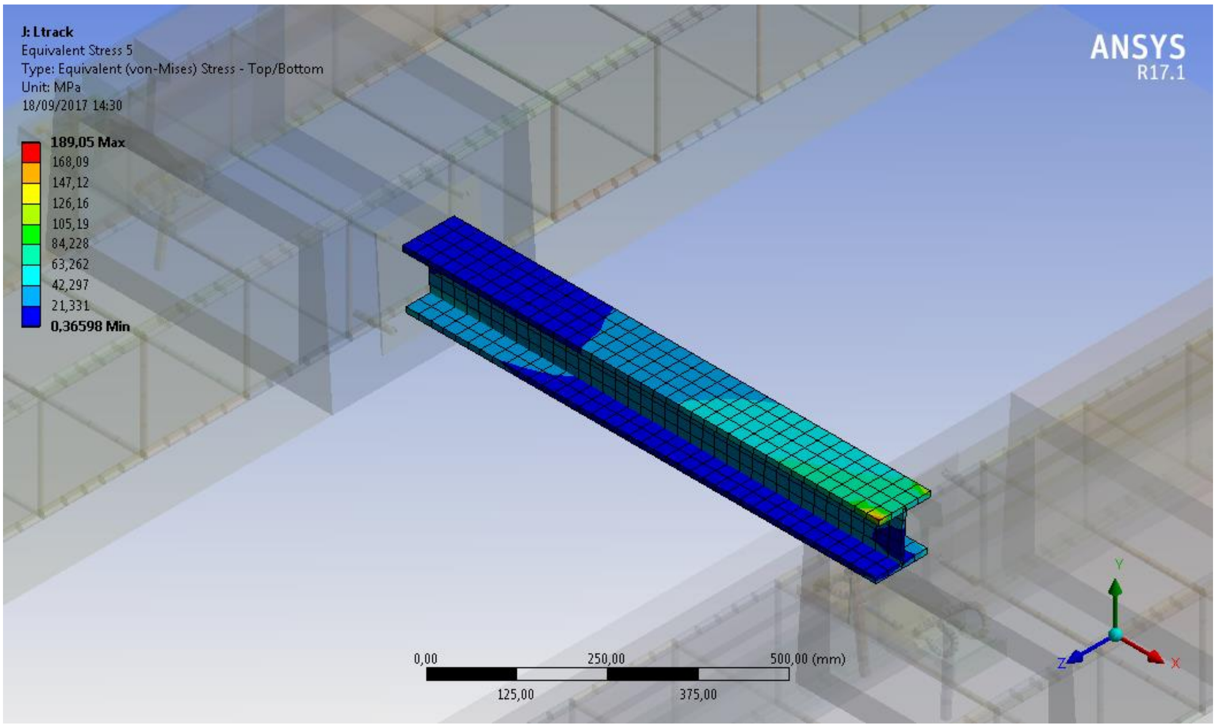


Figure 55 : L-TRACK 3D model

Maximum stress is 189,05 MPa, registered at the edges of the beam flanges, providing a safety factor of 1,26.

4.3.2.3 Stiffness levels calculation

This section presents the work done by Vossloh Cogifer for L-Track modelling and dynamic simulation (constant load) with main focus on **Non-linear definition of the fastening system.**

4.3.2.3.1 L-Track modeling

Finite Element model is built in ANSYS APDL language.

Beam and shell elements are used.

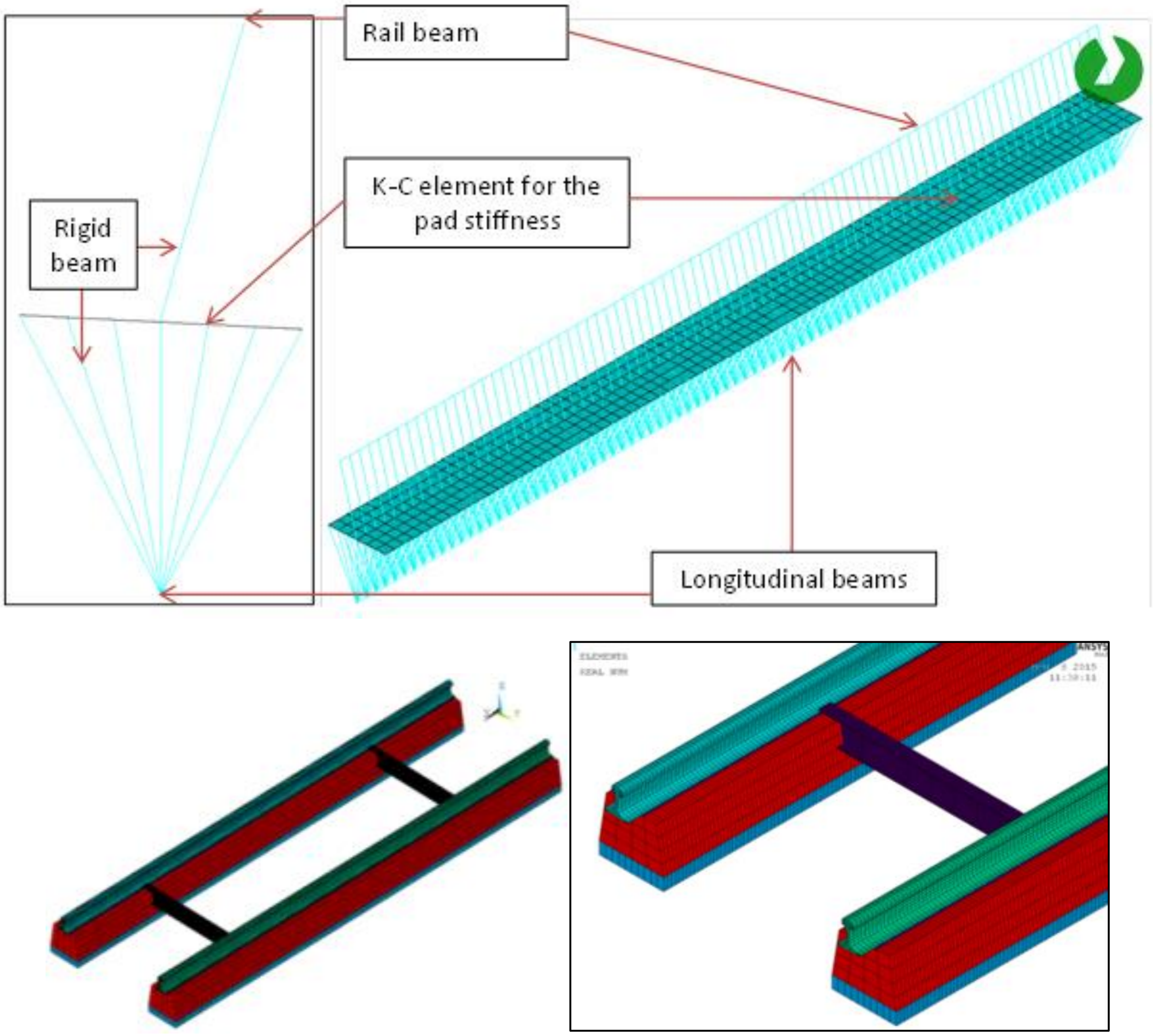


FIGURE 56 : L-TRACK 3D MODEL

4.3.2.3.1.1 NL ELASTIC PAD

The non-linear definition of the rail pad is used.

The pre-load of the fastening system is taken in account.

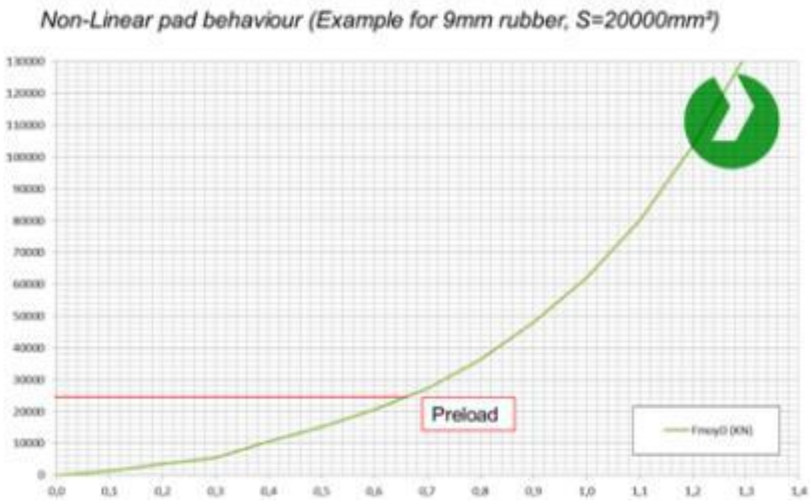


FIGURE 57 : NONLINEAR PAD BEHAVIOUR

4.3.2.3.1.2 L/NL SUBLAYERS

The sublayers are defined as one global linear of non-linear spring.

Input from Cemosa is required for Ka asphalt layer, and Kp platform layer.

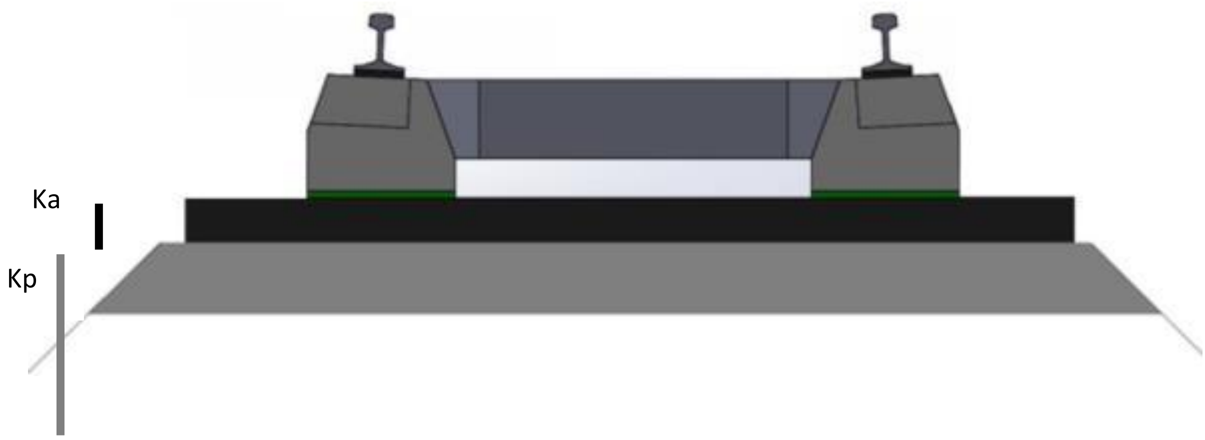


FIGURE 58 : NONLINEAR SPRING DEFINITION

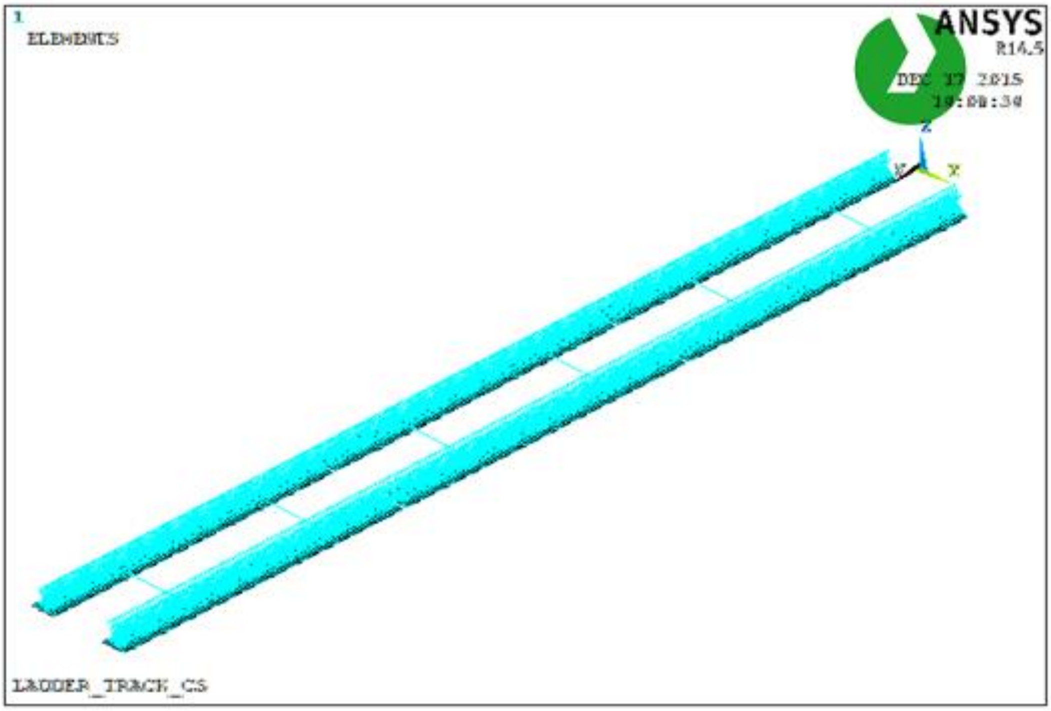
4.3.2.3.1.3 (CS) MODELLING

Example of (CS) L-Track with 3 modules without plate between modules.

3 modules : model length : 18,3m, 9mm Rubber pad used : NL stiffness behaviour

Linear Platform stiffness relatively soft with 240KN/mm for Seq =1,15m²

Fastening preload : 12KN,



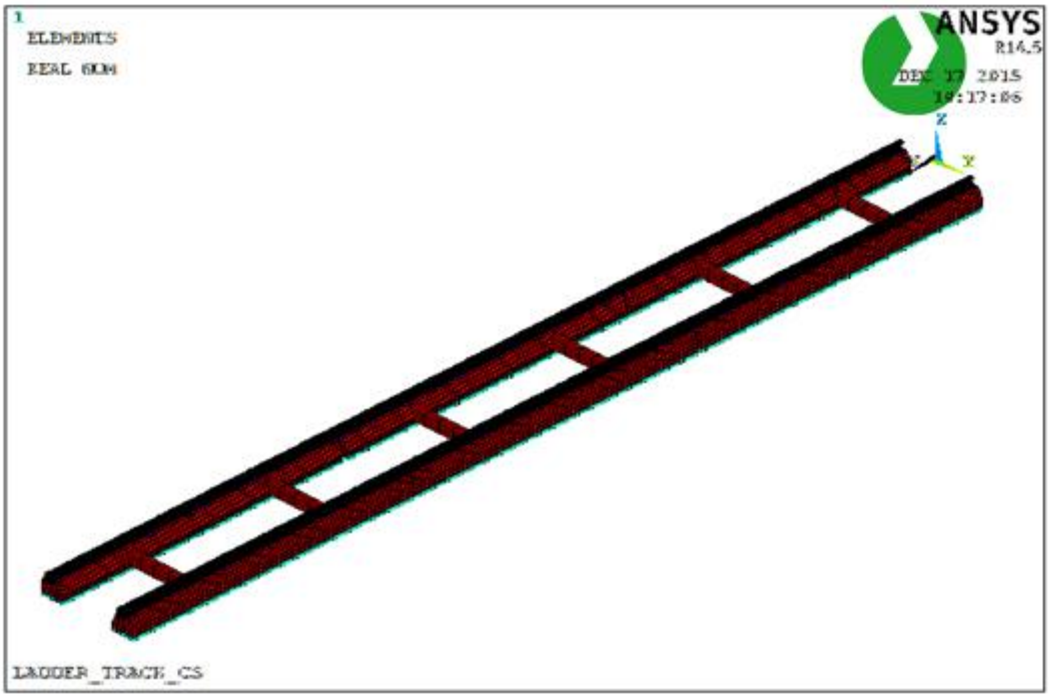


FIGURE 59 : L-TRACK 3D MODEL RESULTS

4.3.2.3.2 (CS/DS) Simulation : Constant load along 3 Modules (A)

Axle Load : 225 KN, Axle Load velocity 100 km/h

4.3.2.3.2.1 Vertical deflection along the three modules

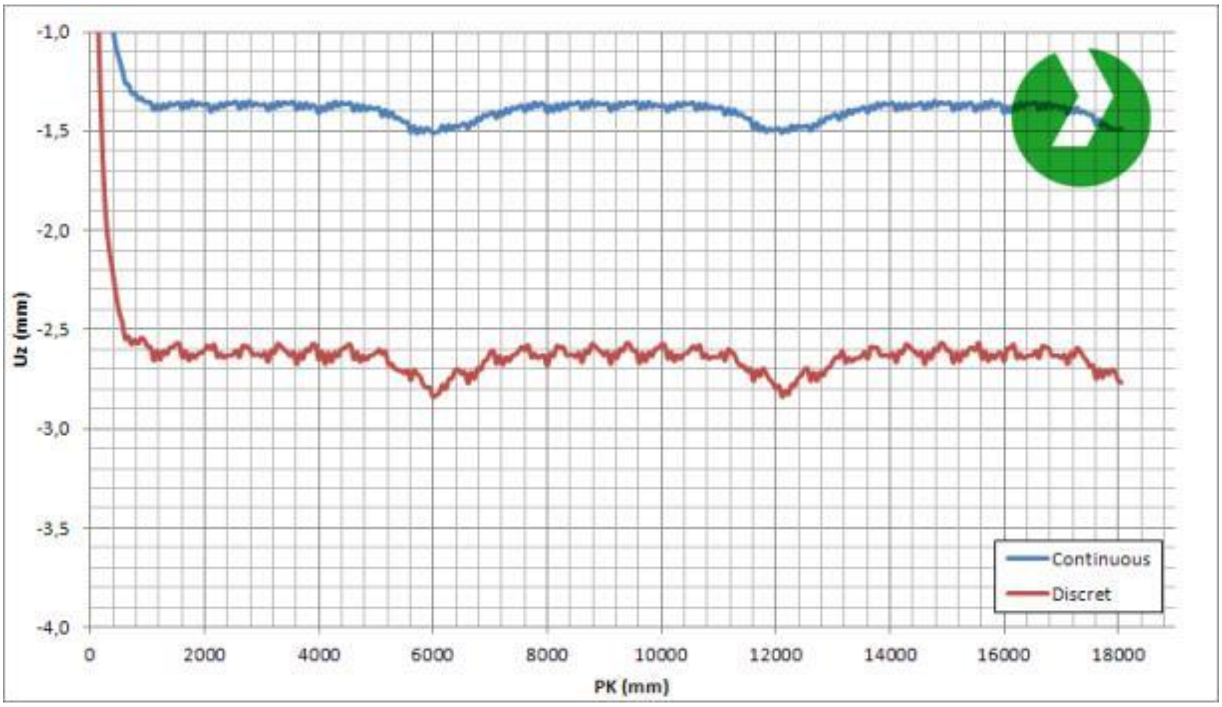


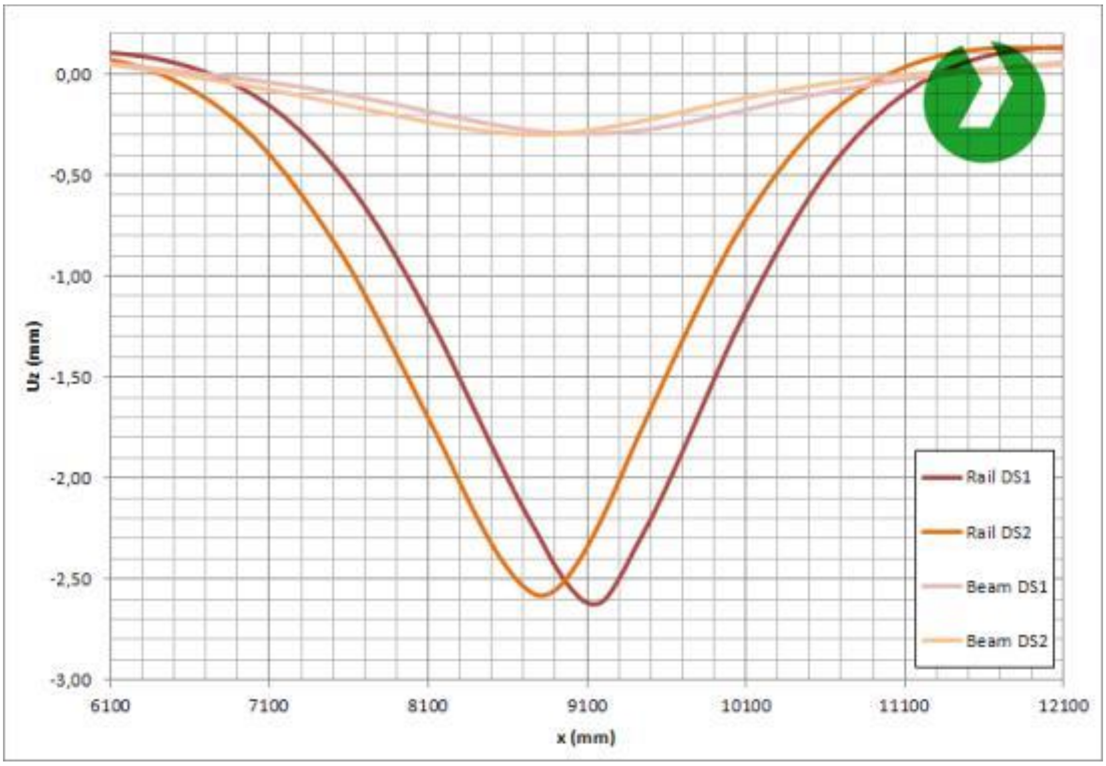
Figure 60 : vertical deflections

The vertical rail deflection is a main parameter for the track dynamics.

The discrete support result shows two weak points: higher variation between the modules and influence of the support space. In that case, there is a risk of frequency excitation.

For continuous support, the variation is limited and no frequency excitation risk.

4.3.2.3.2.2 Vertical deflection in the 2nd module at t=0,33s



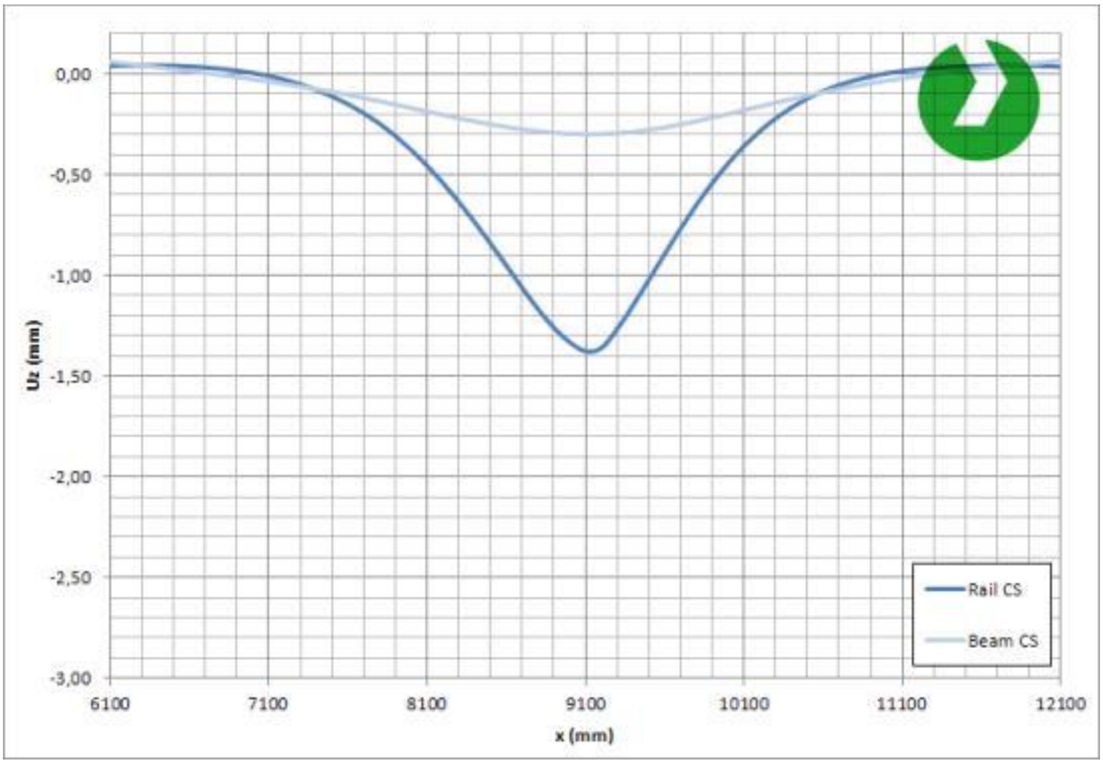
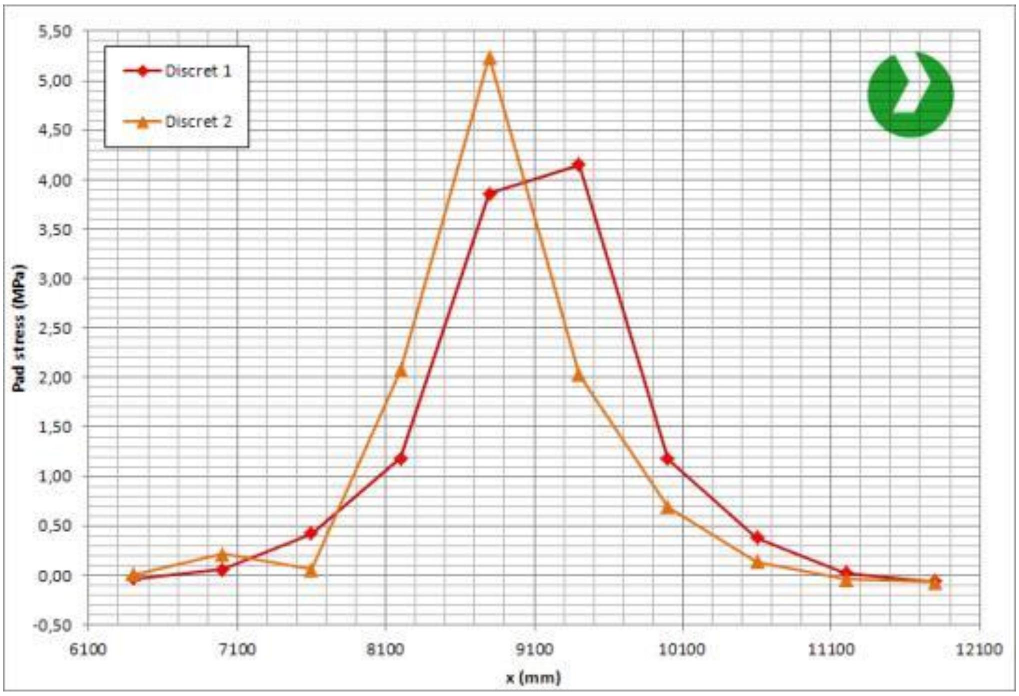


Figure 61 : vertical deflection of the 2nd module

The vertical displacement is 2.6mm for DS and 1.4mm for CS.

4.3.2.3.2.3 Nominal stress distribution in the pad along the 2ND module



Discret = load between 2 supports - Discret 2 = load @ support location

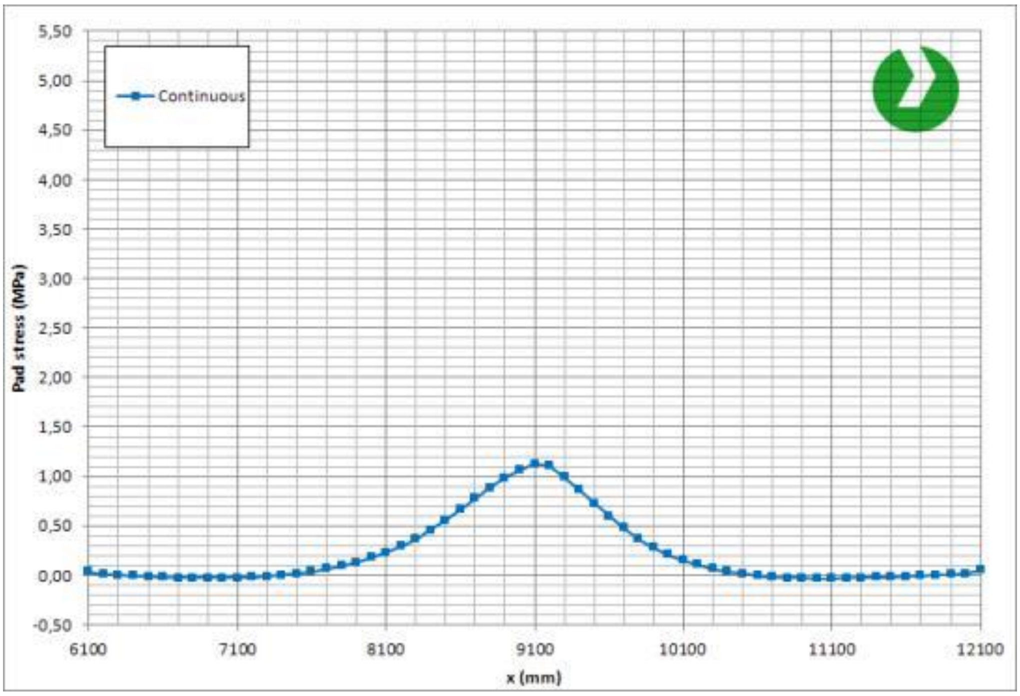


FIGURE 62 : NOMINAL STRESS DISTRIBUTION IN THE CONTINUOUS PAD ALONG THE 2ND MODULE

The stress in the pad (Force / Surface) is 5x higher in DS than in CS.

4.3.2.3.2.4 SOIL PRESSURE DISTRIBUTION IN THE PLATFORM ALONG THE 2ND MODULE

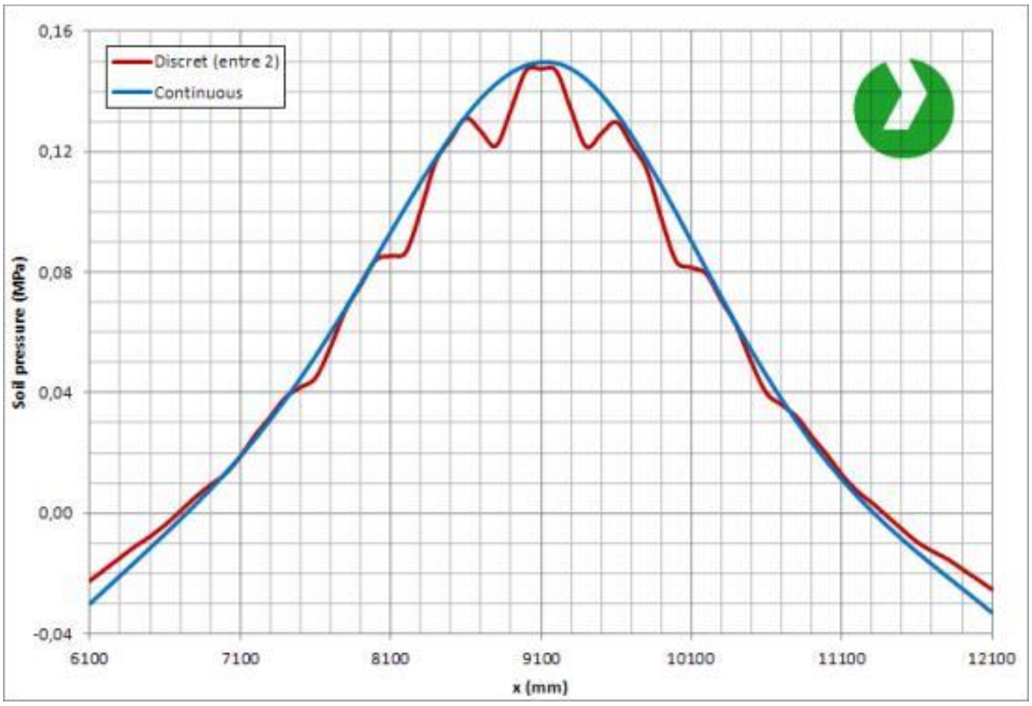


FIGURE 63 : SOIL PRESSURE DISTRIBUTION UNDER THE 2ND MODULE

The maximum soil pressure at the interface is similar for continuous and discrete support due to an identical surface at the beam bottom. (DS) Irregularities are due to the variation of section.

4.3.2.3.2.5 STRESS DISTRIBUTION IN THE RAIL ALONG THE 2ND MODULE AT T=0,33S

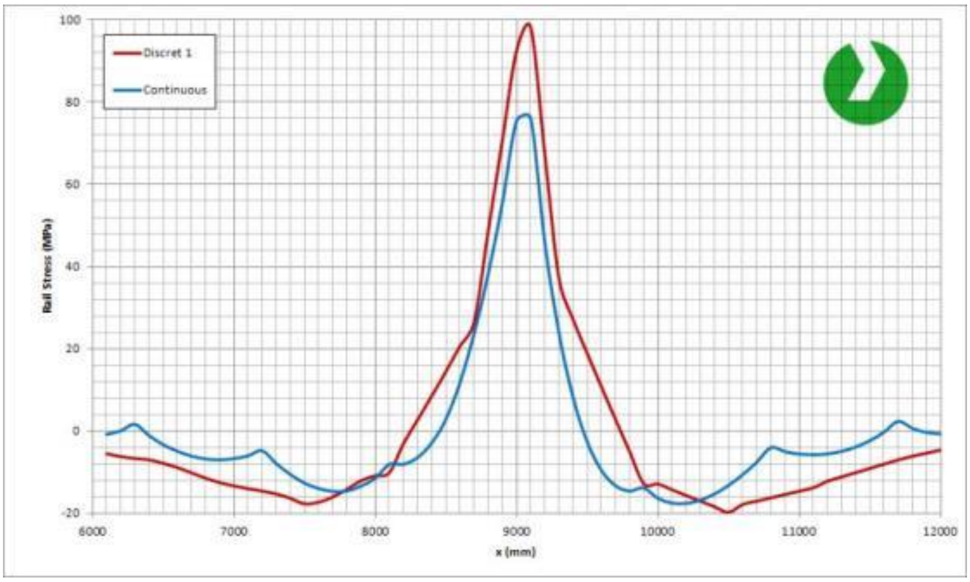


FIGURE 64 : STRESS DISTRIBUTION ALONG THE RAIL IN THE 2ND MODULE

Max Stress=98MPa *Discret1 = load between 2 supports - CS = DS - 22%*

4.3.2.3.2.6 BENDING MOMENT @ CONCRETE BEAM ALONG THE 2ND MODULE AT T=0,33S

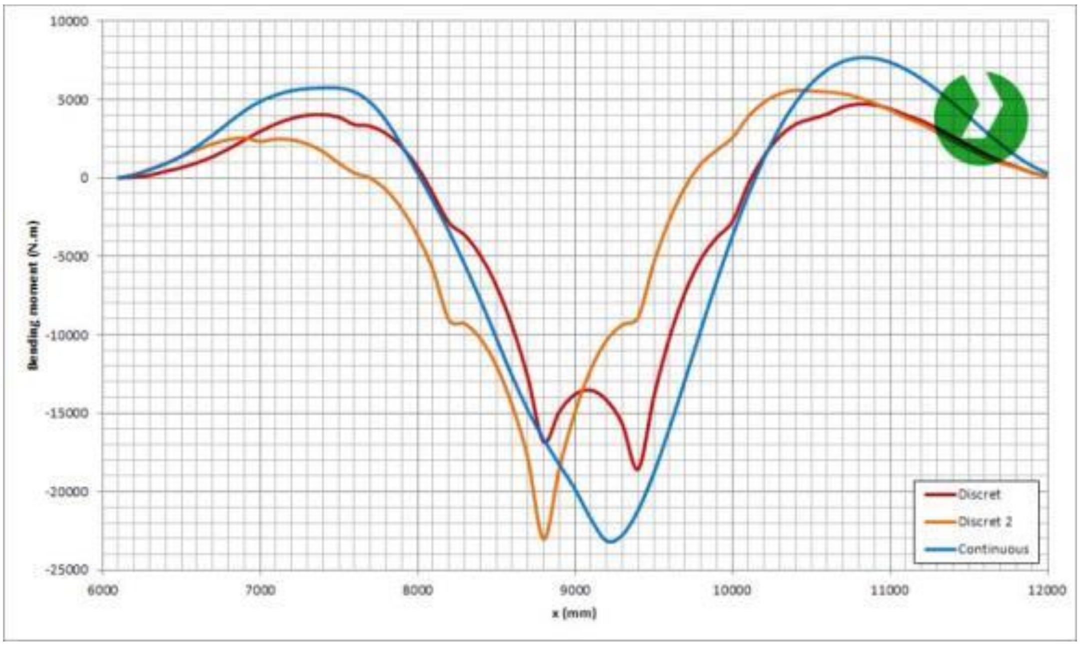


FIGURE 65 : BENDING MOMENT IN THE CONCRETE BEAM OF THE 2ND MODULE

Max Mt = 23kN.m *Discret = load between 2 supports - Discret 2 = load @ support location*

4.3.2.3.2.7 STIFFNESS (APPARENT) ALONG THE 2ND MODULE

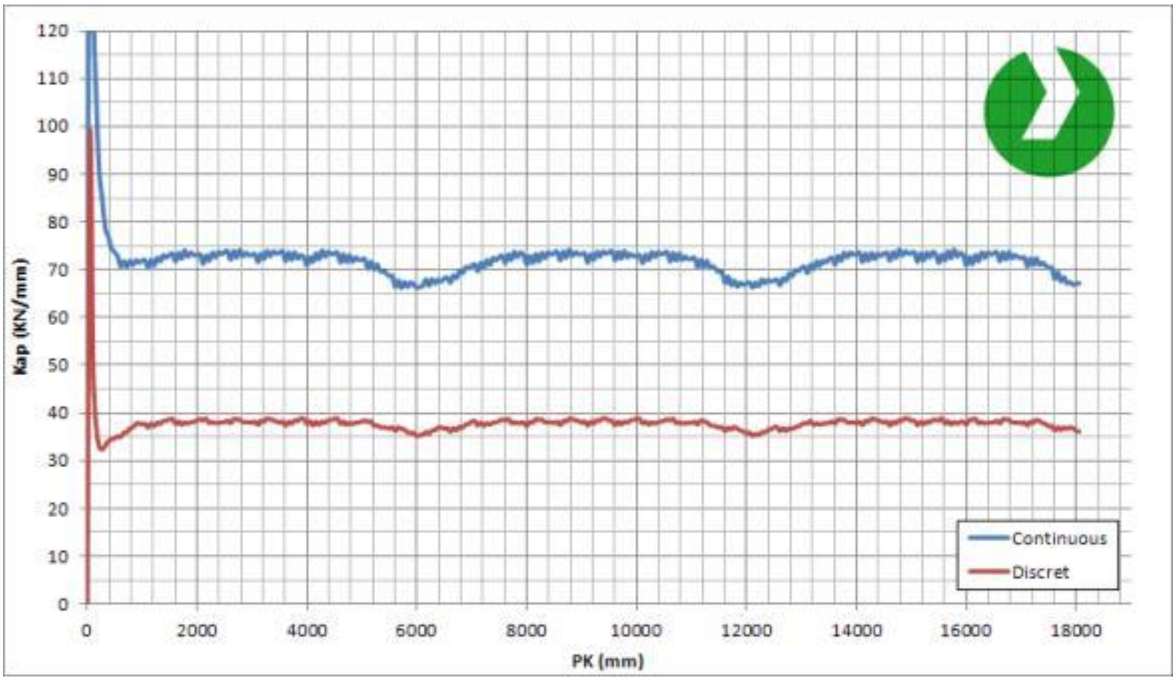


FIGURE 66 : APPARENT TRACK STIFFNESS OF THE SYSTEM

The difference of stiffness is due to the technology chosen for the fastening system.

The vertical stiffness variation is a not main parameter for the track dynamics.

4.3.2.3.3 Conclusions

The dynamic simulation on CS and DS for Ladder Track shows that for a similar pressure provided by the concrete beam to the soil, the track dymanics, vertical variation and rail stress are better for CS than DS.

4.3.2.4 Advanced dynamic calculation (VCSA)

This section presents the work done by Vossloh Cogifer for L-Track **advanced dynamic simulation with coupling of the track FEM response to a real vehicle (**Y25 bogie) through VCSA DYNADeV plateform, considering:

- A model length of 61m, composed of 10 modules, allowing to dispose :
- An entire freight wagon with two Y25 bogies, 11t / axle tree composed of S1002 wheels,
- Simulated path duration of 2,3s at a speed of 100km/h.

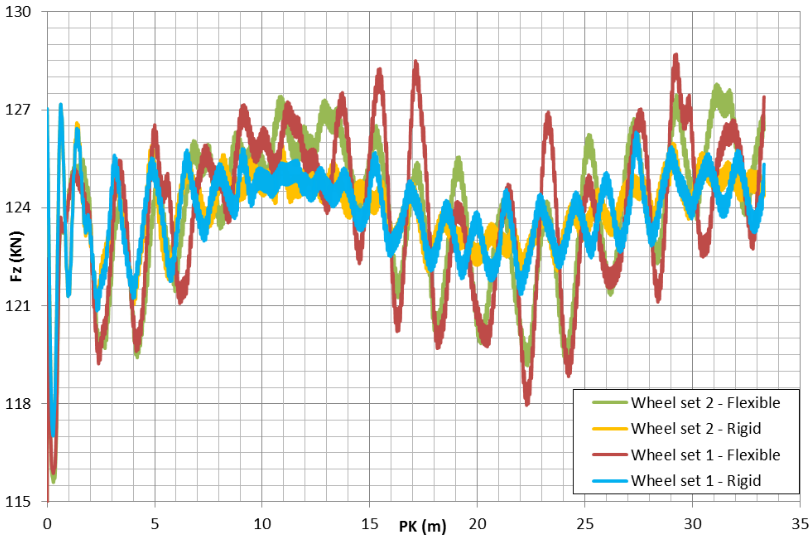
As regards the continuous support, two cases have been here tested. The first one supposes a infinitely rigid platform reporting all the track elasticity in the pad stiffness (60KN/mm for S=160*150mm²). Inversely, the second one considers a more rigid pad (120KN/mm for S=180*150mm²), associated with a more flexible platform (120KN/mm for S=50625mm²).

4.3.2.4.1 FEM Model

The same FEM model principle as previous chapter is used, but it is coupled with a multibody software.

4.3.2.4.2 Force & displacement variations at the wheel-rail contact

The DYNADeV project allows then to follow the force evolution at the wheel-rail contact point, as a function of



the PK.

Figure 68 shows for example what happens in the right side of the first and second wheel for both rigid and flexible cases. As regards the scale, it can be pointed out that the force level remains relatively stable during the vehicle passage, even if the variation is a little bit more pronounced at module interfaces for the flexible case.

In the same way, it is possible to extract the rail displacement as a function of the wheel position. As shown in the following figure**Erreur ! Source du renvoi introuvable.**, the rigid support implies a quasi-constant vertical deflection, with only a gap of a half millimetre tenth at interfaces between modules.

On the contrary, this stiffness variation zone is clearly more perceptible for the flexible support (delta of around 3 mm tenth), supposing a longitudinal beam working more in bending, as already evoked before.

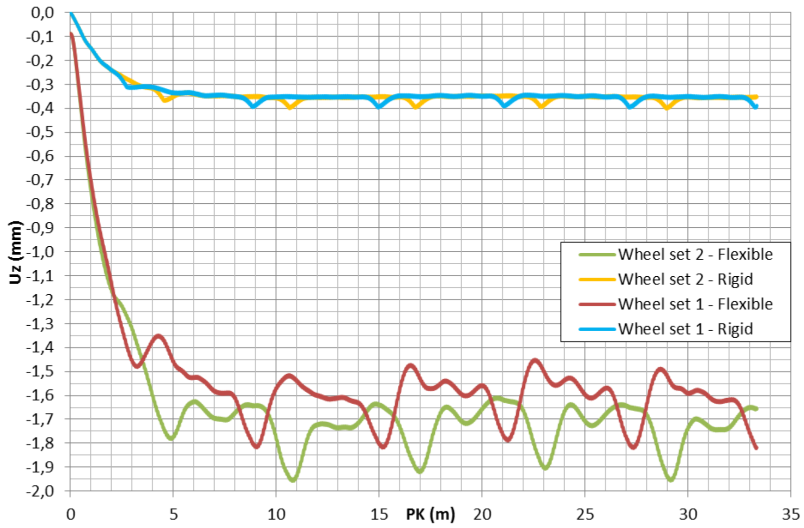


FIGURE 67 : RAIL DISPLACEMENT AS FUNCTION OF WHEEL POSITION

In this second flexible case, it can be also added that the second wheel of the first bogie generates a slight bigger deflection due to the dynamic effect preventing the rail to come back again in its initial position.

Once vertical wheel-rail contact force and displacement have been extracted, it is then possible to deduce the dynamic track stiffness by simply dividing the first one by the second at each time step. In the present study, we obtain Figure 70 and Figure 71, respectively representing the evolution of this stiffness as a function of the PK for the two first left wheels under flexible and rigid supports. Concerning the flexible case, we find again the curve profile of the displacement variation with an average value of 75 KN/mm. It can be noted that a delta of almost 20KN/mm between both wheels can be reached when the second one is passing the module interface. On the contrary, one wheel has quasi no influence on the other as regards the rigid support whit stiffness varying between 360 on modules and 310 KN/mm at interfaces.

4.3.2.4.3 RESULTS

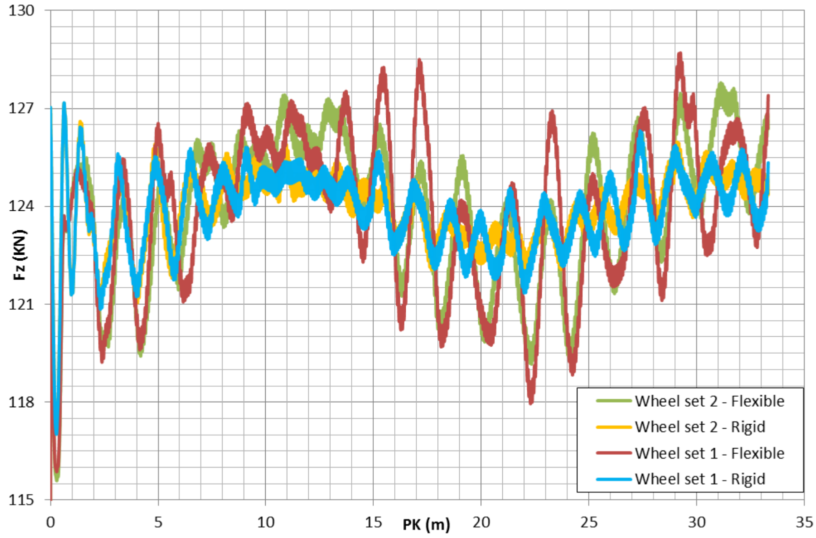


FIGURE 68 - DYNAMIC VERTICAL LOAD AT THE WHEEL / RAIL CONTACT

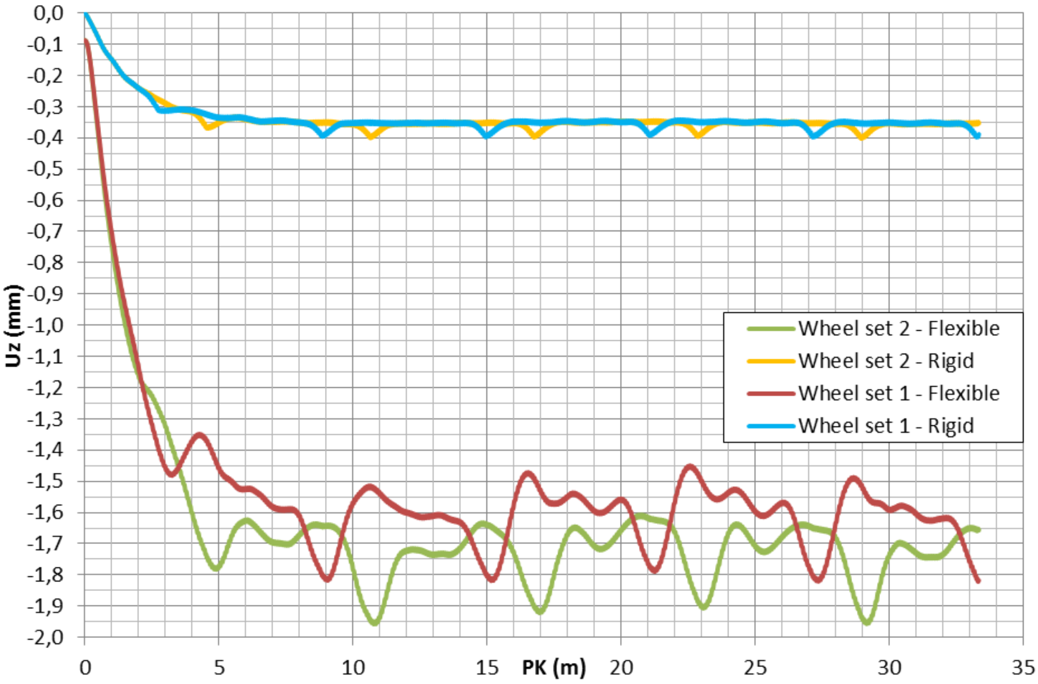


FIGURE 69 - DYNAMIC VERTICAL DISPLACEMENT AT THE WHEEL / RAIL CONTACT

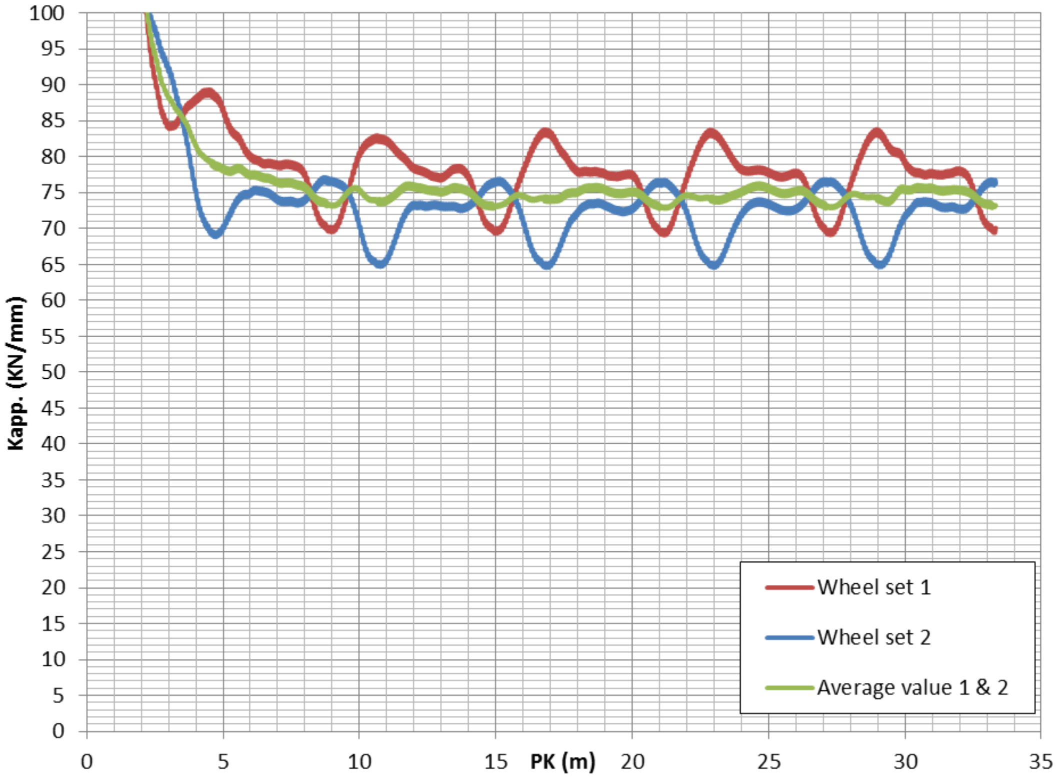


FIGURE 70 - DYNAMIC VERTICAL TRACK STIFFNESS AS A FUNCTION OF THE FIRST LEFT WHEEL POSITION FOR THE FLEXIBLE PLATFORM

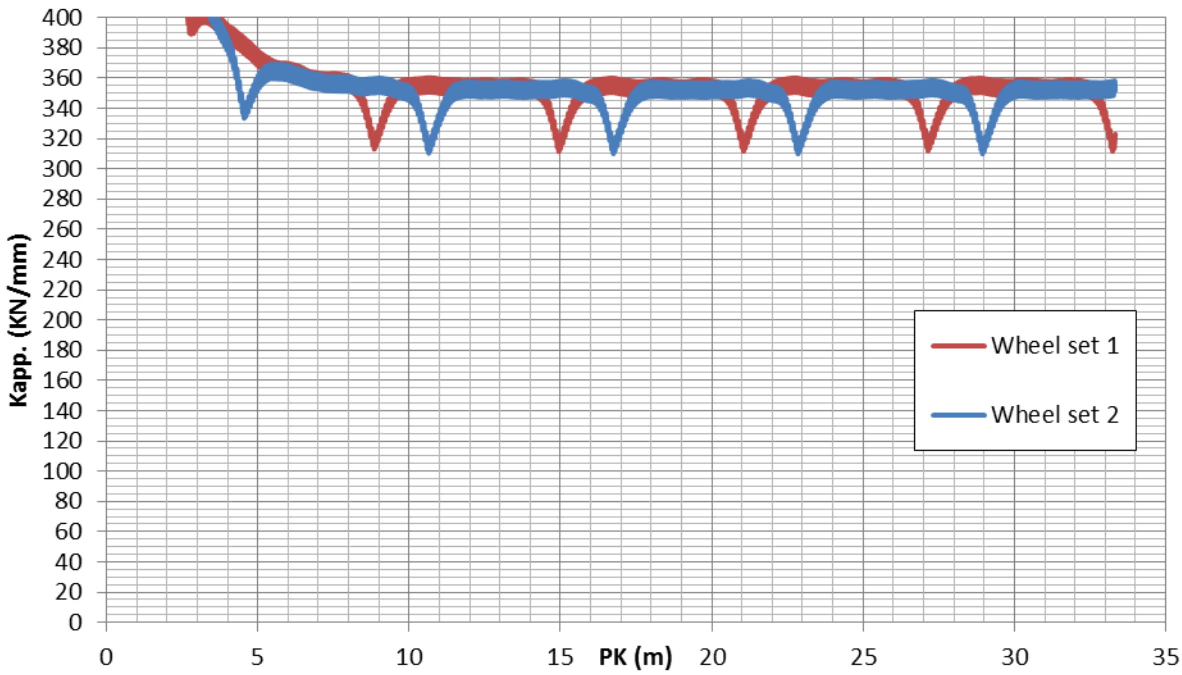


FIGURE 71 - DYNAMIC VERTICAL TRACK STIFFNESS AS A FUNCTION OF THE FIRST LEFT WHEEL POSITION FOR THE RIGID PLATFORM

4.3.2.5 Fastening selection

During the W11 workshops, two different concepts were studied for L-Track:

- Standard solution with discrete supports using existing fastening system
- Continuous support using existing fastening system

VCSA made static and dynamic stiffness calculations. The dynamic simulation on CS and DS for L-Track shows that for a similar pressure provided by the concrete beam to the soil, the track dynamic's, vertical variation and rail stress are better for CS than DS.

The continuous design is chosen for developing a new efficient fastening system and building the L-track prototype.

4.3.2.5.1 (DS) Discrete support

Discrete supports are supporting the rail.

10 fastening systems are located on each beam.

The distance between fasteners is 600 mm.

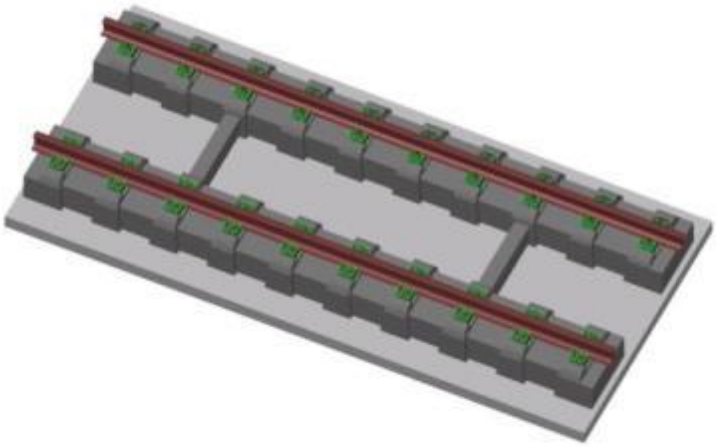
Vossloh 300NG fastening system is used.

Lateral (+/-16mm) and vertical adjustment (-4/+76mm) is done by shims.

BOTTOM UP installation is used.

A mortar is applied between the module and the bituminous layer.

Discrete support using Vossloh 300NG fastening system.



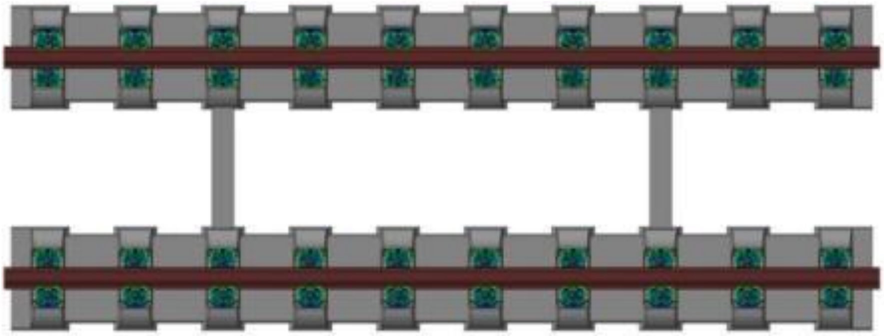


FIGURE 72 – DISCRETE SUPPORT L-TRACK

4.3.2.5.2 (CS) CONTINUOUS SUPPORT

A continuous elastic pad is supporting the rail.

6 fastening or more systems are located on each beam (less due to the continuous rail support/DS).

The distance between fasteners is around 900 mm (R>3000m), and 600-700mm (R<3000m).

Vossloh W21T fastening system is used.

Lateral adjustment is done by adapted insulator (+/-4mm).

Curve is included in the concrete (position of dowels).

Rail inclination is included in the concrete or rail head.

TOP DOWN levelling is used:

A mortar is applied between the modules

and the bituminous layer.

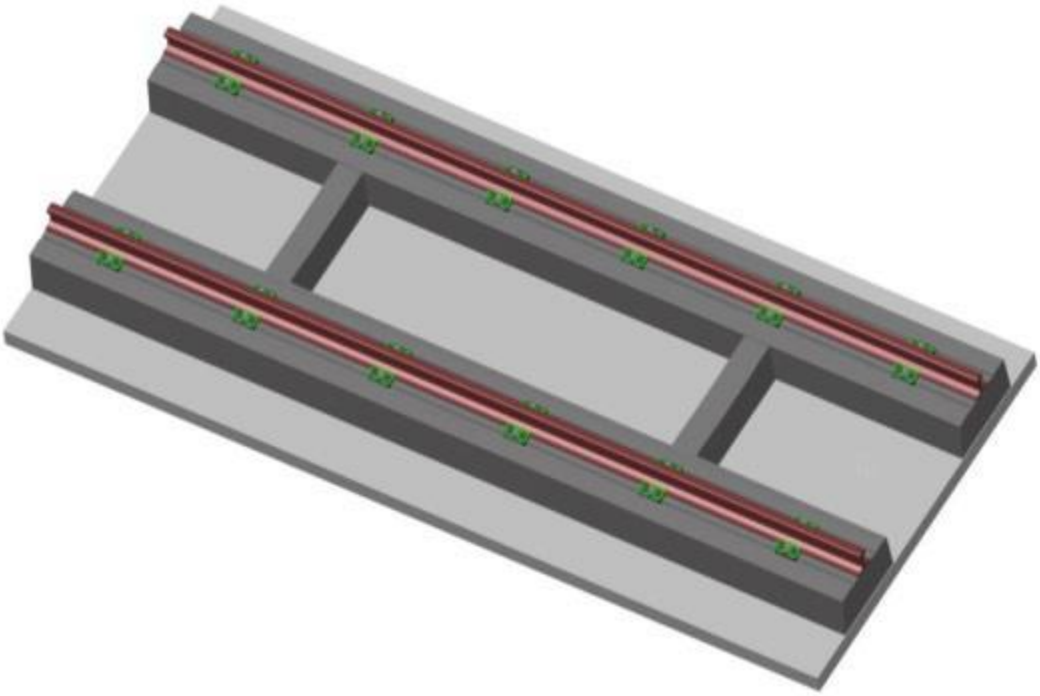


FIGURE 73 – CONTINUOUS SUPPORT L-TRACK

4.3.2.5.3 (CS+) CONTINUOUS SUPPORT + NEW FASTENING SYSTEM

VCSA decided to improve the (CS) design by developing a new fastening design able to provide fine lateral adjustment so that:

- There is No specific module fabrication depending on curves (radius) vs existing designs.
- The “standard” concrete module can be produced with one type of mould.
- The fastening system is fine adjustable without changing components vs existing designs.

The L-TRACK (CS+) design with the new fastening system is AFORDABLE.

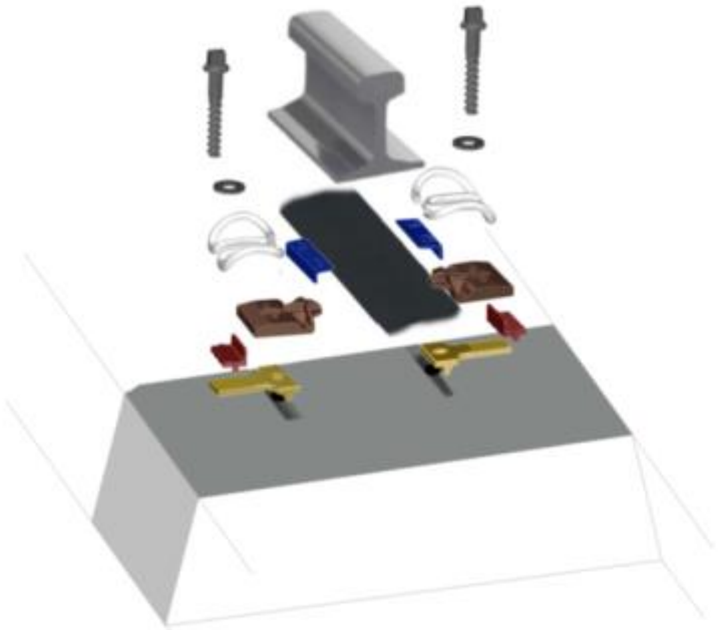


FIGURE 74 – NEW L-TRACK FASTENING SYSTEM

This figure shows the two extreme positions – and the lateral stop provided by the groove:

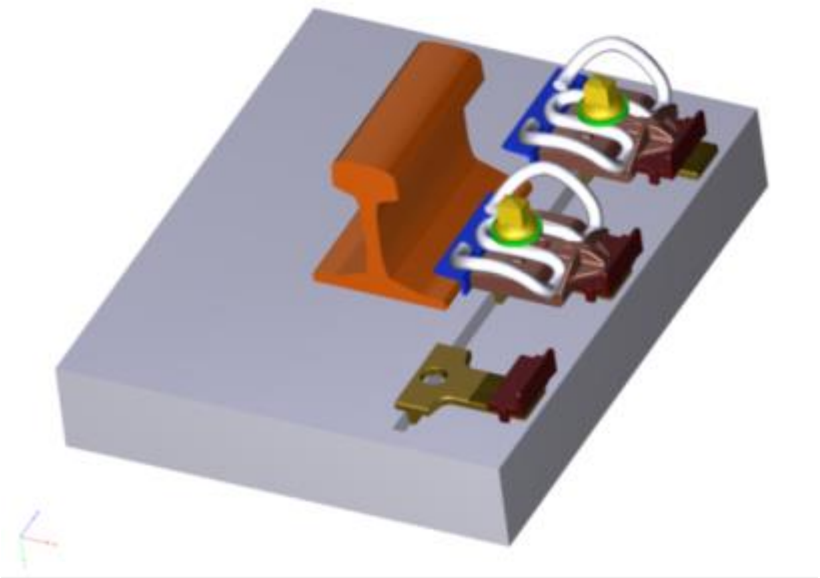


FIGURE 75 – L-TRACK FASTENING SYSTEM, EXTREME POSITIONS

The fine lateral adjustment allows:

- +/- 6,5 mm initial horizontal adjustment for installation (rail in curve ≥ 300m)
- +/- 4 mm adjustment capability for maintenance.

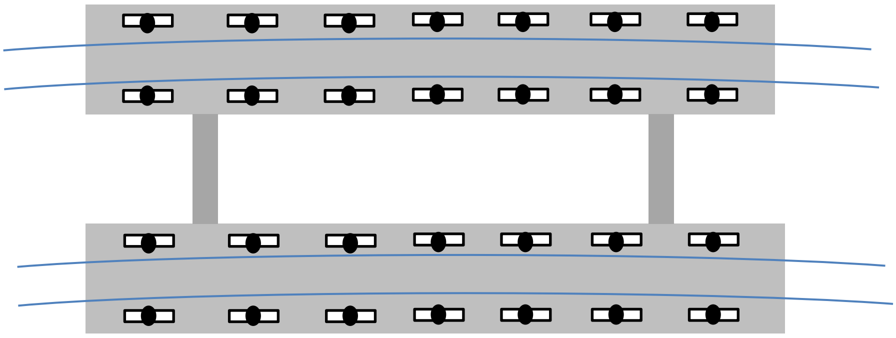


FIGURE 76 – POTENTIAL FOR CURVED TRACK WITH STRAIGHT MODULES

The fastening system was tested in laboratory according EN standard:

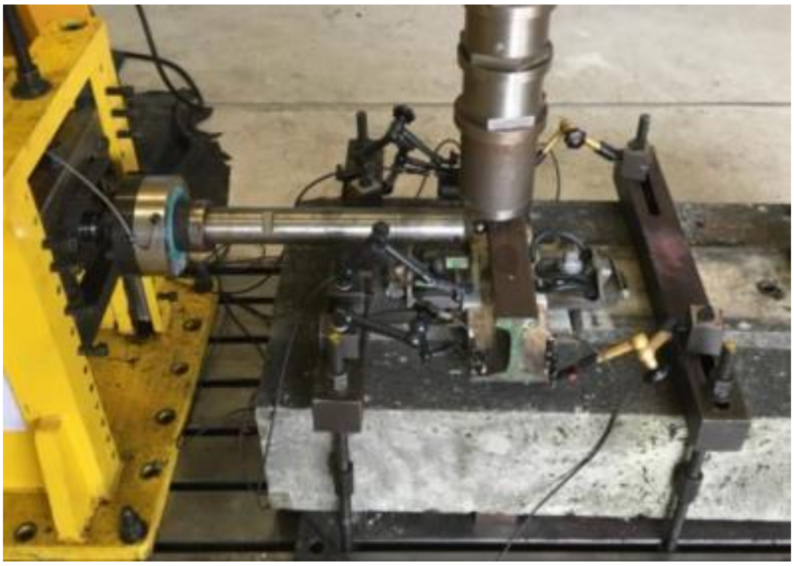


FIG 77 ADAPTABLE FASTENING SYSTEM – FATIGUE TEST

4.3.2.6 System integration (SYSTRA)

As the design of the L-Track is very close to 3MB meaning that both concepts have a ladder shape, system integration of the 3MB detailed in the relative annex III is also absolutely relevant for L-Track.

5 Construction procedure

This chapter sets the guidelines that must be followed in the assembly and construction of the 3MB and the L-Track concepts. Some stages described might be modified if the modular slab track is to be constructed on tunnel, bridge, embankments, metropolitan railways, etc.

5.1 3MB Concept: Construction procedure

5.1.1 General procedure for the construction of the 3MB system

The 3MB modular slab track is composed of prefabricated elements that are partially assembled before the transport to the construction site.

On track site, the modules are laid over a previously constructed bituminous layer. Given that track geometry adjustment is provided by the system on a top-down process, tolerances for said layer are not strict.

Finally, the fastening systems and the rails will be assembled over the blocks by following a Top-down construction procedure.

5.1.2 Stages for the 3MB system construction

The following is a description of the main stages needed for the construction and assembly of the 3MB modular slab track.

Materials

1. **Materials and transport**

The 3MB modules are transported by truck from the factory to the platform. The base slabs will be placed in a pile of 3 levels. The distance between the catenary poles must be observed for the final storage calculation.

DFF21 Rail fasteners shall be pre-mounted onto the rails in pre-set equidistant positions. To that effect, fastener screws shall be tightened against their plastic dowels with enough torque to fix the system to the rail. Rails with pre-mounted fastener shall then be stored on top of wooden blocks to allow space for the screws and dowels

The rest of pieces and elements composing the whole system will be likewise placed close to the modules.

Sequences of operation for the assembly of the 3MB system

2. **Preparatory works**

As stated, a bituminous layer must be constructed over the platform before the modules are installed. The layer is to be executed in advance, with enough time for proper compaction and curing, and shall be checked to ensure geometry and surface irregularities are within tolerance.

Wherever additional horizontal restraint is needed for track stability, cylindrical holes shall be bored into the bituminous layer to hold in situ mortar dowels.

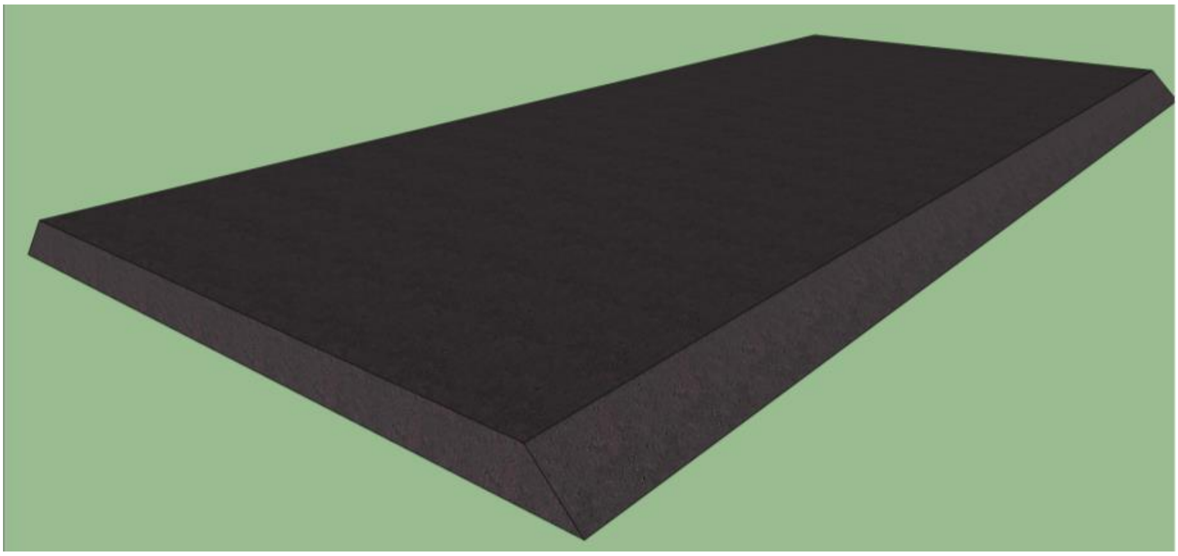


FIG 78: BITUMINOUS SUB-BASE

3. Surveying and marking

A complete surveying has to be done to check the levelling of the whole platform is within tolerance. Marking will be prepared as well to signal the location of base slabs.

In order to enhance positioning precision, base slab perimeter may be marked on the sub base with spray paint or adhesive tape.

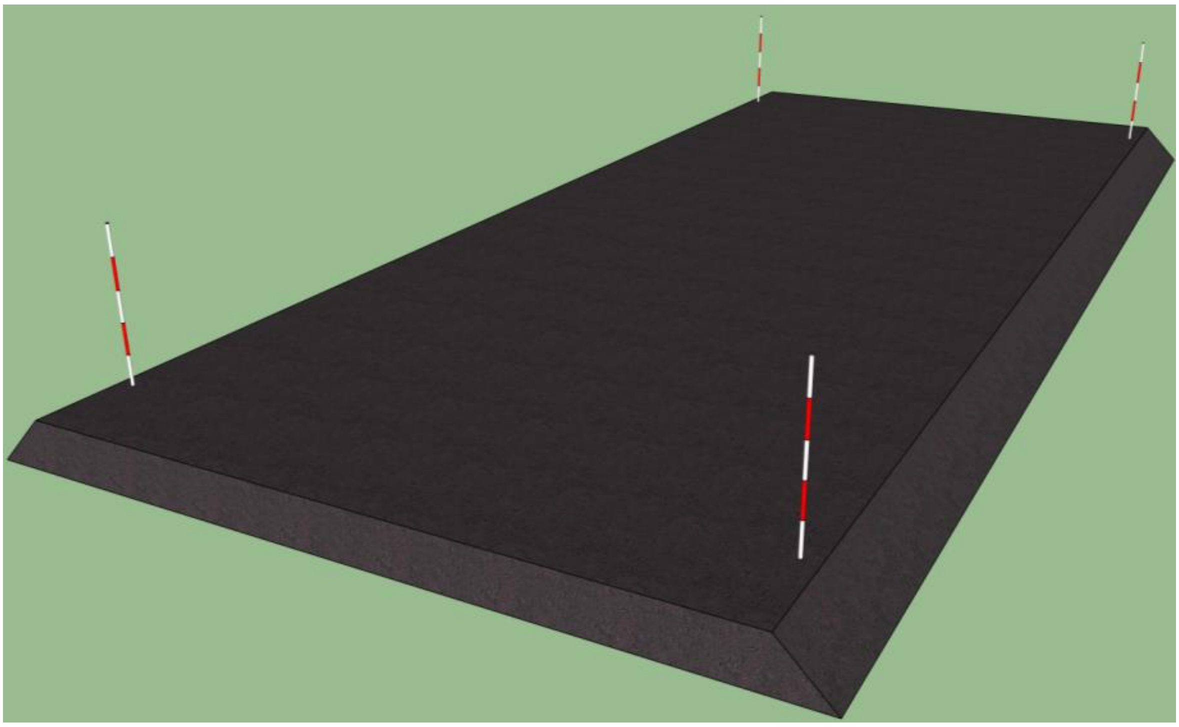


FIG 79: TOPOGRAPHIC SURVEY AND MARKING

4. Installation of the base slabs

The installation of the base slabs (with premounted elastomeric strips) will be handled with a crane. The proper position of the modules is very important to avoid big geometry modifications in the following stages.

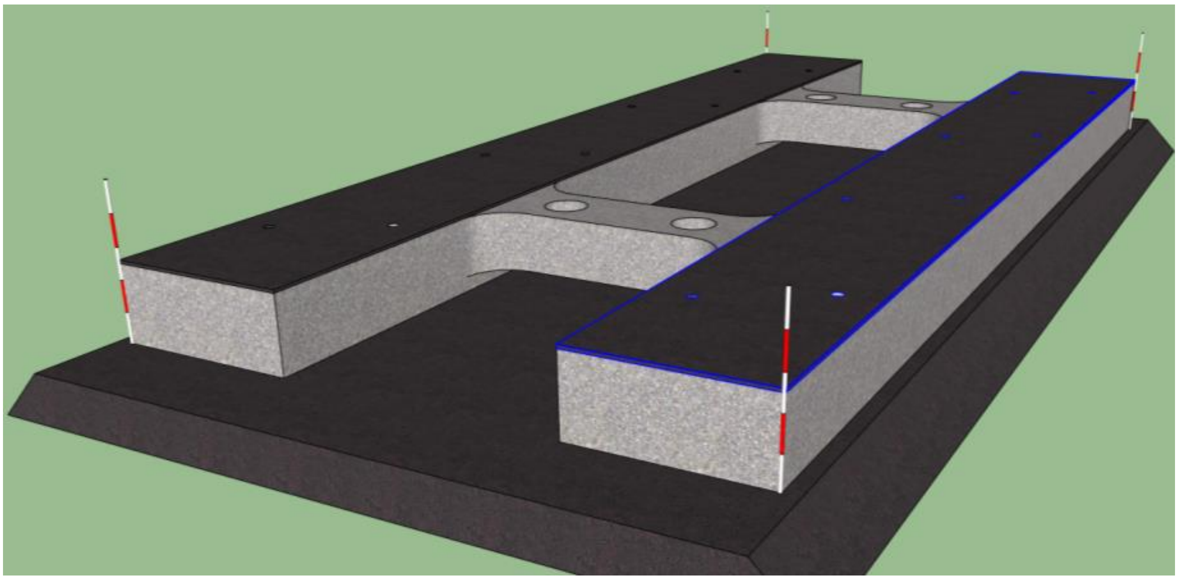


FIG 80: BASE SLAB POSITIONING

5. Moulded block positioning

The positioning of blocks on top of the base slabs will be handled with a crane. Special attention shall be paid to ensure the blocks' cylindrical through hole axes are aligned (within tolerance) with those of the elastomeric strip holes and the nuts embedded in the base slab.

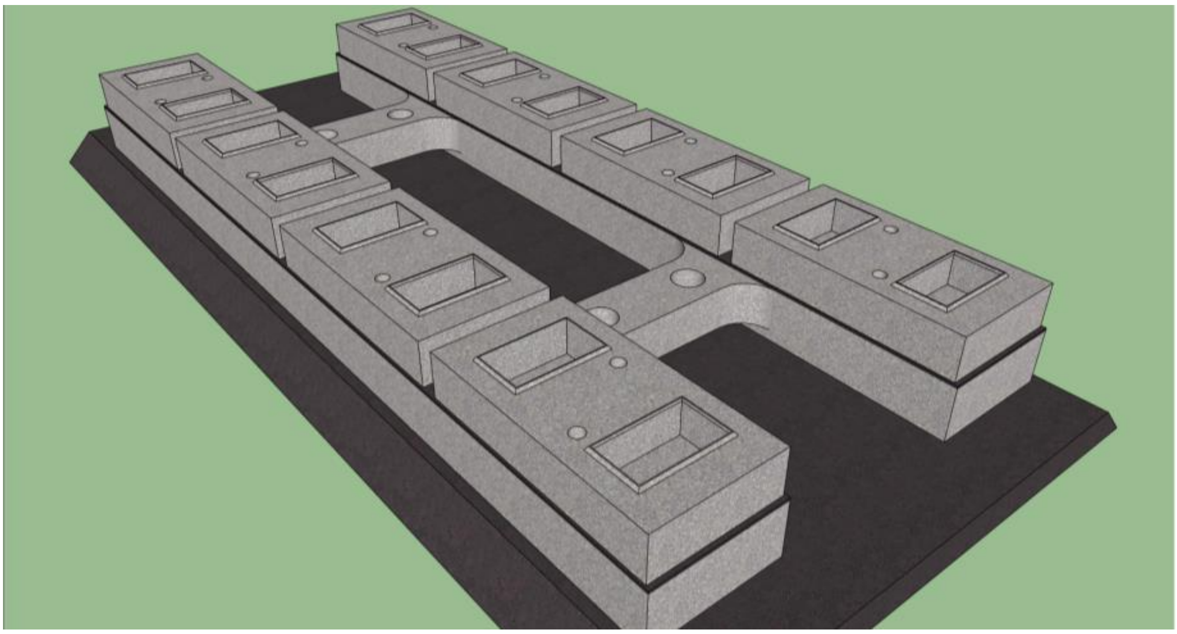


FIG 81: MOULDED BLOCKS POSITIONING

6. Installation of steel pin connectors

With the moulded blocks in place and correctly aligned, the steel pins may be manually positioned and screwed onto the embedded steel nuts. Pin weight allows for element manipulation without auxiliary machinery, but the use of pneumatic wrenches for the screwing process is recommended to ensure fast installation and sufficient torque.

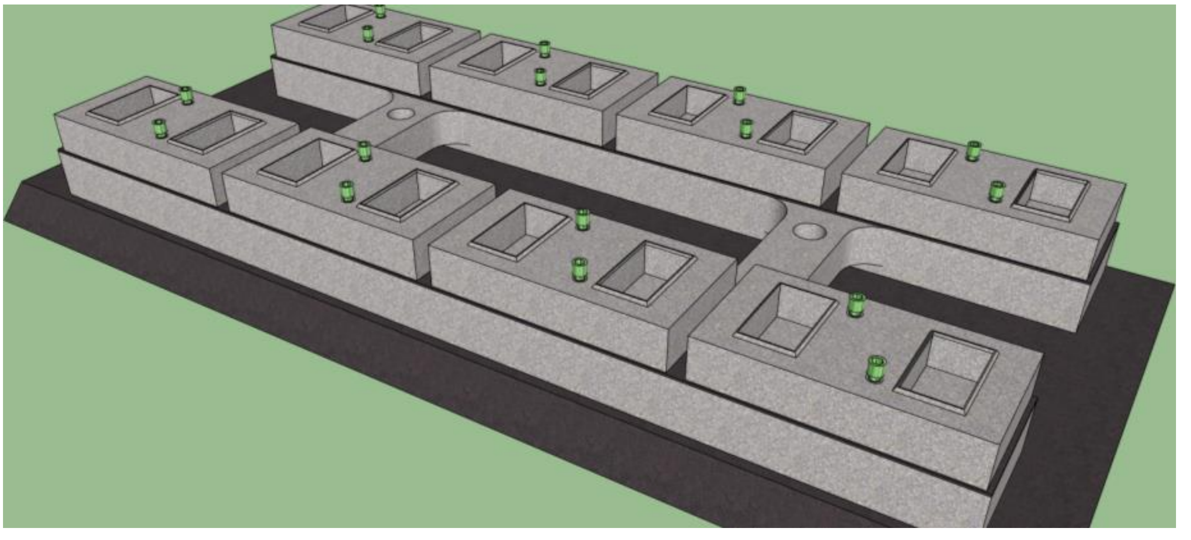


FIG 82: INSTALLATION OF SCREWED-ON STEEL PIN CONNECTORS

7. Pre-positioning of rails

A preliminary rough positioning of rails is then performed using cranes. Pre-mounted fasteners are to be used as reference for positioning, since they must fit inside the moulded block cavities. Once in place, rail weight should be supported by the protruding borders of the moulded block cavities.

Minor manual adjustments (within tolerance) may be made in the position of fasteners to ensure their position centred in the block cavities, as fastener screws should be tightened during the pre-mounting to the point where no free movement exists but sliding the fasteners manually is possible.

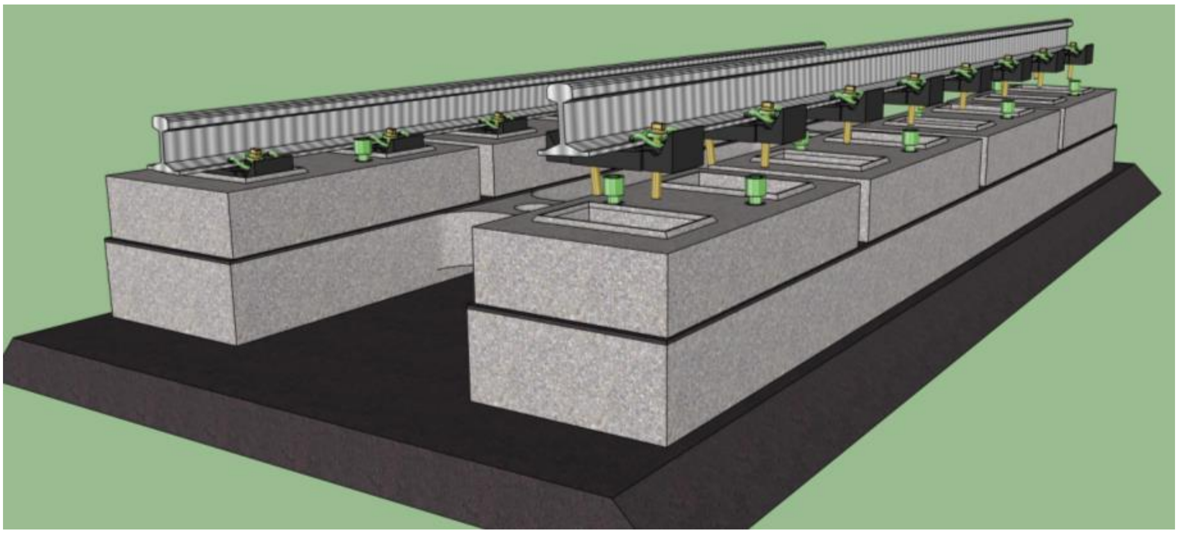


FIG 83: PRE-POSITIONING OF RAILS

8. Installation of gauge and cant props (or *false sleepers*).

Specially designed steel props, known as false sleepers, shall be installed on the rails every 2,4 meters.

The function of the false sleepers is to provide and guarantee correct relative position of rails to one another during fine alignment and mortar pouring (fixing gauge and rail tilt), as well as provide with the mechanisms to perform said alignment. Thus, once fixed in place by means of cranes and screwed onto the rails until gauge and tilt are correct, the manipulation of horizontal and vertical mechanisms within the false sleepers provides means to move the whole cross-section (rails and prop) freely in the plane perpendicular to the track

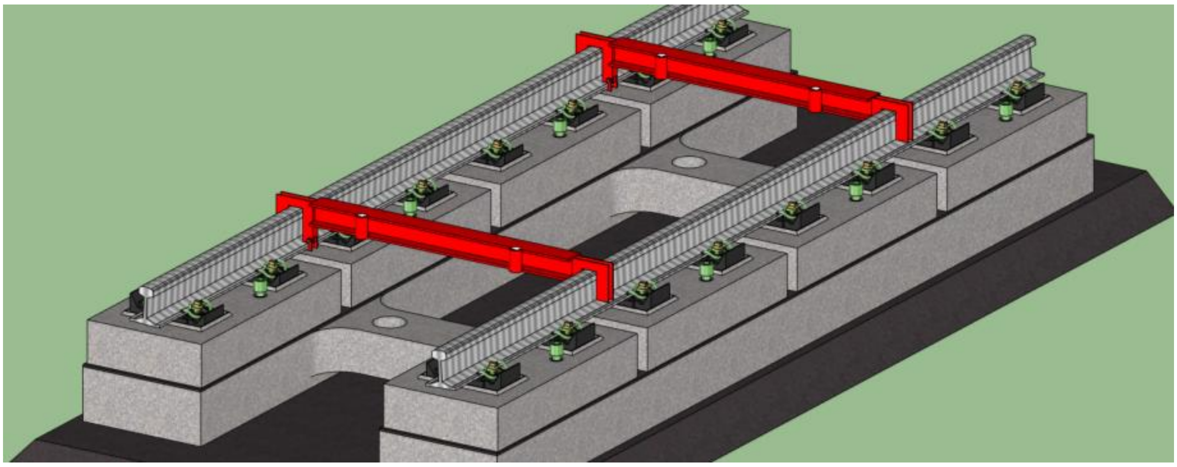


FIG 84: INSTALLATION OF FALSE SLEEPERS

9. Fine rail positioning

Using adequate topographic equipment for geometry reference and adjusting track geometry by means of the false sleeper mechanisms, precise positioning of rails shall be achieved.

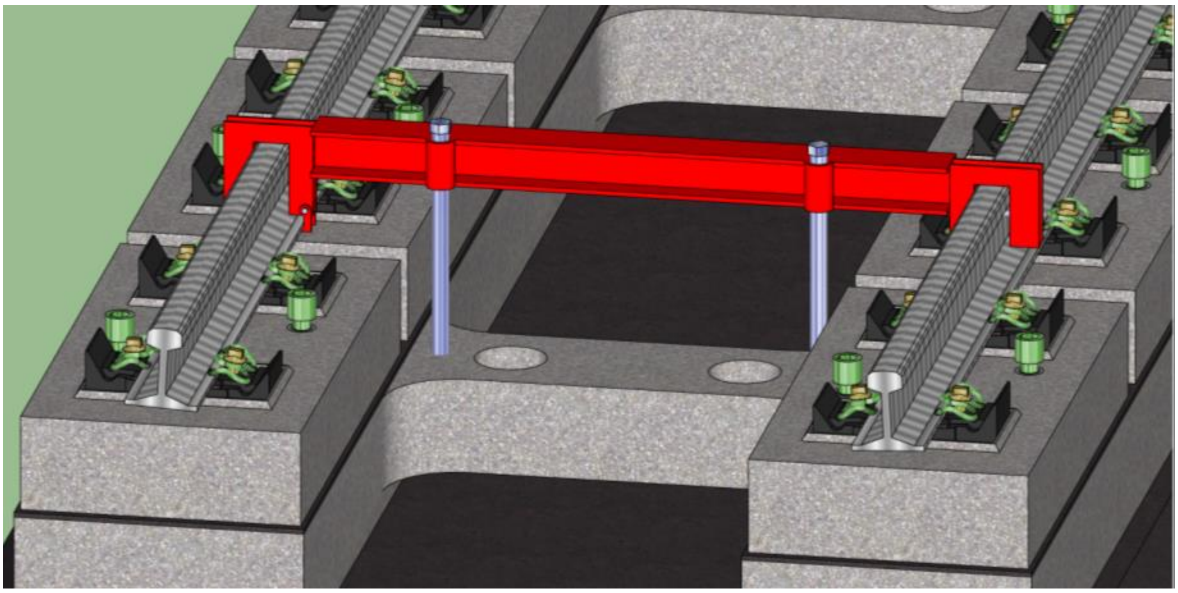


FIG 85: INSTALLATION OF FALSE SLEEPERS

10. Earthing

The earthing must be considered and installed. Layout and criteria for testing of resistance of the earthing system will be done under current standards in force.

11. Final adjustment and check before mortar pouring

The following steps shall be followed immediately before mortar pouring:

- Final adjustment of horizontal and vertical alignment with total station system
- Proper vertical and horizontal securing of the track.
- Fastening system elements (clip, plates, rail, etc) protection with ad hoc covers
- Final track geometry check to within acceptable tolerance

12. Pouring of the mortar

Fresh mortar shall be then poured on block cavities and in the space between steel pins and block cylindrical through holes. The mortar shall be poured directly from the mixer or through pump.

Fastening mortar must cover the plastic dowels completely without overflowing the block cavities. Pin mortar level must be over the specific marking in the block holes, positioned 5 cm below the top face of the block, without overflowing them.

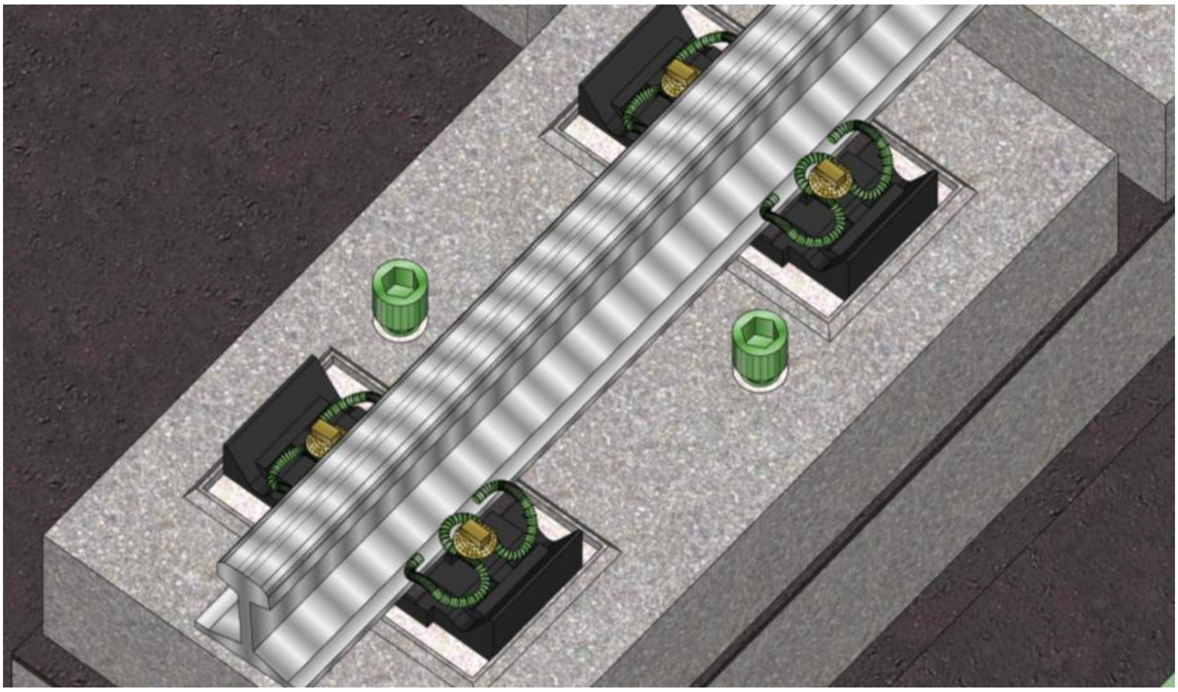


FIG 86: MORTAR POURING IN FASTENERS AND PIN CONNECTION

13. Finishing

After every move of the rails after concreting, the rails shall be inspected. The rails shall be without damages and cleaned from concrete and other dirt.

14. Curing

Recommended time for curing will be respected before doing any action or applying any load.

15. Releasing of fastenings and false sleepers disassembly.

Once the mortar has hardened (within approx. 4hours) the rail fastenings shall be released to prevent forces resulting from the thermal length fluctuation of the rails affecting the integrity of the setting fresh mortar.

Following this operation, false sleeper shall be removed and transported to the next track section.

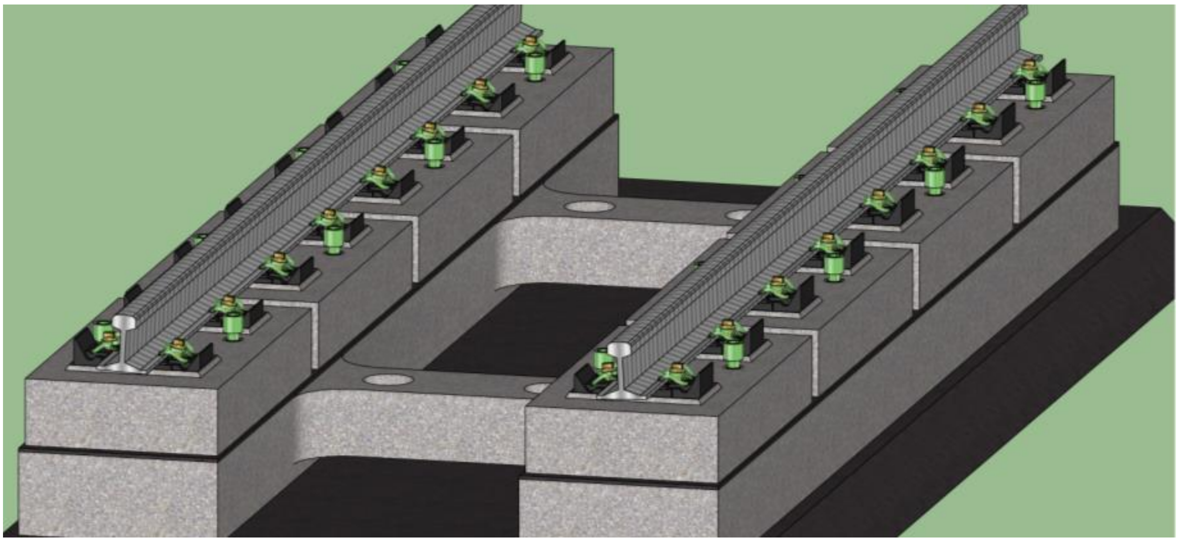


FIG 87: RELEASING OF FASTENERS AND FALSE SLEEPER DISASSEMBLY

16. (Optional) Drilling of stopper holders in the bituminous sub-base

Where frictional contact and bitumen adhesiveness are considered to be insufficient to prevent horizontal displacement of the whole system (e.g. tight curves), in situ mortar stoppers shall be built.

To that extent, the first step shall be to drill cylindrical holes in the bituminous sub-base to hold said stoppers and materialize the horizontal connection between base slab and sub-base.

The holes shall be drilled with specific equipment capable of fixing itself to the stopper holders in the transversal concrete beams of the base slabs, thus guaranteeing the correct positioning of the drilled holes.

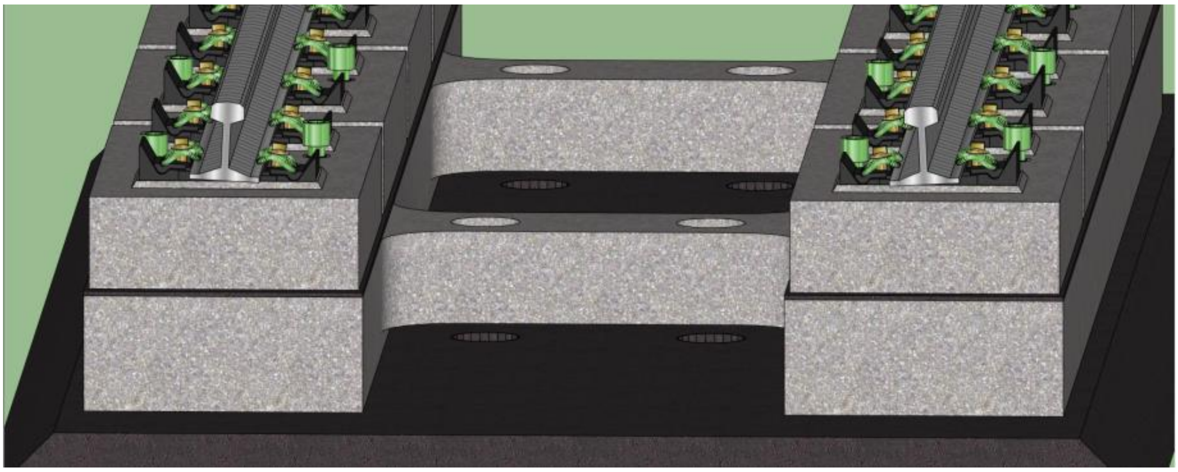


FIG 88: RELEASING OF FASTENERS AND FALSE SLEEPER DISASSEMBLY

17. (Optional) Positioning of plastic stopper formwork

Cylindrical plastic tubes shall be used as formwork for the in situ stoppers. Formwork shall be fixed to the base slab stopper holders and inserted partially in the sub-base holes.

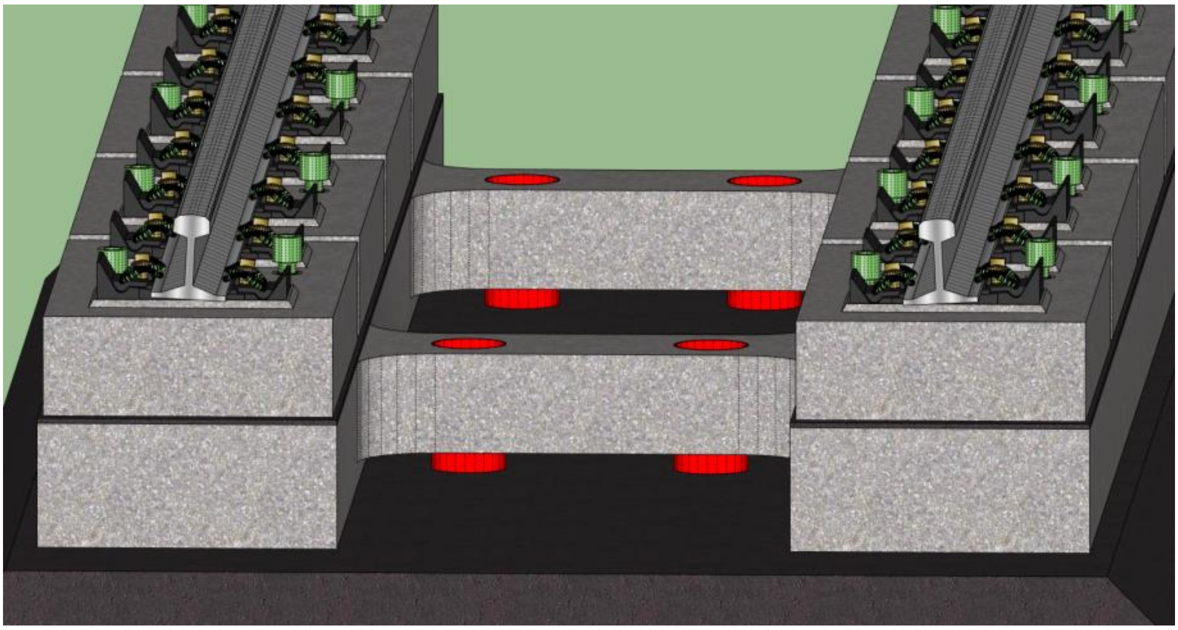


FIG 89: STOPPER FORMWORK PLACING

18. (Optional) Pouring of the stopper mortar

Once formwork is in place, mortar shall be poured inside it to materialize the horizontal connection between sub-base and base slab

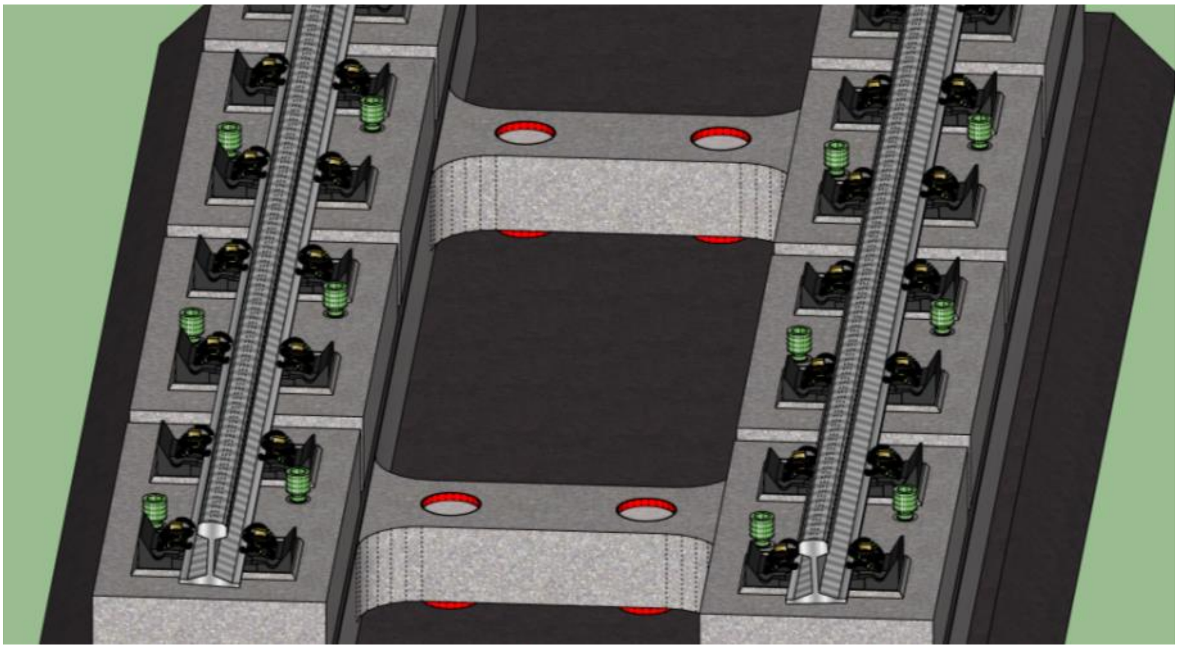


FIG 90: STOPPER MORTAR POURING

19. Tightening of fasteners and final check

Once mortar has achieved at least 70% of its final strength (within approx.. 16-24 hours), fasteners may be tightened to working torque and final geometry check may be performed.

Barring unacceptable geometry discrepancies, all geometry defects outside tolerance levels are to be corrected using the fastening system adjustment capacities. Major adjustments (if any) would require application of the geometry adjustment maintenance procedure (described further down)

5.2 L-Track Concept: Construction procedure

5.2.1 General procedure for the construction of the LT system

The L-Track modular slab track is composed of standard prefabricated modules and the components to fasten and support the rail on. The final assembly of the set is done at the construction site.

On track site, the modules are laid over a previously constructed asphalt layer. The levelling and flatness of the layer surface must be checked to guarantee they are within tolerance, but said tolerance is not strict due to the top-down track alignment procedure.

The fastening systems and the rails are assembled over the module, the horizontal alignment is adjusted using the special adjustment system within the fasteners, and the whole track is lifted to its final place using a mechanized prop or false sleeper system.

Finally, a mortar base is poured under the concrete modules, fixing the track geometry.

5.2.2 Stages for the L-Track system construction

The following is a description of the main stages needed for the construction and assembly of the LT modular slab track.

Materials

1. Materials and transport

The L-Track modules are transported by truck from the factory direct to the platform. The modules will be placed in a pile of four modules. The distance between the catenary poles must be observed for the final storage calculation. The rest of pieces and elements composing the whole system will be likewise placed close to the modules.

Sequences of operation for the assembly of the LT system

2. Preparatory works

As stated, an asphaltic layer must be constructed over the platform before the modules are installed. The layer must be done in advance in order to ensure a proper curing and check the flatness and levelling and the absence of any defect outside tolerance.

Fasteners shall be pre-mounted onto the longitudinal beams to be installed in each working period.

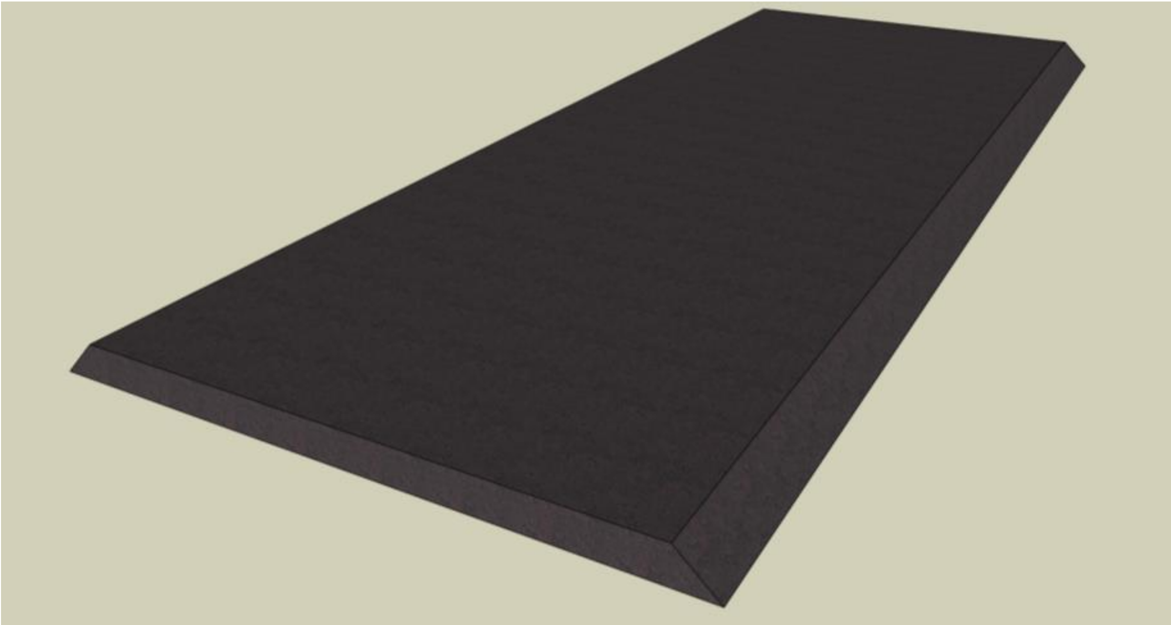


FIG 91: BITUMINOUS SUB-BASE

3. Surveying and marking

A complete surveying has to be done to check the correct levelling of the whole platform. Marking of the rough topographic location of the longitudinal beams shall be performed in this stage, considering beam separation tolerance of less than +5/-2 mm in the area where transversal beams shall be anchored.

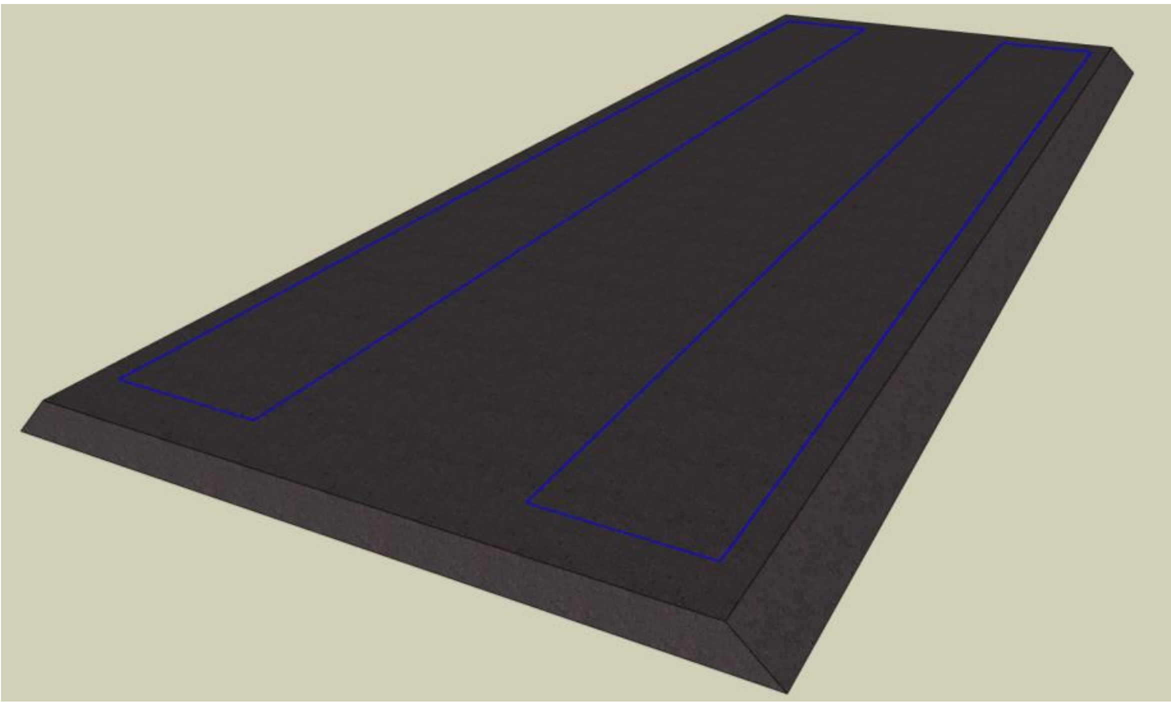


FIG 92: MARKING OF LONGITUDINAL BEAM POSITIONING

4. Installation of the longitudinal beams (with pre-mounted fasteners)

The installation of the beams shall be handled with a crane. The proper position of the modules is very important to avoid assembly problems or geometry modifications in the following stages.

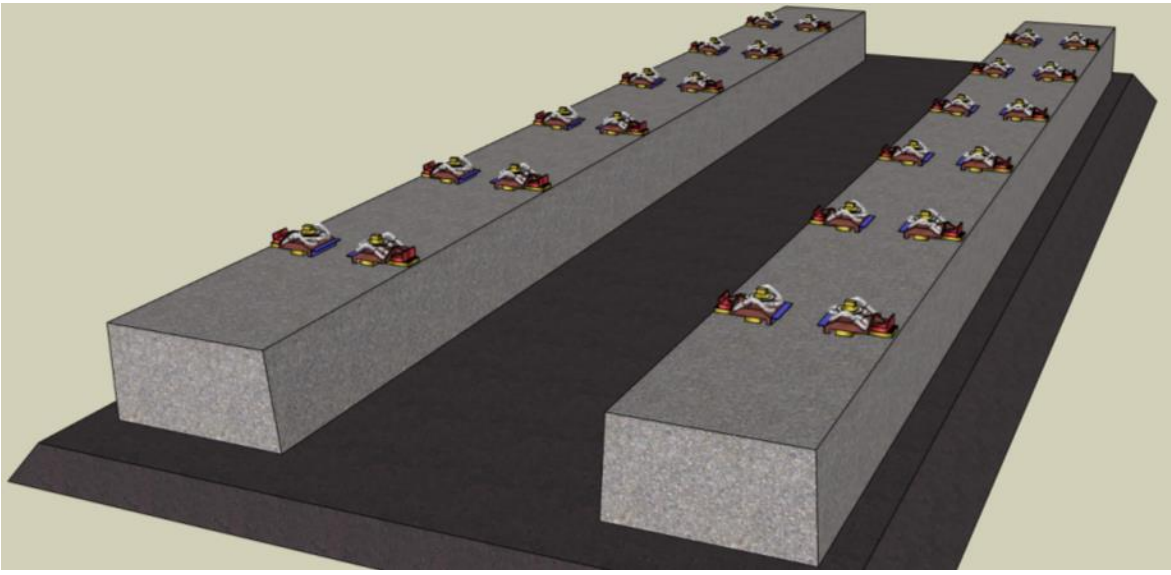


FIG 93: LONGITUDINAL BEAM INSTALLATION

5. Pre-positioning of transversal beams

In order to guarantee that the transversal beams are correctly installed, longitudinal beam separation is within tolerance and the boreholes for the in situ anchoring are placed with sufficient precision, the steel transversal beams shall be pre-positioned and used as reference for locating the drilling and anchoring spots.

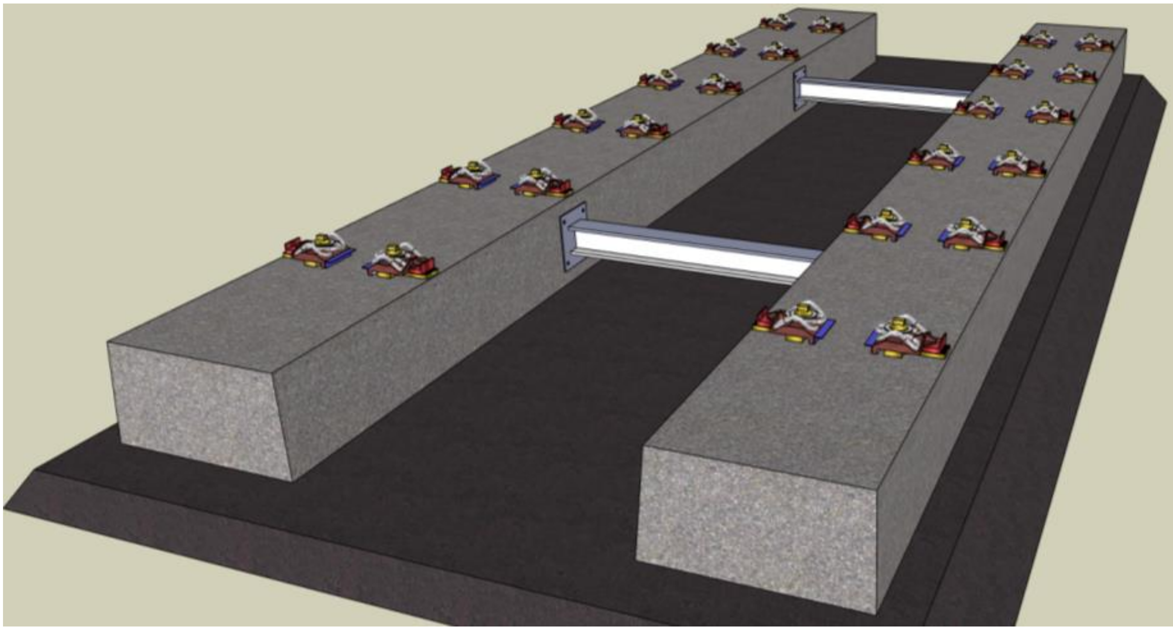


FIG 94: PRE-POSITIONING OF TRANSVERSAL BEAMS

6. In situ anchoring of the transversal beams

With the transversal beams in place, anchoring boreholes shall be drilled into the longitudinal concrete beams using the anchoring plates as a template. Standard 12mm diameter mechanical anchoring bolts shall be used to connect transversal and longitudinal beams.

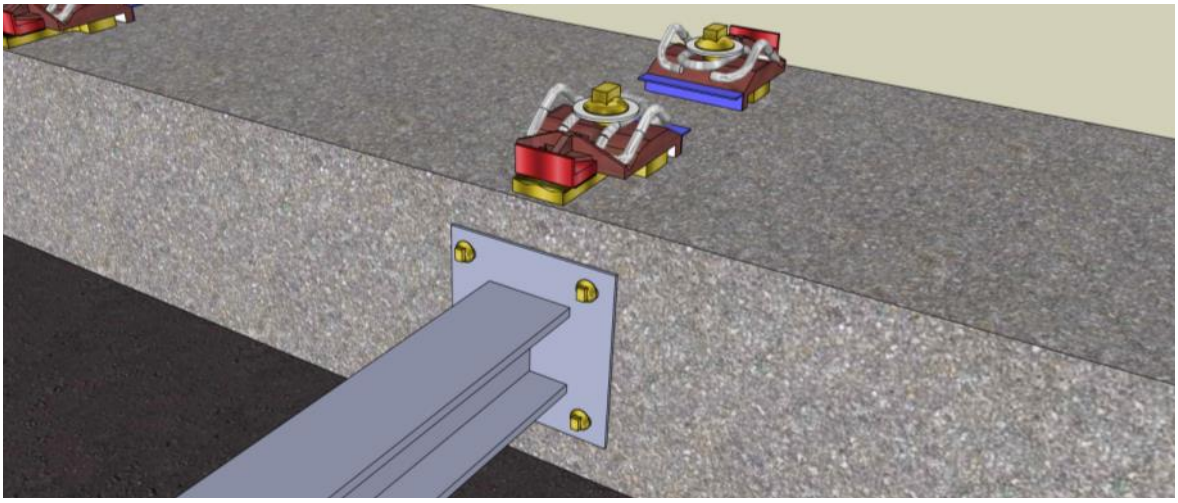


FIG 95: ANCHORING OF TRANSVERSAL BEAMS

7. Elastic pad and rail prepositioning

With the elements composing the fastening system in pre-mounted position, the elastic pad will be laid. Once all elements are in place, the rail will be positioned.

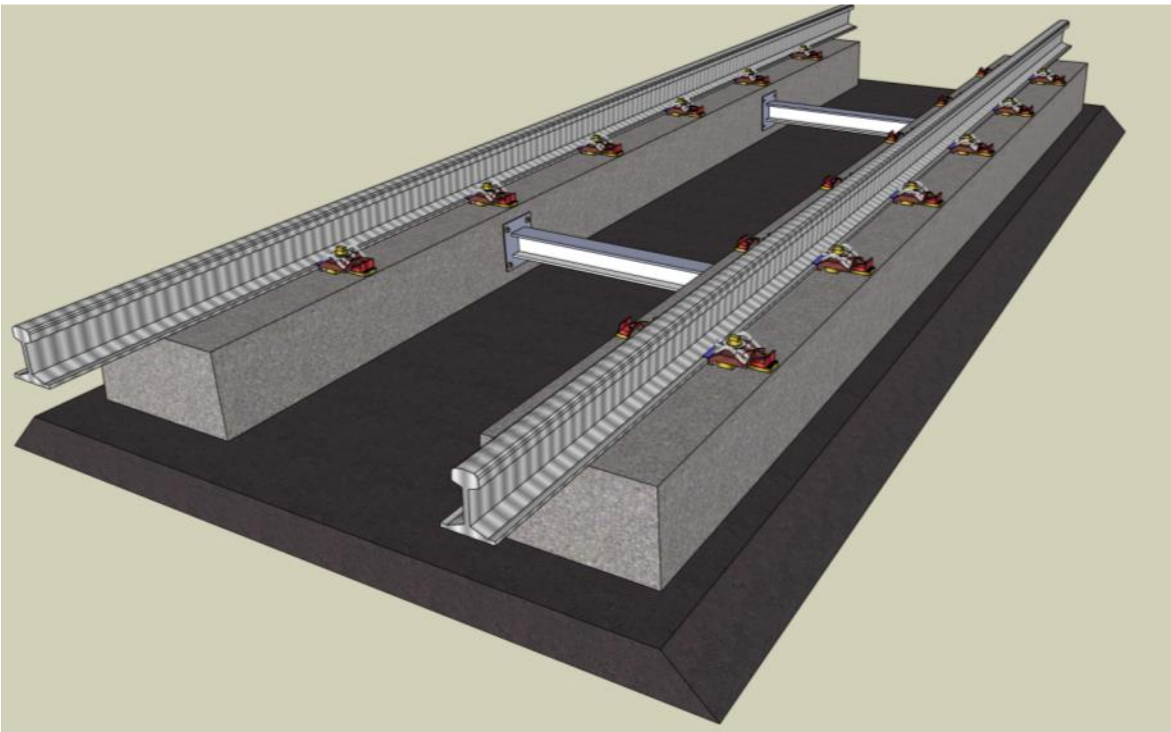


FIG 96: ELASTIC PAD AND RAIL POSITIONING

8. Horizontal adjustment

Making use of the adjustment capabilities inherent to the novel fastening system, adjustments shall be made in the position of rails until properly precise horizontal alignment is achieved.

Once rails are in place, fastener moving parts shall be fixed, springs shall be placed in fastening position, and screws shall be tightened to the point where whole modules may be lifted by acting on the rails

9. Installation of vertical adjustment props and fine vertical alignment

In order to proceed with the top-down vertical track alignment, adjustment props shall be installed and fixed to the rails.

It is understood that the combination of longitudinal and transversal beams, tightened fasteners and adjustment props guarantee the modules move as a single entity.

To that effect, props shall be installed every 1,8 m or less.

Making use of the mechanism in the adjustment props, and aided by adequate topographic means, vertical alignment within tolerance shall be achieved.

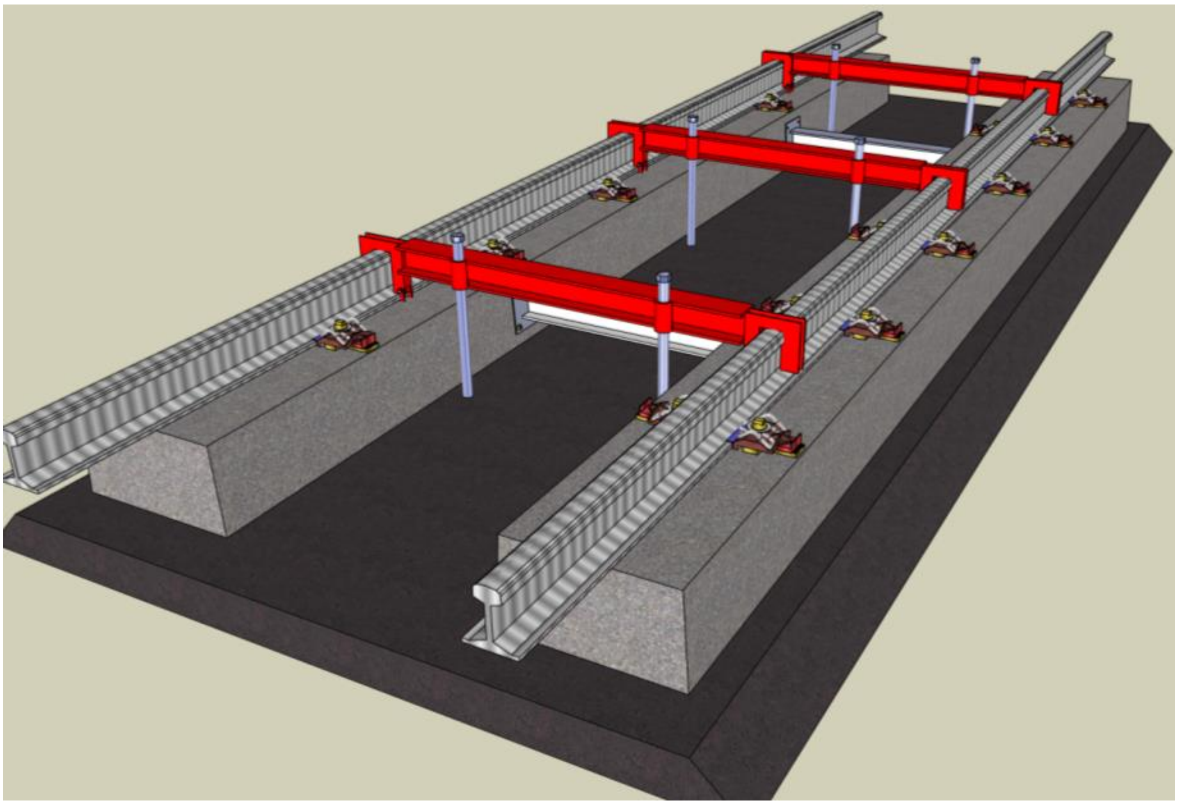


FIG 97: INSTALLATION OF ADJUSTMENT PROPS

10. Earthing

The earthing must be considered and installed. Layout and criteria for testing of resistance of the earthing system will be done under current standards in force.

11. Installation of mortar bed formwork

Previous to the pouring of the adjustment mortar bed, rectangular formwork shall be placed directly below the longitudinal beams.

Formwork positioning shall be checked by using wooden blocks as separators in several spots of the beams perimeter.

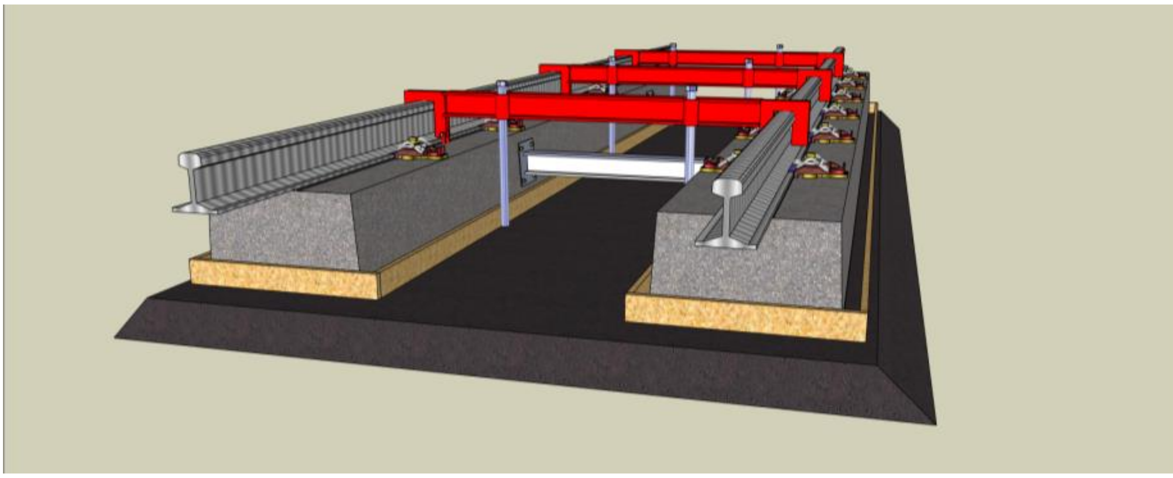


FIG 98: INSTALLATION OF MORTAR BED FORMWORK

12. Pre-pouring check and correction of any levelling imperfection

Final adjustment of horizontal and vertical alignment with total station system must be done as short as possible time before the mortar pouring begins. The track must be properly secured both vertically and horizontally. A fine levelling of the whole module must be done before doing the final assembly.

13. Pouring of the mortar bed and prop removal

Once rails are in place and geometry is confirmed, mortar shall be poured into the formwork. Vertical props shall be removed once mortar has gained 70% of its resistance.

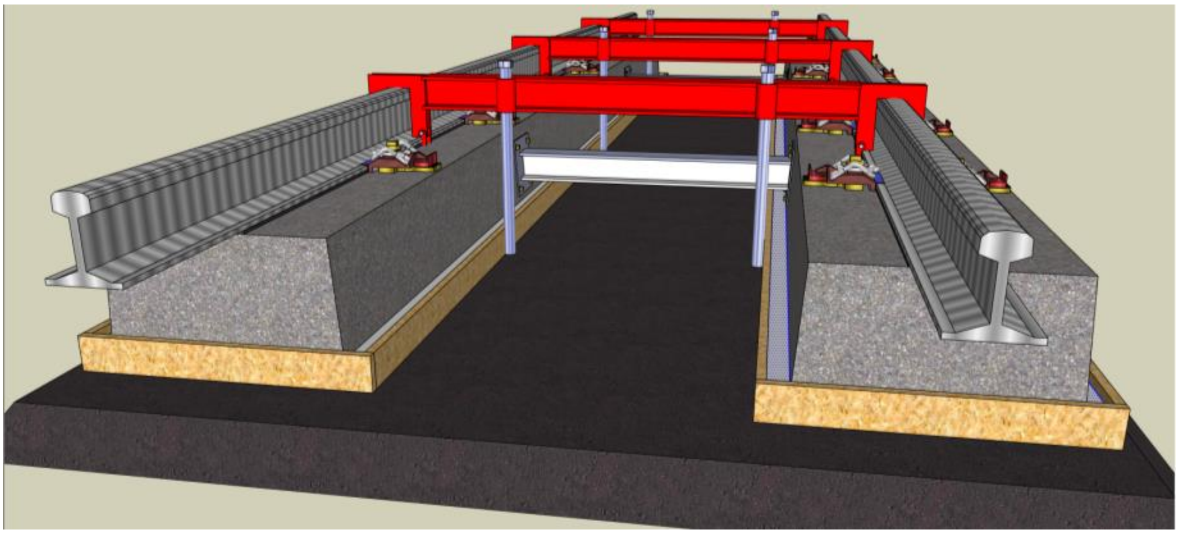


FIG 99: POURING OF THE MORTAR BED

14. Finishing

The rails shall be without damages and cleaned from concrete and other dirt.

15. Final check

Following day, a final recording of horizontal and vertical alignment with total station shall be done.

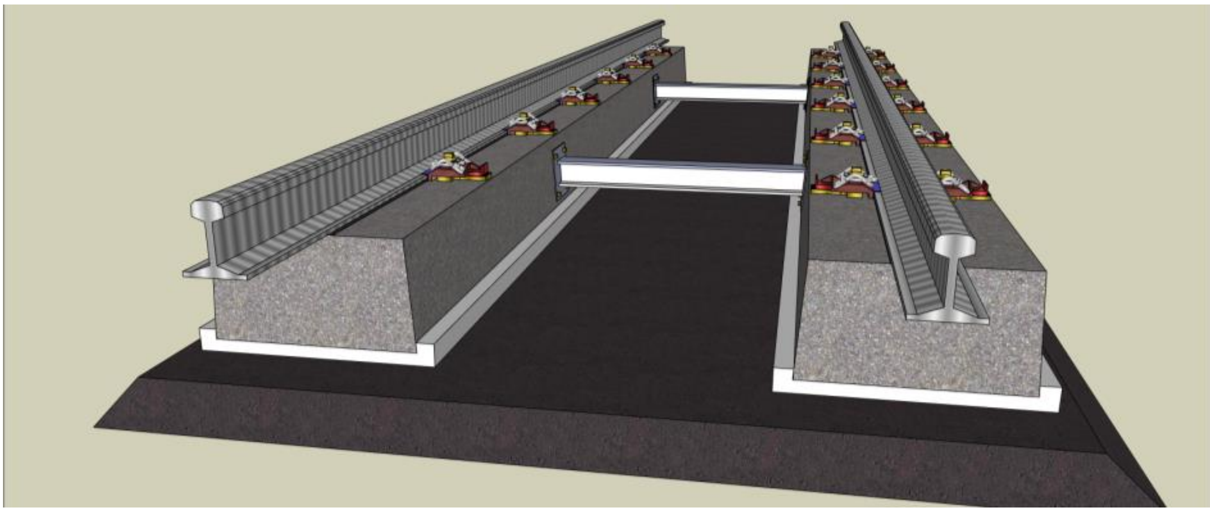


FIG 100: L-TRACK, COMPLETELY INSTALLED

6 Maintenance

6.1 Overview of maintenance aspects

Great increase in traffic experienced by railway networks forces to look for solutions able to minimize maintenance and conservation costs.

An effective solution for this issue is the slab track, which offers important advantages:

- Minimization of maintenance operations.
- Reduction of operating costs (20%-50%)
- Larger loads support in each axle
- Lightening of bridges
- Reduction of tunnel section
- Greater security and reliability
- Reduction of intervention time
- Increase of infrastructure availability

All these advantages explain why the slab track use is being increased as a real alternative to traditional ballast track.

Moreover, criteria for its construction are much more challenging than in conventional track regarding levelling, alignment and track gauge. Once installed, correction of errors is complex.

In operation and maintenance the following issues should be taken into account:

- Maintenance techniques
- How to increase operating speed
- Availability periods
- Compatibility of activities
- Preventive maintenance: inspections
- Corrective maintenance

6.2 Maintenance operations in slab track

Maintenance operations in modular slab track can be classified in:

- **Ordinary or preventive maintenance:** It includes visual inspection and periodic grinding to eliminate deformations wear or lubrication.
- **Exceptional or corrective maintenance:** It consists of crack or break repair, improvement of electrical insulation conditions or local corrections regarding track geometry.

Geometric corrections are the most significant operations in slab track maintenance and conservation. In conventional track are usual activities which are performed almost systematically. In slab track, due to it is a practically immovable; those operations are avoided due to the difficulties and costs it represents.

Geometric corrections, in general, are infrequent if the implementation has been accurate. If any defect happens, the track should be disassembled and reassembled in the estimated length in which the defect could affect the rolling stock ride.

6.3 MAINTENANCE ANALYSIS TO SLAB TRACK SYSTEMS.

The next table shows the performance of each typology in slab track against conservation and maintenance operations.

TABLE 16. SUMMARY OF PERFORMANCE OF DIFFERENT TYPES OF SLAB TRACK AGAINST MAINTENANCE OPERATION.

TRACK TYPE	PREVENTIVEREPARATION	CORRECTIVEREPARATION	GEOMETRIC CORRECTION
Embedded rail	Low frequency	Low frequency	Complicated
Direct support	Frequent	High frequency	Need for reconstruction
Indirect support	Frequent	High frequency	Need for reconstruction
Elastomeric coated blocks	Periodic, especially in fastening systems	Problems with water filtrations	Possible replacement of elements
Monolithic with sleeper	Periodic, especially in Fastening systems	Possible replacement of elements	Possible replacement of elements
Elastomer coated sleepers	Periodic, especially in Fastening systems	Problems with water filtrations	Possible replacement of elements
Sleepers on slab	Periodic, especially in Fastening systems	Possible replacement of elements	Possible replacement of elements
Floating slab with Sleepers	Periodic, especially in Fastening systems	Possible replacement of elements	Possible replacement of elements
Slabs on non- elastic mortar	Periodic, especially in Fastening systems	Possible replacement of elements	Possible replacement of elements
Floating slabs without sleepers	Periodic, especially in Fastening systems	Possible replacement of elements	Possible replacement of elements

Conclusion:

The slab track typology which permits the higher reduction in operations and maintenance costs is the embedded rail. Although, in the event, geometric corrections are required, this one is complicated. The rest of families have a similar performance besides the block systems or elastomer coated sleepers in which a great care shall be taken in case of frost and defrost cycles of infiltrated water.

6.4 Defects identified

In the design, it should be considered the system future maintenance and the different elements which could be impaired or distressed, for this reason it will be necessary to repair or replace.

The different defects of the elements which form the modular slab track are listed following:

Slab

- Structural breaks:The slab breaks compels to do a substitution of the same or the affected slabs, being necessary to determine the cause of the plate break, to proceed with the appropriate action in order to avoid a new break.
- Fissures and cracks: repairable and non-repairable: The existence of fissures/cracks could be caused by different factors, it is necessary to be evaluated their severity (whether they require replacement of the plate or not), their cause (if it is a casual origin or is due to an external cause that can re-break the plate), depth and length (these parameters are connected with the plate damage, it can be controlled if the fissures grows or propagates, which can indicate the useful time of the same, until the moment that the fissures is several enough to be necessary to replace the slab). The location of the fissures is another important parameter, it can affect others elements.
- Water infiltrations under the slab: Water presence under the slab must be avoided, because it may cause breaks and damages in lower layers because of the water compression, which is due to train passage, and it spreads through existing fissures what increases their size.
- Settlements: Should be expected the formation of differential settlements along the live in operation that can caused holes under the slab, these can caused causes unexpected stresses consequently the break of the plate. Therefore it is needed to avoid and fix possible settlements.

Rail

It is important to do visual inspections in the rail for detect with anticipation the eventual pathology. The possible defects are:

- Corrosion
- Ordinary wear
- Wave wear
- Punctual defects (cavities, fissures, lamination, corrosion, cavities, blows, hits…)
- Inclination: it is important to take into account the rail inclination, a fault in the rail can came from the fastening system or a problem in the plate.
- Fatigue
- Welds: It is important to take into account cuts and rail welds to avoid the damage of elements which can cause major damages.

Fastening system and anchorage

The break or loss of the clips involves a loss of strength as well as the loss of elasticity at the fastening system.

The break or loosen of a screw means a loss in the clamping force. In the case a screw is broken, a replacement should be prescribed. Corrosion in this elements must be observed at any inspection.

Elastomeric elements

The degradation of the plate elastomers involves a change at the vertical rigidity. It should be considered the possible replacement of those elements

6.5 General procedure for the maintenance of the 3MB system

If the general procedures for the different slab track systems are observed, a particular procedure for maintenance of the 3MB modular systems can be defined.

6.5.1 Overview

The 3MB modular system is composed of a number of elements, which makes an advantage in the need of replacing any elements that has been damaged or broken. It also creates more points where defects can happen. The design of the system allows a certain flexibility if any geometry or alignment correction in the modules has to be done. The fixing of the block to the module allows the regulation of the block. Besides, the elastic pad situated between the block and the module means an additional elastic layer that reduces the vibration emission.

6.5.2 Preventative maintenance

Regarding preventative maintenance, the main works are listed following:

- Stocking of spare components: on depots and workbases a proper quantity of 3MB modules and spare parts must be stored. Machinery, vehicles and transportation means must be ready for service at any moments. Specific tools for the assembly and disassembly of the different elements must be available at any time. As an approach, a stock of 10 complete modules must be stocked, meaning a defect of up to 50 meters being able to repair or to replace. A specific study of the total quantity of 3MB modules and elements is necessary, taking into account the type of railway and the requirements of the rail traffic.
- Track geometry maintenance: 3MB system allows keeping a good track geometry along the life in service. Geometry will be checked periodically by geometry and dynamic inspection, applying similar criteria to those in ballasted tracks. The lack of squareness can affect the rail condition and create defects; if the defect is too severe the global alignment can be affected.
- Rail maintenance: a preventative grinding will be done to the rail Rolling surface right before the entry in service of the line. Periodically, the rail condition will be inspected in order to

detect any damage or defect. A full grinding of the rail will be done once per year (as an initial approach).

- Blocks and fastening systems maintenance: a periodic inspection shall be done in order to check the condition of the fastening systems. The condition of the blocks and the anchorage of the whole system must be also inspected.
- Platform maintenance: geometric and dynamic inspections must be carried out periodically. This will give information about any defect or damage related to the platform (settlements, lack of levelling, etc.) Additionally, any other defect caused by external issues must be inspected and checked: big rains, herbages, dust, mud, small objects, etc. Drainage and water escapes must be cleared.

6.5.3 Corrective maintenance

Regarding the corrective maintenance for the 3MB, the points to observe in the case of a corrective works are listed:

Slab: in this system, it is formed by a module and a set of blocks with an anchorage to the module. Main aspects to check are listed:

- Full crack of the module: low probability; if it occurred, the whole module must be replaced.
- Cracks and flaws in the module: low probability. If any is detected at an early stage, a careful vigilance must be given and assess whether or not a replacement is needed.
- Water infiltrations: If water is retained inside the modules, the drainage and any water escape must be cleared. If big water presence is detected under the module or platform, the track must be externally supported and schedule a repairing action on the spot.
- Settlements: if any settlement is detected during ordinary inspections, a thorough check of the area affected must be done. Then the track must be supported and stabilized. A partial of complete repair must be scheduled.

Rail: periodical inspections must help in the assessment of the rail condition. Any defect may be studied under the same criteria as in ballasted tracks. In the case of a rail break, the 3MB system is fitted with a proper geometry that allows a quick rail welding.

Single elements: If any defect on a single element of the 3MB system is detected, a specific assessment must determine the repair or replacement of the element. The modular system allows easy and quick replacement of single elements like the blocks or the fastening system

Elastic elements and anchorage: Special attention will be given to the elastic elements condition – rail elastic pads, under block pads. Anchorages of the rail, blocks and modules will be also inspected. If any defect or damage is detected, an assessment must determine the repair or replacement.

Geometry: If any geometry defect is detected, an assessment must determine the severity and extension of the defect and check if it affects a small distance, the whole module or a set of modules. If the geometry defect is small it can be corrected by adjusting the rail seat plates. If the defect is severe and exceeds the tolerance limits, a repair work must be scheduled. The nominal geometry must be restored and replace any element affected. In the 3MB system, the module seats on a concrete platform, therefore no settlements or levelling defects are expected.

6.6 General procedure for the maintenance of the LT system

If the general procedures for the different slab track systems are observed, a particular procedure for maintenance of the 3MB modular systems can be defined.

6.6.1 Overview

The LT is composed of one module. The rail seats on the module on a continuous way and it is fastened discretely with a direct system to the module. The system simplicity reduces the number of critical points and defects. However, the adaptability to the desired geometry and the repair of elements and defects is more complicated. The continuous rail support will extend the life in service of the rail and reduces the maintenance works associated.

6.6.2 Preventative maintenance

Regarding preventative maintenance, the main works are listed following:

- Stocking of spare components: on depots and workbases a proper quantity of 3MB modules and spare parts must be stored. Machinery, vehicles and transportation means must be ready for service at any moments. Specific tools for the assembly and disassembly of the different elements must be available at any time. As an approach, a stock of 10 complete modules must be stocked, meaning a defect of up to 50 meters being able to repair or to replace. A specific study of the total quantity of LT modules and elements is necessary, taking into account the type of railway and the requirements of the rail traffic.
- Track geometry maintenance: LT system allows keeping a good track geometry along the life in service. Geometry will be checked periodically by geometry and dynamic inspection, applying similar criteria to those in ballasted tracks. The lack of squareness can affect the rail condition and create defects; if the defect is too severe the global alignment can be affected.
- Rail maintenance: a preventative grinding will be done to the rail Rolling surface right before the entry in service of the line. Periodically, the rail condition will be inspected in order to detect any damage or defect. A full grinding of the rail will be done once per year (as an initial approach).
- Blocks and fastening systems maintenance: a periodic inspection shall be done in order to check the condition of the fastening systems. The condition of the continuous rail pad must be carefully checked. It is also important to check the fastening of the module anchorages.
- Platform maintenance: geometric and dynamic inspections must be carried out periodically. This will give information about any defect or damage related to the platform (settlements, lack of levelling, etc.) Additionally, any other defect caused by external issues must be

inspected and checked: big rains, herbages, dust, mud, small objects, etc. Drainage and water escapes must be cleared.

6.6.3 Corrective maintenance

Regarding the corrective maintenance for the LT, the points to observe in the case of a corrective works are listed:

- **Slab:** in this system, it is formed by one module composed of two beams and connections between them. Rail is supported directly to the module. Main aspects to check are listed:
- Full crack of the module: low probability; if it occurred, the whole module must be replaced.
- Cracks and flaws in the module: low probability. If any is detected at an early stage, a careful vigilance must be given and assess whether or not a replacement is needed.
- Water infiltrations: If water is retained inside the modules, the drainage and any water escape must be cleared. If big water presence is detected under the module or platform, the track must be externally supported and schedule a repairing action on the spot.
- Settlements: if any settlement is detected during ordinary inspections, a thorough check of the area affected must be done. Then the track must be supported and stabilized. A partial of complete repair must be scheduled.

- **Rail:** periodical inspections must help in the assessment of the rail condition. Any defect may be studied under the same criteria as in ballasted tracks. Given the continuous rail seat on the module, the occurrence of defects is reduced. Rail performance is similar as in embedded systems.

- **Single elements:** If any defect on a single element of the LT system is detected, a specific assessment must determine the repair or replacement of the element. The modular system allows easy and quick replacement of single elements like the fastening system or the anchorages.

- **Elastic elements and anchorages:** Special attention will be given to the elastic rail pads condition. Anchorages of the rail and modules will be also inspected. If any defect or damage is detected, an assessment must determine the repair or replacement.

- **Geometry:** If any geometry defect is detected, an assessment must determine the severity and extension of the defect and check if it affects a small distance, the whole module or a set of modules. If the geometry defect is small it can be corrected by adjusting the rail seat plates. If the defect is severe and exceeds the tolerance limits, a repair work must be scheduled. The nominal geometry must be restored and replace any element affected. In the LT system the module lays on an asphalt layer. In the case any levelling defect occurs, it can be repaired by adding mortar underneath or carrying out a modification in the asphalt layer.

7 Testing and prototyping

7.1 3MB Tests

7.1.1 Introduction

This subchapter describes all the 1:1 scale model tests performed in CEDEX Track Box (CTB) on 3MB slab prototype, in the frame of Task 1.1.3 of WP 1.1. A detailed description of the tests and their results are collected in Annex IV.

CEDEX Track Box (CTB) is a 21 m long, 5 m wide and 4 m deep facility whose main objective is to test, at 1:1 scale, complete railway track sections for passenger and freight trains, at speeds up to 450km/h. The reproduction of the effect of the approaching, passing-by and departing of a train in a test cross-section is performed by application of loads, produced by three pairs of servo-hydraulic actuators. The railway track response, in terms of displacements, velocities, accelerations and pressures, is collected from a great number of linear variable differential transformers (LVDTs), geophones, accelerometers and pressure cells that can be installed inside both the embankment and the bed layers (ballast, sub-ballast and form layer) of the track. On the other hand, the railway superstructure response is recorded with mechanical displacement transducers, laser sensors, geophones and accelerometers installed on the different track components.

7.1.2 Description of the experimental section

The cross section used in the present study is formed by the following elements: embankment, form layer, slab foundation layer, slab track, rails and fastening system, as it can be seen in Figure 1.

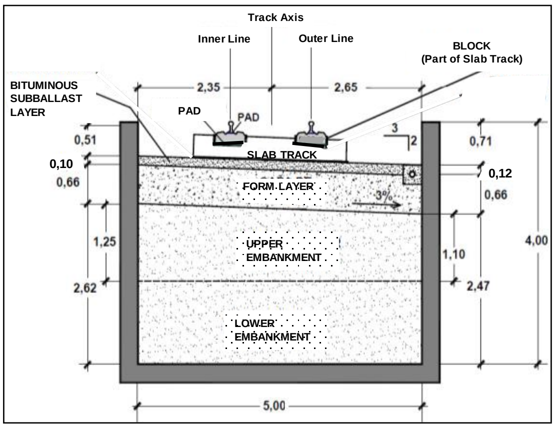


Figure 101 Cross-section of 1:1 scale model built in CTB (dimensions in m)*

7.1.3 Instrumentation installed

The analysis of the dynamic test results was carried out with 54 sensors installed to cover all the main parts of the slab prototype (rail, blocks and slab). This instrumentation includes LVDT sensors, laser systems, potentiometers and accelerometers. Figure 2 shows only the position and names of the accelerometers installed.

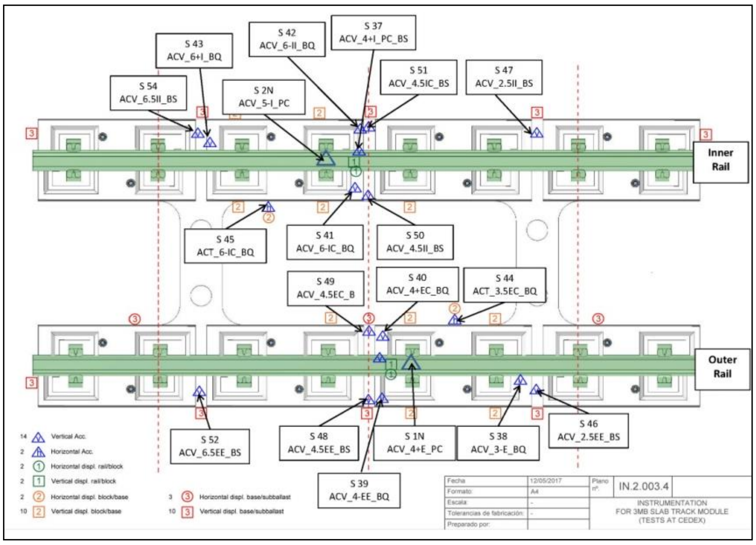


Figure 102: Position and names of the displacement sensors installed

On other hand, the instrumentation installed for the static tests consisted of seven vertical laser systems located along first the outer rail and then along the inner rail.

7.1.4 Tests performed

The tests performed in the 3MB slab prototype were 6 static tests and 20 dynamic tests according to the following sequence:

- Static test nº 1 in the outer rail.
- Stabilization test consisted of 100.000 sinusoidal cycles to stabilize all the slab elements and to get a more uniform response.
- Plate tests on the foundation layer to check the influence of the stabilization loads in the mechanical behaviour of the prototype foundation.
- Static test nº 2 and nº 3 in the outer and inner rail, respectively, to determine the track stiffness.
- Check Static test I performed in both rails, using the instrumentation installed for the dynamic tests, to check the slab state.
- Dynamic tests simulating passenger trains travelling at speeds between 40 and 300 km/h.
- Dynamic tests simulating freight trains, with 250 and 300 kN/axle loads, travelling at speeds between 40 and 200 km/h.
- Check Static test II performed to check the slab state after the first passenger tests and all the freight tests.
- Dynamic tests simulating passenger trains travelling at speeds between 300 and 400 km/h.
- Check Static test III performed to check the slab state after the test completion.

7.1.5 Results obtained

The extensive instrumentation installed in 3MB slab prototype made it possible to record the following measurements: total track vertical displacements, slab base vertical accelerations, block vertical accelerations, rail vertical accelerations, rail – block relative vertical and horizontal displacements, block – slab base relative vertical and horizontal displacements, slab base – foundation layer relative vertical and horizontal displacements.

The results are represented, for both passenger and freight trains, as the evolution of the representative value of the mentioned parameters with the train speed. Figure 3 shows, as examples, the track vertical displacements obtained in the passenger and freight train simulation tests.

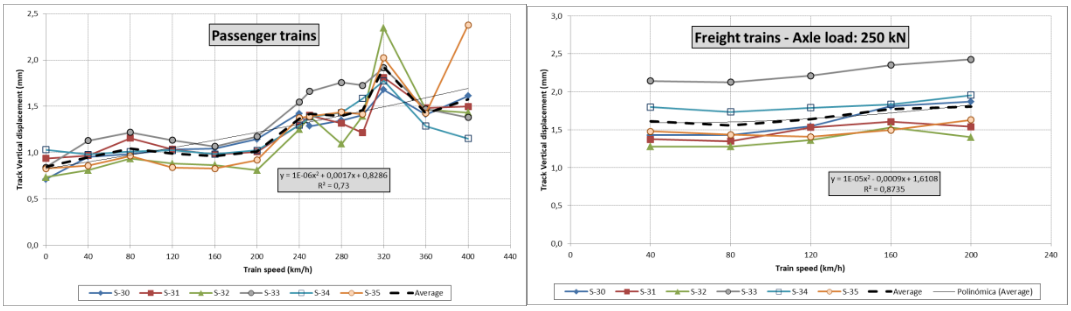


Figure 103: Track vertical displacements obtained for passenger and freight trains

As a summary of the accelerations measured in the tests, Figure 4 shows the trend of the test results for the rail, block and slab base vertical accelerations. It can be seen that the increase with the speed is exponential in the three elements with the following maximum values obtained for a train speed of 400 km/h: 1.4 g for the slab base, 5 g for the blocks and 7.8 g for the rail.

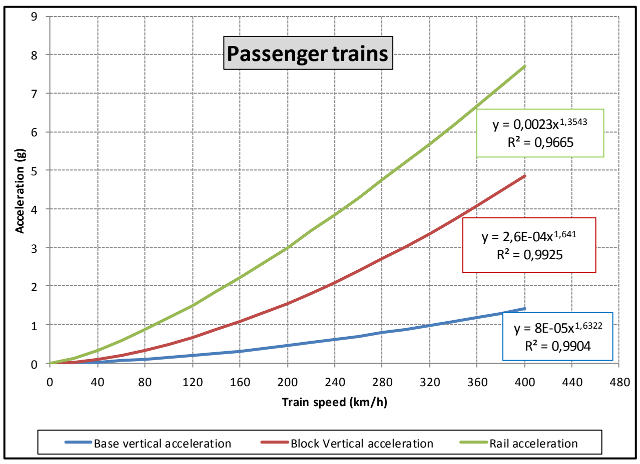


Figure 104: Vertical accelerations measured in different track elements when simulation passenger train pass-by at different speeds

With respect to the vertical movements, it can be seen in Figure 5 the average values obtained in the different sensors that were measuring the foundation layer – slab base – block – rail relative vertical displacements, besides the total track vertical displacement during the passenger train simulations at speeds from 40 to 400 km/h. The analysis of the figure makes it possible to state that 15% of the vertical displacement is due to the concrete foundation layer placed on the bituminous layer, 30% to the elastomeric material placed between the slab base and the block and the rest (55%) due to the rail pad.

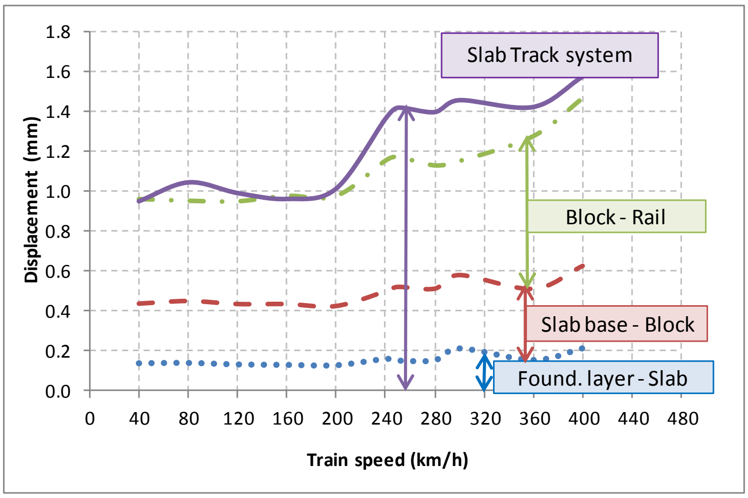


FIGURE 105: VERTICAL ACCELERATIONS MEASURED IN DIFFERENT TRACK ELEMENTS WHEN SIMULATION PASSENGER TRAIN PASS-BY AT DIFFERENT SPEEDS

The main conclusion that can be drawn from the test result analysis is that the 3MB slab track prototype has had a good performance since, on one hand, the results obtained (in terms of displacement and accelerations) are in the range of the usual values measured in real slab tracks and, on other hand, there has not been either any structural damage or unexpected malfunction of any of the slab elements during the test performance.

7.2 L-TRACK TESTS

Due to unforeseen circumstances, an even though the L-TRACK demonstrator was fabricated and installed in the CEDEX track box facilities, it was not possible to perform the tests planned within the timeframe of the project.

Nevertheless, the tests shall take place in the future months, and the results shall be analysed and compiled in a report, to be labelled Annex VI

8 Life Cycle Cost

8.1 Construction costs

Traditionally the construction cost of slab track systems is much bigger than for ballasted track. That is one reason why slab track is not very widespread around the world. The construction cost of a slab track system in plain lines consists of manufacturing of precast elements, delivery, assembly and installation of complementary equipment, such as noise absorbers or derailment devices.

The estimation of the global costs for the manufacture of this modular slab track and the implementation of this system on track are very variable, as it depends on many factors. With regard to the manufacture stage, some of the most relevant factors are:

- Availability of raw materials and components
- Supply chain for each component
- Location of the factory with regard to the construction site
- Logistics and transport issues

With regard to the construction stage, some the relevant factors to observe are:

- Project type
- Construction procedure
- Track section length
- Man force and machinery costs at the construction area/country
- Transport needs and costs
- Customs duty
- Presence of special structures on the section
- Complementary equipment

In addition to this, some other aspects must be considered in regard to the mass production of the product:

- Costs for a prototype manufacturing may be decreased by nearly 30% when in industrialised stage.
- Construction cost may vary depending on the track extension. Specially dedicated machinery may be developed for large projects, whilst renewal of short track sections may need lower investment in handling devices.

Given the fact that calculating an accurate cost estimation is very complicate and ineffective, the only way to set a basis for calculation is to consider the order of magnitude in the price of each component required for the manufacturing; and also to consider the order of magnitude on each costs required for the construction of a reference slab track segment. In the following section this methodology will be applied in the case of 3MB system, as it is the first prototype constructed and estimative cost are available. Subsequently, another chapter will be dedicated to a rough estimation for the LT system.

8.1.1 Estimation of manufacturing costs for the 3MB System.

Based on the procedure defined in the previous section, the key values for each component can be the following:

Table 17. Key values for each component of 3MB system

		$A \times 10^{OoM}$ [€]	
Component	**Units per module**	**OoM [adim]**	**A [adim]**
Bit. ballast layer	1	3	1.2
Concrete base	1	3	0.6
Block	8	2	0.5
Under block pad	1	3	0.4
Pin system	16	2	0.5
Fastening system	16	2	0.8
Rail	1	3	0.6
Mortar	1	2	0.4
Others	1	3	1
Man-force + machinery	1	3	3.2

The following assumptions are considered:

- Values for the A parameter are merely indicative.
- Calculations are made for one complete module – approx. total length: 5000 mm. Single track.
- Average cost of the raw materials purchased in Europe.
- Manufacturing costs are calculated on the basis that the manufacture procedure is on a industrialised stage.
- All components are included in the items list. However, the final list of components – and therefore their cost- shall depend on the project specifications.

8.1.2 L-Track construction costs (INECO)

Based on the procedure defined in the previous section, the key values for each component in a L-Track module can be the following:

Table 18. key values for each component of L-TRACK system

		$A \times 10^{OoM}$ [€]	
Component	**Units/module**	**OoM [adim]**	**A [adim]**
Bit. ballast layer	1	3	1.2
Concrete bearings	2	3	0.6
Metallic connectors	2	2	1
Under rail pad	1	3	0.4
Fastening system	12	2	0.8
Rail	1	3	0.6

		$A \times 10^{OoM}$ [€]	
Component	**Units/module**	**OoM [adim]**	**A [adim]**
Mortar	1	2	0.4
Others	1	3	1
Man-force + machinery	1	3	3.2

The following assumptions are considered:

- Values for the A parameter are merely indicative.
- Calculations are made for one complete module – approx. total length: 5000 mm. Single track.
- Average cost of the raw materials purchased in Europe.
- Manufacturing costs are calculated on the basis that the manufacture procedure is on a commercial stage, not prototyping stage.
- All components are included in the addition. However, the final list of components – and therefore their cost- may depend on the project specifications.

8.2 MAINTENANCE COSTS

The following assumptions are made to calculate the costs of maintenance and renewal operations of the modular slab track system.

- Calculations are made for a total length of 106 km of double track.
- Operational life duration is 102 years with tonnage of 40MT/ year for 320 km/h maximum speed.
- Average of SNCF workers hourly costs.
- Maintenance and renewal operation are adapted from SNCF standards for ballasted track.
- Only track is taken into account that means than all operations related to catenary, sub-station, signalling, bridges and tunnels, low currents and stations are out of the scope.

8.2.1 3MB MAINTENANCE COSTS

Firstly track maintenance operations specific to 3MB are defined with assumptions.

- **Preventive and corrective maintenance :**

Monitoring on site	Track and blocks by technicians
	Track and blocks by managers
	S&C by technicians
	S&C by managers
	Expansion joint by technicians
	Expansion joint by managers
	Environment by technicians
	Environment by managers
	Summer preparation
	After first heats (> 45°C)
	After bad weathers

Monitoring on board	Geometry and gauge records
	Rail surface supervision
	Rail profile laser monitoring
	Track components supervision
	Cabin tours
	Ultrasonic rail testing
	After firsts heats

Systematic preventive maintenance
Track grinding
S&C safety verifications
S&C others verifications
S&C ultrasonic tests
S&C grinding
Expansion joint operation control
Expansion joint ultrason tests
Drainage testing
Vegetation : chemical treatment
Vegetation : clearing

Conditional preventive maintenance
Straightening rail
Block replacement
Fastening : clamping or punctual replacement
Geometry correction : track tamping
Geometry correction : S&C tamping
Geometry correction : EJ tamping
Geometry correction : punctual tamping
Geometry correction : slab
Ballast : unloading and profiling
Concrete : cracks
S&C revision

- **Renewal**

Operation
Rail and Fastening clips renewal (RR + FR)
Turnouts renewal (metalic parts) (TR)
Block renewal (BR)
Total track renewal

Then every operation is assessed with operators and machines hourly costs with assumption on the frequency.

8.3 3MB LCC MODEL (SYSTRA)

The Life Cycle Cost (LCC) of 3MB model only gathers the maintenance costs since the construction costs are not available. A comparison with ballasted track maintenance costs is made:

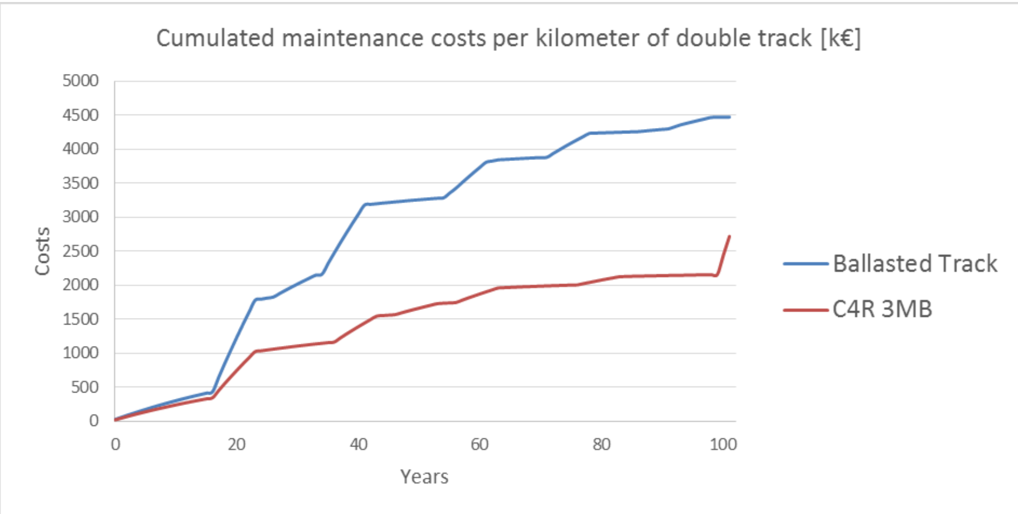


FIGURE 106: MAINTENANCE COST COMPARISON FOR 3MB AND BALLASTED TRACK

An inflation rate of 3% and a discount rate of 6% are taken into account in the calculation.

9 Business model

9.1 INTRODUCTION

The business model supports the viability of the business regarding the new concepts of slab tracks developed during the Capacity for Rail project. This business model includes different sections in which the external and internal factors, purpose, goals, and on-going plans for achieving them, are analysed.

At the level of develop of the new concepts of slab track reached at the date of publishing of this deliverable, it has been not possible to analyse with the level of details the entire variable involved in the business and decision support model. Besides, some of the different stages of the business model require a particular analysis by every one of the partners related with its internal costs and business strategy. However a global and well-oriented analysis has been possible to perform where different internal and external factors has been detected, analysed and a number of strategic decisions has been proposed.

In order to get accurate outcomes, a set of several steps have been followed. These steps represent different phases of a more complex analysis. Shown below the explanations and analysis of every one of the different phases of this global study.

9.1.1 PEST ANALYSIS

PEST analysis develops a framework of external environmental factors used in the environmental scanning component of strategic management. It is a widely used tool that let analyse the political, economic, social and technological environments related with your business. Normally, it is part of a wider analysis which finalizes with the business operation and management plan.

As a result, a global idea or ‘big picture’ is obtained that helps corporations or businesses to understand the changes which they are exposed to, and from this, exploit the opportunities that they present.

9.1.1.1 Political

Current political world situation lives a period of convulsion and turbulences. Recent events such as jihadist terrorism, migration crises, demographic changes in different regions of the world along with an unstable political scenario in diverse countries of the first world such as United States, United Kingdom or European Union, provides us with an general idea about the global policy state where the opportunities dwindle in contrast with the weaknesses.

United States presents an unstable framework forecast regarding the policy due to the 2016 general election, where the master lines followed during the last years could be drastically change in dependence on the result of the election. On the other hand, terrorism with ISIS as the most powerful terrorist organisation in history has led to made hard decisions in terms of safety and security. This problem connected US with other countries which are in the ISIS’ hit list. This list includes nations with a high number of unintegrated communities such as France, Russia or Turkey.

In Europe the situation is not quite different. The leaving of United Kingdom from the European Union, also known as *Brexit*, might provoke unexplored consequences which are not totally evaluated by the international economic and political associations. In political terms, *Brexit* may signify some serious issues in the development of current European treaties. A proceed for the formal leaving of the EU has to be implement to regulate the process and save the rights and obligations with the rest of European partners. Moreover, *Brexit* could help to the increase in the number of anti-European movements in some countries as Netherland or Austria.

The effects of financial and economic crisis are still presented in the European policy. Slow growth and lower living standards are going to make people discontented. One of the most considerable consequences of the crisis is the appearance of a new phenomenon of radicalization in the political scope which has recently happened. The raise of extreme movements in terms of ultra-left and far-right parties, in the majority of European countries, supposes an added unstable factor to a situation still extremely fragile.

The latter is owed to add the uncertainties in the political future of some countries such as Spain or Austria. The case of Spain is extremely relevant due to its important weight in the EU GDP, strategic location, the size and large population of the country. After two elections the political parties do not come to an agreement to choose a government and the next budget for 2017 is totally paralyzed. The case of Austria is seriously worrying. The raise of extreme parties which question the membership of the country to the EU and relationship and frontiers policy could be represent a risk in a short-term.

This convulse political state in Europe is directly linked with the situation in Middle East. Turkey lives with a recent *coup d'état* attempt and the direct consequences of it. This instability in the area is directly linked with the war in Syria, which has triggered a set of migration movements, originating the 'Refugee crises'. The destiny of the most of this people is the main European countries such as Germany where more than 1 million of emigrants from areas war areas are living now. These movements have provoked some racism episodes which have resulted in the emerging of new ideas related with the close of borders or the restriction in the traffic of people.

Regarding South American countries, the most serious and unpredictable case of policy state is Brazil. The celebration of World Football Championship in 2014 and the Olympics in 2016 has meant a great expense for the public finances. However, this great amount of money has not translated into improvements for the people in matter of public services. In addition the suspicion of corruption has led to riots, disturbs and protest marches. All these events have provoked the deposition of the former president due to fraud charge.

China, the only country of scale with a global economic strategy, stands out as the most important, but uncertain, driver of many global outcomes. However, some experts agree with the fact that most international players are not ready for this or do not agree with China priorities.

In the rest of the world, the volatility is presented because of an unusually amount of leaders known for their erratic behaviour. In this pack of personalities could be included Vladimir Putin (Russia's president), Tayyip Erdongan (Turkey's president) along with Mohammed bin Salman (Saudi Arabia's Deputy Crown Prince) or Petro Poroshenko (Ukraine's president).

All these facts draw a difficult scenario of uncertainty and instability where it is not easy to have a clear idea about the national infrastructures plans forecast in the short and mid-term.

9.1.1.2 Economic

Global economic environment has suffers relevant changes in the last times. The uncertainties surrounding the forecast are extraordinarily high. Despite of the fact that we are in an expansive phase of the economy, the effects of the financial crisis are yet presented in the most of European countries particularly in the southern countries such as Greece or Portugal where the bailouts has strong effects on the capacity of investment for the national governments.

According to the European Economic Forecast Spring 2016 (European Commission, Spring 2016), the European economy continues to expand modestly. Some facts such as the low oil prices, the relatively low exchange rate of the euro, very ample monetary policy and slightly supportive fiscal policy continue to underpin growth this year.

However the same report shows some risks which must have taken into account. These risks are related with the possible lift in the price of the oil and the lagged boost from the euro's depreciation that is likely to have run its course.

Regarding the GPD, this one in the euro area has now achieved its pre-crisis peak of eight year ago but it has taken much longer to reach this milestone than in other advanced economies. The level of investment remains depressed and structural unemployment rate far too high. The latter is critically relevant in important economies such as Spain or Italy. Besides, other factors, as the slow trend growth of productivity, could delay the recovery.

Brexit may signify a serious threat to the economic recovery. Moreover the FMI predictions talk about a decrease of around of 1-1.5% in the British GDP and 0.2-0.5% of EU GDP due to *Brexit*. This fact along with the investment shortfall, due to the budget restrictions, could represent the most likely risk to the European economy in the next years.

Regarding the global economic outlook, it remains weak in last months, amid heightened financial market volatility and commodity prices. According the prospects, the emerging countries' economy will remain fragile due to the commodity price declines, tightening financial conditions and a host of home-grown vulnerabilities. In fact, economy growth fell to 3.2% in 2015, its slowest value since 2009. There are many causes in this decrease, but the main reason is the gradual slowdown in the growth of emerging countries.

Advanced economies, such as US and Japan, also show signs of deterioration in the last times. Growth in both countries has been lower than expectations in advanced, while recessions in Brazil and Russia have been deeper than expected, and the rebound in other emerging economies has disappointed.

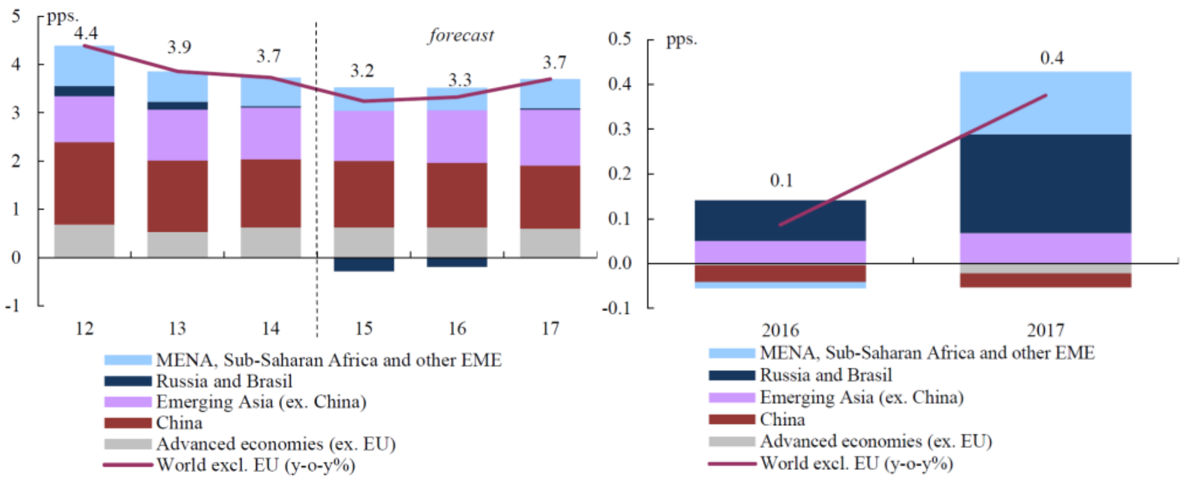


FIGURE 107: GLOBAL GDP GROWTH AND SOURCES OF REBOUND OUTSIDE THE EU (EUROPEAN COMMISSION, SPRING 2016)

These analyses do not offer the best outlook for the future of infrastructures plans which require great amount of money and resources which are not currently available.

9.1.1.3 Social

Currently, social demands play an important role in the infrastructure plans. Not only from an economical point of view, but also considering the environment, the sustainability, the efficiency, the security, the smart and green transport, social inequality or climate action. All of these are part of the current social concerns. As a result of this new social sensitivity, all these demands must take into account in any planning or operation what it directly translate into a new challenge for planners, technicians and engineers.

Due to the financial and economical restrictions, one of the most important demands in our society is the efficiency of the new infrastructures. These must be useful and economically sustainable at the same time. They must be accurately adapted to the current and future needs, but not be over dimensioned. Besides, the cost should not be only evaluated in matter of money but also in societal benefits, particularly in those countries which has suffered most severely the effects of the financial crisis.

Sustainability is one of the more relevant challenges in this new mentality. The new infrastructures must be sustainable in a long-term. Expenses in infrastructures are considered as investments for the future generation but not as debts for them. This change in the way of thinking is related with serious issues due to past huge investments in infrastructure. These investments have not tackled to the social problems and have result in a large increase of public debts for decades.

Smart and green transport is other of the main new challenges which must be taken into account in the development of the new infrastructure programs. A new policy in relation the environmental has emerged mainly due to find a way to tackle to the pollution and environmental issues, because of the use of fossil fuels. In alignment with this issue, the *smartization* of the transport constitutes another possible line of action which is currently in a constant development. This technology must minimize the fuel costs; reduce the pollution and optimizing the travel times.

One of the main social concerns is in relation with the inequality in the society. There are many theories about the causes, pros and cons of the inequality. Inequality is defined as the gap between the highest income earners and the lowest income earners. However, nowadays a new concept of inequality has appeared. It defines the inequality as the difference not only in financial sense but also in wealth, education or culture. The assessment whether the inequality is beneficial or not is not as important as the knowledge of the causes of inequality. The causes of inequality are varied and diverse. Among the causes could be mentioned the lack of facilities, problems in the access to education, the different skills and abilities or the social environment where people grow. Moreover the social inequality is closely related with the economic troubles. Market failure occurs when there is an inefficient allocation of resources in a free market (Pettinger, 2011).

Global warming is beginning to create serious troubles on the Earth. Floods, droughts, hurricanes or other extreme meteorological phenomena represent important hazards in housing and infrastructures. One of the crucial and critical challenges in XXI century is related with overcome and mitigate these hazards. New methodologies and tools in order to achieve this challenge must be implemented during the first decades of the century. Society is completely aware of this need, what has provoked a change in the policy, both in national governments and private corporations, in relation this issue in the last times.

9.1.1.4 Technological

The boost of technology in the last decades has supposed radical changes in the most of areas of life. The world of working, health, communications, transports or social interactions have been completely transformed by the use of technological devices which to a large extent have eased and helped to improve our quality of life.

However, there are yet many challenges in relation with the technological development to address during the XXI century. In this challenge, information and use of it (*information and communications technology – ICT)* plays a primary role. Many areas of traditional operations could be transformed by applying information technology. The application of new technology of information must fulfil some of the following aspects (Popper):

- Enhancing the efficiency of information gathering and production
- Achieving synergy by combining different databases
- Horizontal and vertical connectivity
- Ensuring wider accessibility
- Use of smart grid
- Multiplying contacts thus increasing the density of information-sharing networks
- Increasing the ultimate effectiveness of information utilization

In the field of transport infrastructures, some of the ideas previously mentioned are being applied in the new developments carried out from the first decade of 21st century. Particularly, among the land transports, it is the rail, the mode of transport which has shown the larger advance in the use of ICT tools.

Mainly, the use of advances technologies in the infrastructure are linked with the monitoring and data analysis. The principal target in the use of ICT is the use of data from monitoring in order to detect possible defects or failures in the general statement of the infrastructure before these defects could affect the operational capacity of the infrastructure. As a result, an improvement in the conditions and a better planning for maintenance tasks could be achieved. Moreover, all of these will translate into a safety in operational costs and a reduction in the downtimes.

Apart from the use of ICT in rail, the recent developments show a clear tendency in the design and construction of new models of ballast-less rail through the use of the slab track. The ballast presents a number of drawbacks in comparison with the ballast-less systems that makes it an unsuitable system for high speed rail. Some phenomena as flying ballast could be effectively overcome with the use of slab track systems. On the whole, slab track offers a solid and robust solution for high speed rail with fewer issues thereby facilitating and reducing maintenance tasks. However this system also presents some notable inconveniences which make difficult its generalization as the main rail system. Among the more remarkable drawbacks it is possible to mention the embankment height limitation due to the little tolerance regarding settlements and the difficulty in the replacement tasks of the slabs once they are broken or deteriorated.

In alignment with these ideas a set of commercial systems has been developed from the last decades of 20th century. These systems, mainly European, offer different alternatives in the use of slab tracks. Among the different systems could be highlighted the system Rheda2000® which is widely used in stations and some lines in Germany, Züblin, LVT-Sonneville, Stedef, Bögl, BBER or Shinkansen.

Every one of above systems has a number of special features which make the system more appropriate for several case of use. Along with these features, a number of drawbacks and benefits are presented in every one of these systems.

For all above reasons, slab track represent a major challenge in the development of high speed rail. Some of the main drawbacks regarding some phenomenon as ballast-flying could be avoided with the use of this technology. Despite this fact, slab track technology presents some disadvantages related with its own geometry and its features which provoke restrictions in the height of embankments or complicate the switches and crossings.

9.1.2 SWOT ANALYSIS

SWOT analysis is a business technique for a project or an idea which identifies the strengths, weaknesses, opportunities for growth and improvement and the threats the external environment presents to its survival.

	Helpful	Harmful
Internal origin	Strengths	Weaknesses
External origin	Opportunities	Threats

Therefore, it is a type of analysis in 4-steps which cover different point of view of the business. Every step of the analysis is defined as:

- Strengths, characteristics of the project which give advantages over others
- Weaknesses, characteristics that place the project at a disadvantage relative to others
- Opportunities, elements in the environment that the project could exploit to its advantage
- Threats, elements in the environment that could cause problems for the project.

9.1.2.1 Strengths (internal origin)

Despite their disadvantages, ballastless rail systems such as slab track present a number of benefits over the traditional ballast systems. These advantages are mainly related with the fact of the absence of aggregates (ballast) allow implementing cleaner, dust-free and environmentally friendly engineering solutions. Moreover, the non-presence of ballast, and its substitution for a slab allow the access of road rescue vehicles in the track in case of emergencies or accidents, not only in tunnels but also in open plain rail sections.

Regarding the maintenance tasks, although they are lower in number than in ballast systems, these one are more complex and intensive in workforce, due to the fact that the need of replace the damage o cracked slab by a healthy slab in case of failure. However, the new concept of slab track developed during Capacity for Rail project avoids this issue, due to its modular design which allows replacing damaged components of the slab without the need for the replacement of the whole slab. This represents a great leap in the generalisation of use of the slab track systems in longer rail stretches, because until now, this technology is generally used in small stretches or singular points such as stations or tunnels.

The avoidance of ballast flight in the slab track systems represents other of the main benefits over the traditional ballasted track systems. This fact is particularly remarkable in case of high speed rail where the phenomenon could causes important damages in the rolling stocks.

Technological advances in the last decades have provided us with a great amount of tools whose use could help and improve some of the main weak points of the transport infrastructures. Current technologies of slab track present a number of limitations regarding the use of ICT in monitoring of the structural health for the whole system (slab, rail and so on). In fact, these kinds of technologies are not use yet in the most of cases, and the evaluation of the state is carried out by traditional methods.

Both typologies of slab track developed during Capacity for Rail Project, included an innovative monitoring system specially implemented for its design and special features. This system will represent a major step in the knowledge of the stress and strain state of the concrete and steel bars of the slab. Data from the monitoring could be used in order to optimize the maintenance tasks what means in cost reductions and improvements in the level serviceability of the corridor. Besides, the use of data mining and analytics techniques could redound in the development of advanced algorithms for preventing failures in the diverse elements of the system.

Fabrication of the track base slabs at an off-site production facility increases the reliability of the construction quality and execution schedule. Mistakes on-site are kept to a minimum by using track base slabs which are precast in factory conditions

Furthermore, the new concept of slab track is specially designed for very high speeds which are expected to achieve in the next decades. Current systems are designed for medium or high speed, in spite of the fact that speeds over 400 km/h are expected to achieve in some years.

9.1.2.2 Weaknesses (internal origin)

These disadvantages are mainly related with the limitation of the height of the embankments and the restricted geometry designing and execution. The limitation will mean the main obstacles in order to market this technology of track. This intrinsic feature to the technology will represent one of most relevant weaknesses of the system, since, the limitations will mean in notable increase of the costs in the rail projects. In fact, the special needs in the conditions of the embankments along with the costs of the slabs make the slab track system more expensive in the construction phase than the traditional ballast system although this increase of the costs is offset by lower maintenance costs during the life of the infrastructure. The overcosts in the construction phase of the slab track in relation with ballast rail (1.5-2 times) are approximately compensated from the age of 30 (**Erreur ! Source du renvoi introuvable.**).

Other important issue regarded with this technology is the lack of experience in the use of the models developed during the Capacity for Rail project. While the experience with ballasted track systems exceeds 150 years, the slab technology barely reaches 50. This lack of experience in the use of these prototypes makes the engineers more confident to deal with ballasted systems and could mean in the possibility of reticence by the rail administrator at the time of includes these technologies in the different national rail specifications.

Although the number maintenance tasks are lower in the slab track systems, these tasks are intensive in workforce and complexity and make difficult to keep the level of serviceability and maintainability with costs, at least, similar to the ballasted track systems.

As for the noise, the level of acoustic emissions is notable higher in the existing slab track systems than in the conventional ballasted track systems.

9.1.2.3 Opportunities (external origin)

Some of the XXI century challenges are related with the use of data and information from different sources. This fact could represent a major opportunity in the use of the new technology of rail track developed during Capacity for Rail project which, through its monitoring system, allows the acquisition of big volume of data related with the current state of the different elements of the system.

The international and financial environment in which the budgetary constraints are on the agenda of most of the countries and administrations, the use of modular systems in the engineering works will mean in a better adjust of resources and a more and accurate planning of the great transports networks.

Nowadays, the society demands high level of comfort and wealth. Slab track systems should improve these levels through a set of the intrinsic characteristics of the system. Regarding these special features, the reduction of noise due to the non-presence of sleepers or the absence of dust since the non-existence of ballast are the more notorious.

The economic recovery and the intense transport infrastructure planning in the emergent countries will represent a great opportunity of the development and market of the results of the Capacity for Rail project. The growth prospects in the rail market are positive, with annual mean increase around 2.7% for the period 2014-2020. According to the World Rail Market Study, made by UNIFE, average investments worldwide of around 176,000 m€ are planned for the period 2017-2019.

Figure 108: . Annual growth estimates of the rail market by regions (2014-2020) (Source: World Rail Market Study. UNIFE)

Within the high-speed sector, the evolution of kilometers built during the last years has undergone an exponential growth whose tendency is estimated to continue along the same lines according to the International Union of Railways (UIC).

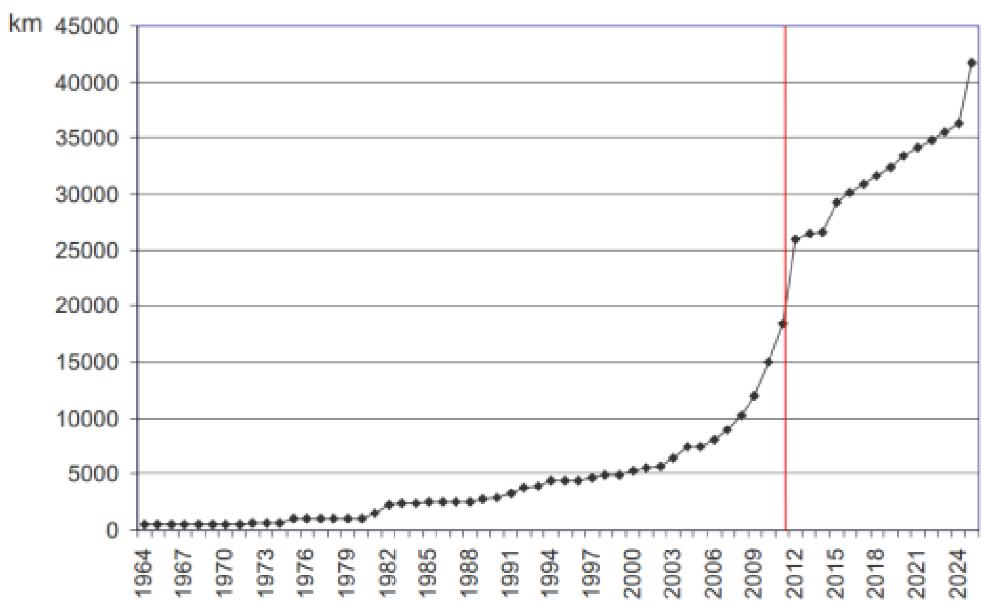


Figure 109: Evolution of high speed kilometers built worldwide (UIC,2012)

This evolution is accompanied by a greater number of countries interested in the implementation of this type of infrastructure, which are mainly concentrated in Europe and Japan, to spread to the US, Latin America, India or the Middle East in the year 2025.

9.1.2.4 Threats (external origin)

The initial investment for the slab track systems is notably higher than the traditional ballast systems. This fact along with the current monetary restrictions in the national budgets due to the financial crisis, which is still present, and the uncertainties in the future of the economy, could represent a major challenge at the time to start to commercialize the product.

As said before, the lack of experience in the generalized use of the slab track in long sections along with the great experience over the 150 years in the use of ballasted systems, supposes the more important obstacle to overcome. Engineers, contractors and administrator are still reticent in the use of new technologies different from the traditional ones.

On the other hand, the unstable framework regarded with the policy in some advanced economies such as USA or UK due to different factors, it does not allow us to see a promising horizon for the infrastructure investments. The national debt in UK will raise 143.000 m€ more than previous predictions due to the effects of *Brexit*. Together with this raise in the national debt level, the growth of economy has been cut from 2.2% predicted for 2017 until 1.4%. All of this will impact on the national infrastructure planning which is under the risk of severe cuts.

9.1.3 CAME ANALYSIS

9.1.3.1 Correct the weaknesses

Despite the costs of execution of the slab tracks are twice or three times higher than the costs of execution of the traditional ballasted systems, the costs of maintenance tasks are quite lower, because the system is notably more robust and the needs of maintenance are lower. If the Life Cycle Cost analysis (LCCA) is made (**Erreur ! Source du renvoi introuvable.**), the results show crystal clear conclusions about the total amount of costs which both system required during all the period of life of the infrastructure (under the hypothesis of 100 years of life).

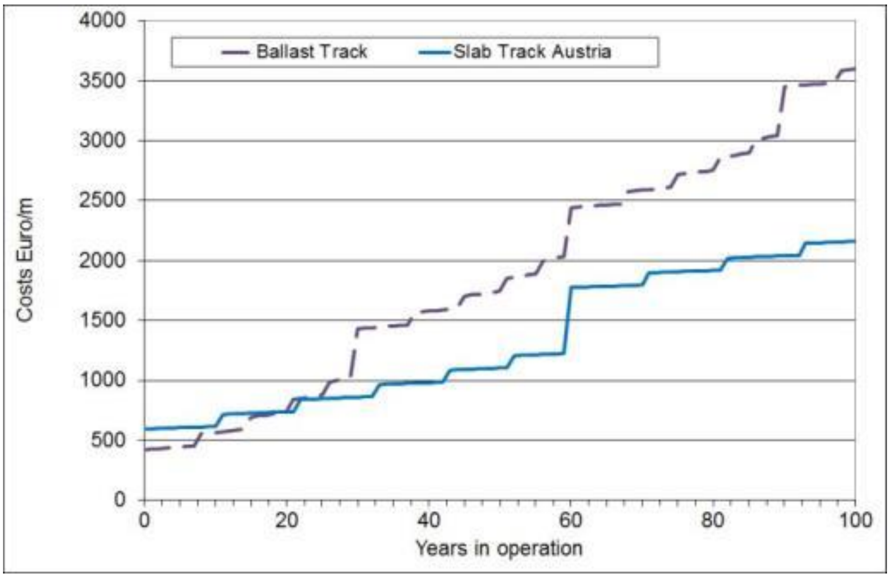


FIGURE 110: TOTAL COSTS (CONSTRUCTION & MAINTENANCE) FOR BALLASTLESS AND SLAB TRACK SYSTEMS DURING THEIR PERIOD OF LIFE (TRACK)

This fact through of the whole life period of the infrastructure will mean in the assumption of the slab track systems are cheaper than the ballasted ones.

The lack of experience in the construction and exploitation of this typology of track supposes other of its great challenges to overcome in order to get the access to the market. The lack of experience about its behaviour under rolling stock could make amend through a research works, where some of the uncertainties were solved. Together with the research works, the public presentations, transport engineering congresses and other dissemination events will help to take over the use of the developments reached during the Capacity for Rail projects.

The construction of demos where the technology will probe the developments and achievements in the field of the slab track systems are other relevant way of overcome the reservations at the time of implement the system in real tracks.

Regarding the comfort and service levels, noise and vibrations represent other of the most relevant issues to overcome. In this case, several attenuation measures as the use of elastomeric pads, sheets and other technologies, has been developed in the last times. Accordingly, the different models of slab track developed during Capacity for Rail project, are designed taking into account all these technologies.

9.1.3.2 Adapt/adjust to the threats

Threats are mainly related with the economic and unstable framework worldwide situation. This is a non-possible factor to control. However it is possible to deal with this fact paying attention over the areas where the investments in infrastructures are still powerful.

Emerging countries such as India or China still offers solid and robust index of growth and very challenging infrastructures plans. These ones are remarkable markets where the number of potentially passengers and the length of the main routes, offers great possibilities. Along with these countries, other ones, such as Arab Emirates, Panama, Colombia or Mexico shows good forecasts in matter of infrastructures plans.

In spite of the political instability in the biggest economies, some countries such as USA or Norway has been planning extensive infrastructure plans for the next decades which includes important investments in matter of high speed rail. This fact could represent important possibilities in order to access to important engineering rail projects.

9.1.3.3 Maintain the strengths

Modular system used by the models of slab track designed during the Capacity for Rail project represents one of the most advanced technologies developed regarded with the slab track systems. This technology will mean in important reduction of the maintenance tasks in matter of time and costs. This fact linked with the special features of the slab track systems, supposes the generation of a track system with remarkable safe of money and maintenance time where the operation tasks are noticeably easier to do than the other slab track systems.

The implementation of a monitoring system inside the slab allows getting a better knowledge about the tensional and behaviour state of the track. This better knowledge will translate into a best planning of the conservation tasks, the development and application of deterioration models in order to optimize the maintenance and operation tasks and the possibility of early detection failures. Along with these facts, the use of ICT in civil engineering represent a great step forward in the use of large volumes of data and its use in the improvements of the different phases of the engineering: design, construction, operation and maintenance. The monitoring system installed in the different models of slab track developed in the Capacity for Rail project allows the access of a great amount of data which help to improve and optimize the different phases of the construction process. This monitoring system is totally innovative and no one of the existing slab tracks systems includes something similar. This represents a notably differentiating factor over the rest of technologies which could raise the promotion of the system in the near future.

9.1.3.4 Explore the opportunities

The systems developed during the Capacity for Rail project could be not only use in the construction of new infrastructures. The field of renewal and upgrading of the existing ones should be put in value at time to market the designed models of slab track. Modern economies such EU or USA, might have not the needs of construction large rail network, however the upgrading and renewals of existing ones represents major challenges in a medium-term. The raise in the loads and the speeds of rolling stocks requires new capabilities. This one linked with the raise in the comfort and safety demands by passengers and the reduction of operational costs by the administrators, supposes a great opportunity to commercialize a new system of track which help to carry out all this new prescriptions and societal and economical concerns.

9.1.4 Business Model Canvas

9.1.4.1 Fundamentals

The business model Canvas is a strategic management and lean start-up template for developing new or documenting existing business models. Initially was proposed by Alexander Osterwalder based on this earlier work on Business Model Ontology. Formal business descriptions become building blocks for your activities. There are many different conceptualizations of business. The model proposes a unique reference model based on the similarities of a wide range of conceptualizations of the business model. According to your business template design, a company can easily describe your business model.

The business model Canvas consists of 9 key blocks which are following described in the next paragraphs. Each key blocks of the model could be clustered in major blocks which meet and associate activities with strong links in common. This formal framework is arranged as the following structure:

- Infrastructure: key activities, key partners and key resources.
- Offer: value propositions.
- Customers: customers segments, channels and customer relationships.
- Finances: cost structure and revenue streams.

The name of Canvas comes from the possibility of representing all the key blocks in a unique scheme in which add all the information. The next figure shows this scheme (**Erreur ! Source du renvoi introuvable.**).

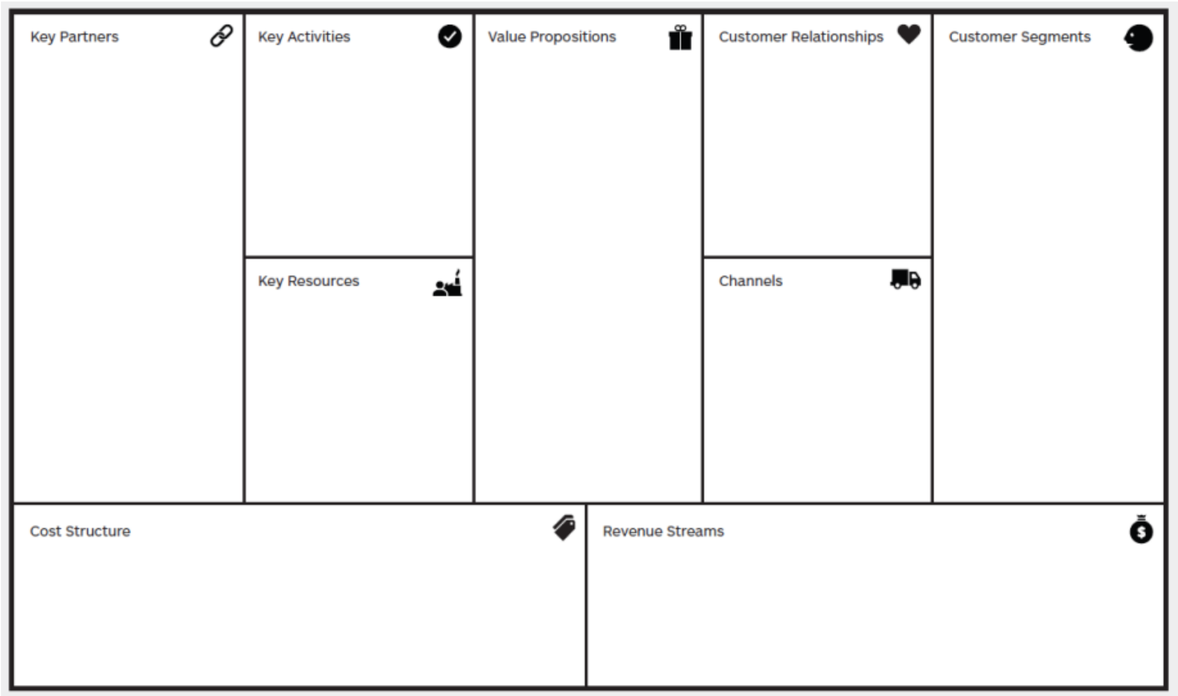


FIGURE 111: THE BUSINESS MODEL CANVAS

9.1.4.2 Key partners

The different members of the consortium involved in the developments reached during SP1 perform the most of the relevant and required roles in order to cover the different phases or stages in the engineering process.

Despite of the fact that the consortium is solid and robust in its own composition, some key partners could be required in order to speed up the process to get the market. On this subject, the active and strongly participation of some additional recognized prestige construction and engineering firms as associated partners will help to include the new concepts of slab track in the new rail engineering project. In addition the involvement of some additional administrator could be relevant, so the development could be tested in different demonstrator before reach the market.

Other main possible gap in the composition of the consortium related with this SP1 is the participation of a dissemination company who could help to spread and implement the developments, achieving the end-users and the possible customers.

9.1.4.3 Key activities

The production process will depend on the business model of every one of the partners involved in the developments of new systems.

In the case of engineering firms, it will recommended the specialization and training in the designing department of some group of technicians who are involved in the application and use of the new concepts of slab track in the rail engineering projects. Construction companies should do the same, not only in case of designing but also in the construction and maintenance tasks.

Administrators and other parties must be receptive in the use of the new concepts in existing lines, which could be used as demonstrators to probe the correct performance of the new systems under real conditions.

9.1.4.4 Key resources

- Human resources

R&D departments of the different members of the consortium plays a relevant role in the process of development and technical support regarding the new models of slab track designed in the project Capacity for Rail. As generators and creators of the new concepts of slab track, they should support the technical viability and solve all possible doubts and uncertainties about the implementation of this technology in real conditions. In addition, one of their most crucial tasks is the transference of information from them to the engineering departments, which must be involved and are in charge of include the new solutions in the rail engineering projects.

Commercial departments are the key factor of the partners which is crucial to be included at the time of spreading the developments reached in the Capacity for Rail project. In order to get an strengthen of the market links between the customers, i.e. infrastructure managers, railway administrator, and the designers and owners of the new designs, will be needed to arrange technical meetings, close contacts and any other type of relationship. This will mean the needed of great amount of work hours and personal resources involved in the process of dissemination and transference of information.

- Financial

Innovation and development process for every one of the designs developed during the project requires a substantial amount of resources by the different partners involved in the project. Although the final design of products will achieve at the end of the project, new improvements, and upgrades will be needed to implement during the post stages of the innovation process. For those stages, some financial support must be guaranteed.

Publicity and commercialization of the results will require a strong investment in publicity in order get and consolidate the distribution channels which will serve as ways of achieve the total commercialization of the designs and developed of the project.

- Intellectuals

The protection of results will require the previous definition of who are the co-owners of the developments achieve during the project. Once this will have been done, the partner should decide the need to come to a join ownership agreement. This ownership agreement could represent the more appropriate solution when a consortium is not sufficiently specific. This mean of protection has associated a set of costs which will be shared between the parties.

9.1.4.5 Value propositions

The proposal at the time to offer the new systems must be aligned with the advantages and benefits which the system brings over the rest of existing slab tracks systems. These benefits are previously detected in the SWOT analysis.

- Dust-free system which will mean in environmentally friendly engineering solutions.
- Easy access of road and other kinds of vehicles in the track in case of emergencies or accidents.
- Modular system where the maintenance tasks are notably easier than in the current slab track systems.
- Low number of maintenance tasks what will mean in lower costs of maintenance.
- Avoidance of ballast flight and its issues regarded with the rolling stocks.
- Use of ICT tools to monitor and check the external and internal behaviour of the different components of the system.
- Fabrication off-site which will increase the reliability of the construction processes.
- New design specially designed for very high speeds keeping the comfort and safety conditions.

9.1.4.6 Customers relationships

The innovative designs developed during the SP1 of the Capacity for Rail project requires the need of a close relationship between the customers and the different members of the consortium in order to spread the benefits in the use of these ones and to solve the possible doubts in relation with them.

In this way, the existence of a direct assistance line between customers and the consortium is considered crucial at the time to obtain good results in the commercialization of the results. This assistance must be both technical and financial, explaining and solving the advantages and possible doubts and issues occurred during the design and construction process.

It is highly recommended the creation of a technical and commercial committee in order to attend all this possible issues related with the slab track systems developed in the project.

9.1.4.7 Channels

This block deals with the different possible ways at the time to achieve the customers. Because of this project addresses to set of new solutions for the slab track, the issue is not only focusing on the improvements of existing channels but also in the search and business strategy to commercialization of these ones.

The procedure to obtain, develop, create and consolidate a set of channels to commercialize the results obtained in the C4R project consists of a set of steps which are following described:

- Raise awareness

The new models and developments reached during the Capacity for Rail project should be spread and disseminated in order to raise awareness over the new engineering solutions for the slab track. A number of different alternatives could be checked in order to release the results of the project. The main and more relevant ones are:

- Attendance to specialized events in transport and civil engineering such as Transport Research Arena (TRA), Congreso Panamericano de Ingeniería de Transito, Transporte y Logística, International Congress on Transport Infrastructure and systems (TIS) or the International Conference on Transportation and Traffic Engineering (ICTTE).

- Celebration of workshops and dissemination events during and post the project where experts in the field of rail and transportation engineering, infrastructure managers, construction companies and other stakeholders will be invited.
- Elaboration of technical reports where technical characteristics of the new systems of slab tracks are crystal clear reflected.

- Assessment

The assessment by the possible customers of the new systems of slab track developed in the project could be done by several ways:

- Standardization: the models developed must comply the current normative and prescriptions in every country where they will be implemented and constructed. The only way to get this is through the test and standardization of the different components which be part of the systems. This procedure will guarantee the post adequate behaviour and the safety prescriptions.
- Elaboration of design guides and engineering solutions where the slab track models developed in the Capacity for Rail project will be included resulted in alternative to the current solutions.
- The execution of demonstrators in rail stretches will help the adequate assessment of the new models of slab track in real conditions.

- Purchase

The commercialization of the new slabs by the consortium must be object of a deep study where every partner will play a role according to its business. In this way, the different partners of the consortium are totally complementary between themselves, and no relevant overlapped are detected.

- Post-assistance services

Technical assistance during the different stages of the construction process: planning, design, construction and maintenance will help and speed up the implementation of the new systems of slab tracks developed in C4R.

9.1.4.8 Customers segments

Among the customers, national governments, infrastructure managers and railway administrators plays a primary role as end-users of the developments and designs reached during the SP1 in the Capacity for Rail project.

Some of the main infrastructure manager and railway administrator in Europe and worldwide are following listed:

- Germany: *Deutsche Bahn Netze (DB Netze)*
- France: *Société Nationale des Chemins de fer Français (SNCF)*
- United Kingdom: *Network Rail (NR)*
- Spain: *Administrador de infraestructuras ferroviarias (ADIF)*
- Italy: *Rete Ferroviaria Italiana (RFI)*
- Poland: *Polskie Linie Kolejowe*

- The Netherlands: *ProRail, Infraspeed*
- Portugal: *Infrastuturas de Portugal (IP)*
- Sweden: *Trafikverket*
- Belgium: *Infrabel*
- Austria: *ÖBB-Infrastruktur*
- Hungry: *Magyar Államvasutak (MAV)*
- Czech Republic: *Sprava zeleznicni dopravni cesty (SZDC)*
- Denmark: *Banedanmark*
- Greece: *Οργανισμός Σιδηροδρόμων Ελλάδος (OSE)*
- Croatia: *HZ Infrastruktura*
- Norway: *Jernbaneverket*
- Japan: *Japan Railway Construction, Transport and Technology Agency, Railway Technical Research Institute*
- Korea: *Korea Rail Network Authority*
- Iran: *Railway Services and Technical Construction Engineering Company*
- Algeria: *Anesrif*
- Australia: *Australian Rail Track Corporation*
- New Zealand: *KiwiRail Network*

In addition to these great infra managers, the main construction companies along with the engineering design firms must get in touched with the developments of the SP1 due to the possibility of speed up the procedure of inclusion the new models of slab track in the great rail infrastructure projects.

9.1.4.9 Cost structure and revenue streams

Cost and revenue structure should be calculated in dependence of the business and engineering sector of every one of the partners in the consortium. The definition of the different costs and revenue streams address the different stages of the engineering cycle and must be objected of a post in-depth individually study. Generally, the traditional and different cost structure could be classified as the following way:

- Fixed costs
- Variable costs

This structure of costs will be different between the members of the consortium. The particular and possible changes in the chain due to the effect of the new concepts of slab track should be studied for the particular case of each partner. As said before, in the case of study, this structure of costs and revenues could be related with the different phases of the engineering process:

- Engineering
- Construction
- Technical assistance
- Maintenance tasks

In the general case of the engineering firms, this change should not be really accurate because of the same engineering department could address the design of new rail solution taking into account the new models of slab track. In the case of constructors and administrator, the new slab tracks models represent a good chance of improve and upgrade the existing construction methods what could have repercussions in the cost and management structure of the company as well as the rail administrator where the new concepts supposes a crucial opportunity in order to reduce variable costs associated with the maintenance tasks.

On the other hand, the revenue streams will be also very different depending on the kind of business of each partner. In the case of study, this revenue streams will bring through the commercialization of the new concepts of slab track through the usual exploitation channels. These channels will be regarded with the different tasks carried out by the partners in the project. One of the main changes in the revenue streams due to the results of the project is the promotion and technical status that every partner could reach. The gateway to new markets and the access to the public administration through the developments of the project will allow the possibility of come to agreements in matter of engineering, construction or maintenance projects which will affect the revenue streams in a positive way.

9.1.4.10 CANVAS Overview for the modular ST systems

KEY PARTNERS

- Key partners in Consortium: **Systra, Acciona, VCSA, Cemosa, UOH, Ineco**.
- Alternative key partners: Experienced slab track manufacturer, to which license the use of the patent.

KEY ACTIVITIES

- To complete the design.
- To check optimal functionality (verifying all requirements are satisfied)
- To contact targeted manufacturers.
- To make the railway sector aware of the new product. Publicity & dissemination.

KEY RESOURCES

Being able to keep the existing consortium as a multidisciplinary team.

VALUE PROPOSITIONS

New slab track system aimed at:

- New tracks in conventional lines, high speed lines, very high speed lines and also urban lines (metro, etc.)
- Especially applicable to renewals in metropolitan lines and conventional lines.

Clients will pay for this system as it saves time in the slab track construction. The interruption in the service is lower – the availability increases (“A” in RAMS)

We offer a system that reduces time in the construction stage and facilitates the assembly on track.

CUSTOMER RELATIONSHIPS

Clients expect from us competitive products and innovative solutions based on slab track technologies.

CHANNELS

→International infra managers through ongoing projects.
→Informative meetings with selected potential clients.
→Commercial fairs and exhibitions in which the consortium partners participate. The slab track must be advertised as a distinguishing product.

Brochures and technical leaflets must be produced

CUSTOMER SEGMENTS

- Railway administrator – high speed and very high speed, mainly.
- Urban railway administrators – metro and commuter lines.

COST STRUCTURE

Most relevant costs for this business plan are the following:

- Patent cost and Intellectual Property registry cost for both designs.
- At the moment, the slab track designs are at a prototype stage. After the C4R project ending (Oct 2017) the developments must follow There are defined milestones to work on.
- Partners in the Consortium must fund the remaining activities. A way to do it could be through new Innovation projects.
- A joint ownership Agreement has been defined between the partners. From now on, following rules must be followed: 1- Any modification will be jointly owned by the parties. 2- Any development will be owned by the party that generates it.

REVENUE STREAMS

In order to get revenue by selling the product, the general strategy is: the product must be more convenient than the most expensive similar system in the market. This is an aspect that must be carefully observed.

A priori, revenue comes from the licensing to a manufacturer. Then there are two alternatives:

- The manufacturer itself can sell the product, therefore all benefit keeps in the manufacturer.
- The use of this system is recommended in a Project lead by any of the consortium partners. In this case we get a share of the incomes obtained by the manufacturer when selling the slab track.

10 Conclusions

As a result of task 1.1, two new and ground-breakingly innovative slab track concepts were developed, designed, built and, in case of the 3MB, tested.

The tests performed in the singular testing facilities owned and managed by CEDEX, one of the acting partners of the task, and the subsequent analysis of said results show that the developed systems are compatible with current European rail regulations and provide additional features and advantages of significant value.

Furthermore, the developed concepts have been deemed worthy of intellectual protection by their IPR owners, a fact that speaks high volumes of the great potential of the envisioned solutions and has substantiated in formal patent applications to the World Intellectual Property Organization under the Patent Cooperation Treaty.

However, to this date the business case and cost estimation for production, logistics, installation and maintenance remain in very early, approximate and qualitative stages of definition, and require more extensive work to be considered mature.

It is the firm intention of the collaborating partners to pursue the optimization, further development and industrialisation of the production and installation procedures, with the objective of achieving fully developed, marketable and competitive versions of the two novel slab track concepts.