GUIDELINES AND EXAMPLES FOR THE **ENGINEERING, DESIGN AND REALISATION OF HIGH-SPEED RAILWAY LINES AND NETWORK** AS AN INTEGRATED SYSTEM

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Schematic overview

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1. Genesis of the Project

Stages and entities involved:

- 1980-1990: former *Ferrovie dello Stato* (Italian State Railways, in short *FS*) decide to build a new High-Speed Network (300 km/h), based on two main lines: the *Padana* Turin-Milan-Venice one and the *Dorsale (backbone)* Milan-Rome-Salerno one.
- Given the scale of the project, FS decided to set up a mixed public-private partnership (PPP), named *TAV (Treno Alta Velocità – high speed train)*, with the task of building and operating the new network.
- TAV relies on three *general contractor* to implement the project, namely:
    - Turin – Milan and Bologna – Florence lines: FIAT S.p.A.
    - Milan – Bologna and Milan – Verona lines: ENI S.p.A.
    - Rome – Naples and Verona – Venice lines: IRI S.p.A.
- TAV railway plant engineering projects requires to be carried out by the Consorzio SATURNO, which groups the main companies in the sector, always however under management of the General Contractors
- ITALFERR, the FS's engineering company, was appointed as responsible for the supervision of the works and the subsequent acceptance of the works.

2. Engineering and design standards and regulations

The key documents, on which the engineering and design was based, are listed below:

A. The Design Standards, contained in a hefty dossier - dated 1992 - called ''Basic Specifications of the Italian High-Speed System“. It defined the general principles, the type of traffic, the technical characteristics of the infrastructure, the operating model of the nodes, the RAMS (Reliability, Availability, Maintainability and Safety) analysis of the installations and lines, the network management model, the management centre, the facilities for electrical traction, telecommunications, security, signalling and lighting, the special facilities, the maintenance criteria for the installations, the rolling stock and the lines, the definition of the maintenance points and the features of the HS trains. The dossier is kept up-to-date.

B. For the design, reference was made to the FS's internal Design Manual, a compendium of several articles containing all the knowledge of railway infrastructure design, from civil works to installations. Today, some of these regulations are subject of Italian and/or European laws, decrees and ministerial circulars.

C. The railway tracks and routes were established following measurements and in-depth studies with local authorities ('Conferenze di Servizi') and environmental impact analyses. Many tracks were built alongside the pre-existing highway infrastructure, such as the A4 toll motorway in the case of the Turin-Milan link, creating ''multi-modal corridors'', with the aim of limiting the environmental impact of the railway work.

D. Execution of the works was based on ITALFERR standards or technical specifications contained in multi-volume documents called “Civil Works Construction Specifications” and “Plant Construction Specifications”.

E. The European Technical Specifications for Interoperability (TSI), created by a directive of the European Parliament and the European Council on 23 July 1996, have had and still have the purpose of technical harmonisation in the railway field in order to facilitate, improve and develop rail transport in Europe and in third countries with significant interchange with EU. TSI lay down essential requirements concerning infrastructure, energy, control-command and trackside/on-board signalling, rolling stock, traffic operation/management, maintenance, telematics applications for passenger and freight services subsystems.

F. The Fiches or *leaflets* of the *Union Internationale des Chemin de Fer* (UIC) are technical recommendations - often becoming technical norms or CEN standards – that concern rolling stock, infrastructure, railway facilities and safety standards. UIC, founded in 1922, is the oldest existing regulatory railway institution in the world.

G. The RFI Specifications for civil works and railway installations regulate, from a technical and functional point of view, railway design, maintenance and operation. These specifications are sometimes more restrictive than those existing in the international field.

H. The technical standards CENELEC (European Committee for Electrotechnical Standardisation), UNISIG's ERTMS/ETCS (Technical Consortium of the new train control system), UNI (Italian standardization body) and CEI (Italian Electrotechnical Committee) also apply to the design of railway installations.

Design Framework.

1. Preliminary Project: drawn up by ITALFERR (FS engineering company) to define the feasibility of a certain railway work from a technical and economic point of view.
2. Definitive Project: this is drawn up based on the Preliminary Project and refines the aspects of its insertion in the territory, economic estimate, programme of works. Normally, the environmental impact study and the 'Conferenza di Servizi' are based on this project. In this phase, expropriations, interferences with other services are also defined, and the environmental monitoring project must be developed.
3. Executive Project: defines all the details of the works, from calculations to maintenance, safety and coordination plans, as well as environmental site management and monitoring.
4. «*As built*» Project is the one that updates the Executive Project to the actual built works and is fundamental for the subsequent maintenance.

For the construction of the Turin-Milan and Milan-Naples lines projects, terminology was slightly different, but the contents were the same.

Plurimodal corridor on Turin-Milan HSL.

Highway and railway proximity is highlighted, as well as the overpasses that cross both of them

3. High Speed vs High-Capacity Line

Although at first the infrastructure required by the FS was a high-speed line (HSL), it was later renamed high-speed/high-capacity (short HS/HC), which has both high-speed and high-capacity features.

- **High Speed Lines**: intended for fast passenger trains (250 km/h or higher). Therefore, these are designed for lighter loads, as trainsets for passengers are lighter, and with higher gradients (e.g., 35‰ on the French high-speed network). This reduces the amount of civil works such as bridges and viaducts and, overall, the construction is less expensive. However, it is less flexible and there is a lack of junctions with the conventional network, and the only connections with it are at the large stations, where stops take place.
- **High-Capacity Lines**: intended for high traffic of both passenger and freight trains, at a speed lower than 200 and 100 km/h, respectively.
- **High Speed /High-Capacity Lines**: intended for fast passenger trains, and **freight trains up to 160 km/h**. These are designed for any type of rolling material, light or heavy-duty, and therefore require lower gradients (less than 12‰). There are several **interconnections** with the conventional lines, to ensure that the network is more flexible and integrated into the national infrastructure, at a slightly higher cost than a pure HSL.

4. Current Organisation of the HS/HC System

Over time, the organisational apparatus has undergone changes and evolutions, due to both regulatory changes and corporative changes of the actors involved.

Today’s structure (2023) is organized as follows:

- Ministry of Infrastructure and Transport (MIT): it is responsible for the two operational chains of network construction and management on one hand, led by the FS Group; and safety on the other hand, headed by ANSFISA (National Agency for Railway, Road and Highway Safety), formerly named ANSF.
- Gruppo Ferrovie dello Stato (FS Group): it manages the construction and operation of the infrastructure through the *Rete Ferroviaria Italiana* (RFI), current commissioner of the works:
    - ITALFERR for project and works’ supervision;
    - TRENITALIA for operating lines.
- RFI uses general contractors and the SATURNO Consortium fort the engineering and design, the development and execution of the works.
- To carry out its activities, ITALFERR also takes advantage of a Technical Verification Commission (CVT, in Italian) that interfaces directly with RFI, the general contractors and the SATURNO Consortium.

To ensure the highest safety level, the FS Group relies on ITALCERTIFER as an independent verifier, as ANSFISA does with other Independent Safety Verifiers (VIS).

5. Study of the Railway track

The study of the track layout must be carried out by following very specific rules, which concern track geometry and vehicle dynamics.

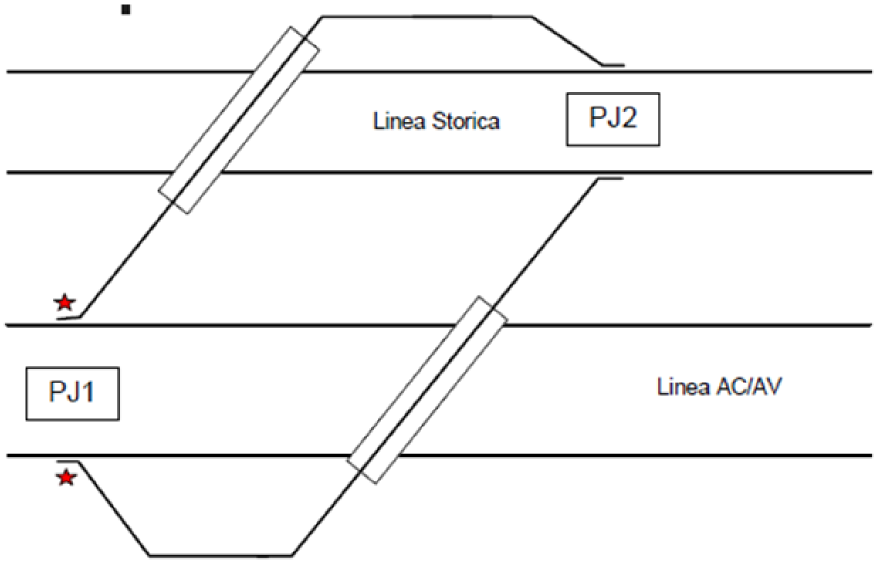
- Reference standards:
  - “Technical standards for the design of railway tracks” RFI TCAR IT AR 01 001, which define the design parameters with their respective limit values and applicable standards;
  - “Technical standards for the determination of operating maximum speeds” RFI TCAR IT AR 01 002, which defines the verifications for the determination of speeds once the track parameters are known.
- Standard parameters of track geometry for HS lines: geometric characteristics such as distance between centres of tracks, track spacing, rail cant, minimum curve radius and vertical transitions, maximum gradient. Some of these, such as distance between centres of tracks and maximum gradient, can be waived.
- Constraints due to rail track:
  - no gradient changes must occur within vertical/planimetrical transitions;
  - no turnouts must affect vertical/planimetrical curve and its transitions.

6. Train circulation systems

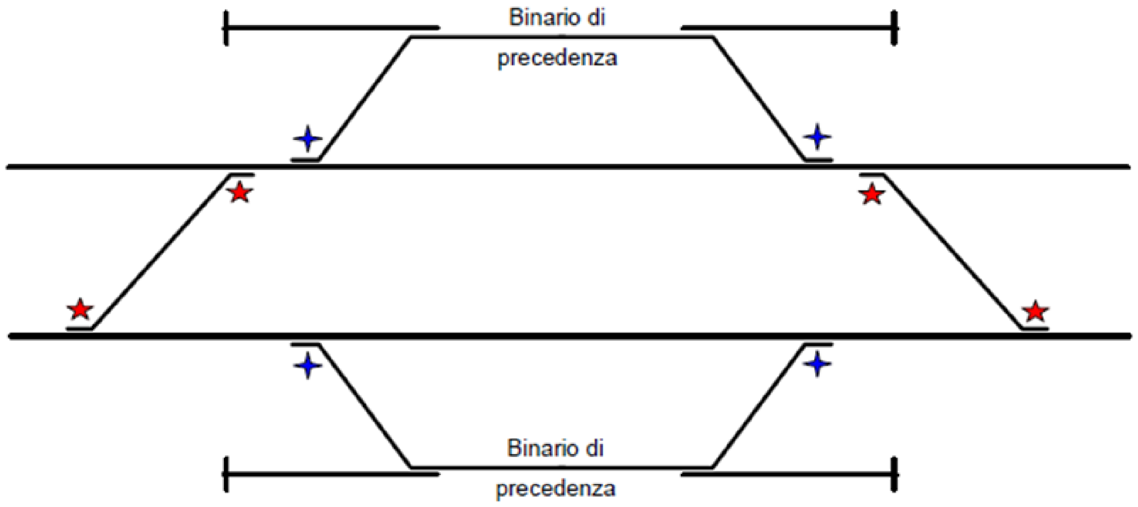
Traffic circulation systems are places where it is possible to **move train sets** from one track to another or to and from the **conventional network**, manage train overtaking and priorities, and support maintenance of the HS/HC network.

These locations (slide 11) are already defined in the ''Basic Specifications,'' and are:

- Communication Posts (PC): service posts where, by means of appropriate 160 km/h turnouts, it is possible to switch from one track to another, to realize single-track circulation in case of traffic problems. They are placed on the line with a spacing of 24 km, and anyway this value depends on the plano-altimetric trend of the track and orographic constraints.
- Management Posts (PM): service posts like PCs, where there are also 750 m long tracks suitable for managing overtaking and priorities. Parking of maintenance train sets is also possible, and they can be used in fact as stations not open to the public. The spacing between the PMs is 48 km, but as with the PCs, the distance can vary.
- Junction Posts (PJ): service posts built near the interconnections with the conventional network, which control entry and exit from HS/HC line. They have no fixed spacing, and their location depends on the position of the interconnections.



Junction Place (PJ1 + PJ2)



Management Place (PM)

Communication Place (PC)

★ Hydraulic turnout tg 0,022

✦ Hydraulic turnout tg 0,074

Service Posts schematics with turnouts description

Turnout 60 UNI/3000/tg 0,022 -speed for passing track-160 km/h - Turnout 60 UNI/400/tg 0,074 -speed-for passing track-60 km/h

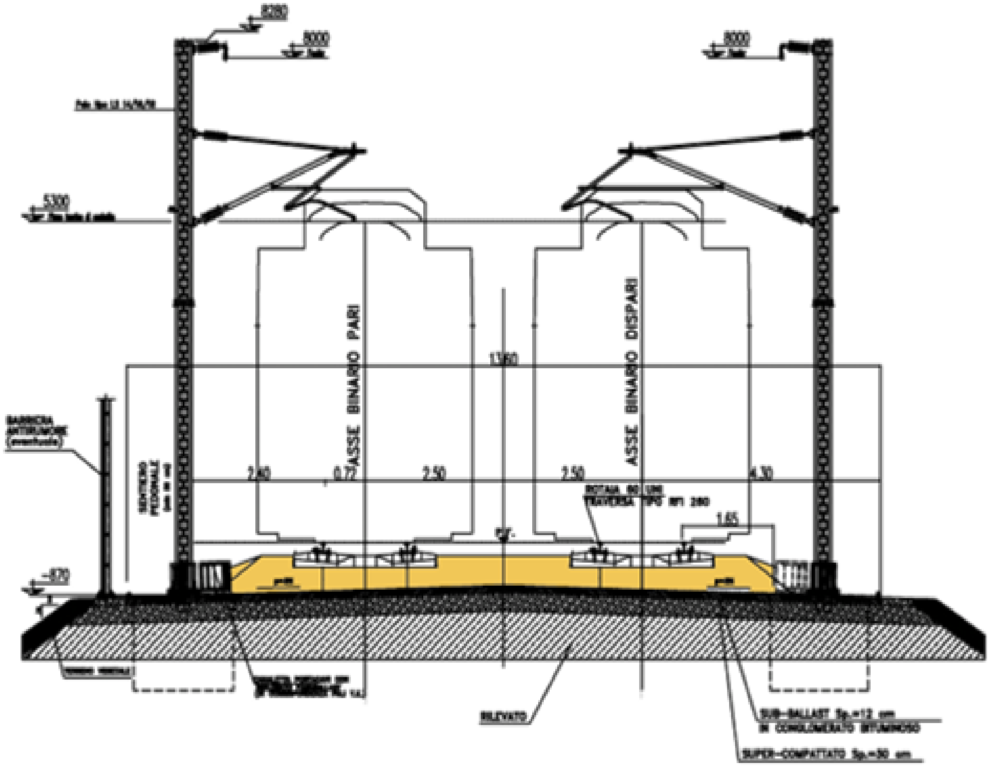
7. Civil works design

The design of the civil works is not very different from that of other infrastructures, e.g., roads, and it is based on what is defined in the “Basic Specifications”, but it also considers more restrictive regulatory constraints.

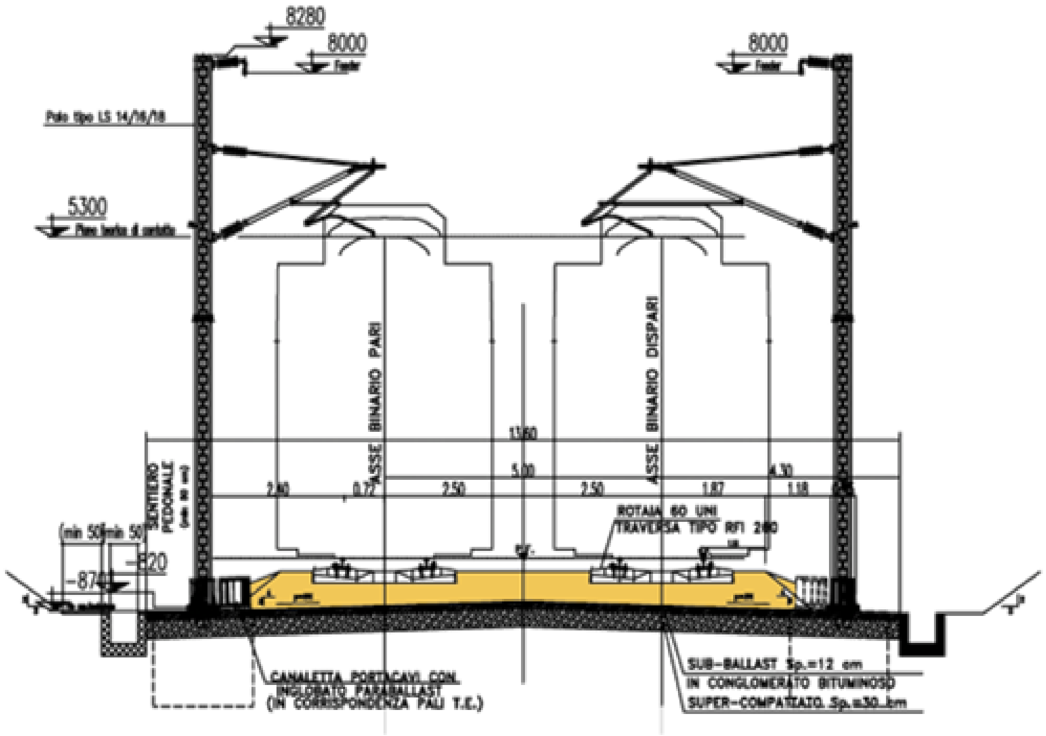
It should be highlighted that:

- The design of high-speed infrastructure requires greater accuracy on tolerances, both in the design and construction of the works.
- The infrastructure must withstand a seismic rank or grade s = 6 in case of earthquakes. This applies to all locations, so that even if one earthquake of lesser intensity should occur, both the resistance of the structures must be guaranteed, and the regular service must not be affected.
- Characteristics of the section of the ground-based rail track:
    - slopes of embankement or cut usually 3 in 2 ;
    - track bed of the ground-based track is 13.60 m wide. It is made of a 12 cm deep layer of asphalt concrete (sub-ballast), to ensure effective protection from rainwater;
    - elements above the track bed consist of ballast, cable ducts, support of an overhead line (ET or TE in Italian), service footpath;
- Characteristics of the section of the viaduct-based rail track :
    - Total track bed width is 13.60 m, with ballast shield walls 10 m apart;
    - elements above the track bed as in ground-based track.

EMBANKED CROSS SECTION



CUT CROSS SECTION



GROUND-BASED RAIL TYPICAL CROSS SECTION OF HS LINES

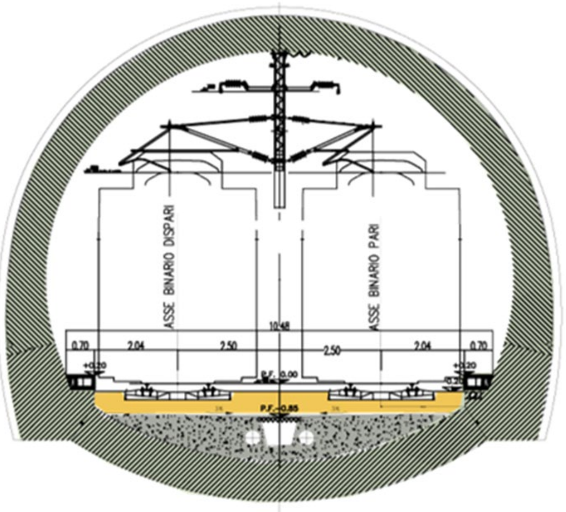
To be noticed: 5m distance between centers of tracks, thinner poles because of the smaller section of AC 2x25kV wires, GABARIT 5 maximum loading gauge, asphalt concrete sub-ballast

- Bridges and viaducts must be calculated for FS train type A with axle loads up to 25 t/axle, and the flexural stiffness of the decks requires a deflection of no more than 1/3000 of the span under maximum static overload. In addition, such works must also be architecturally sound, such as the iconic double steel bridge of the Turin-Milan, as well as functionally valid, paying particular attention to fatigue and corrosion phenomena, and actual feasibility.
- Regarding the technical characteristics of the section in a natural tunnel, it is not possible to adopt a single typology, because this is a function of too many variables, which can be summarized as: construction method, geo-mechanical context, safety standards, size of railway equipment, type of track bed on which trains travel.
- In general, in addition to the works strictly related to the railway infrastructure, there are several civil works related to the construction of a new railway line to be carried out, from construction site roads to buildings for technological installations, and even minor works, such as retaining walls and manholes for water disposal; not forgetting mitigation works, such as noise barriers.
- Finally, the design of the stations. This is a special topic because these works are also of great impact in terms of appearance. For this reason, they have been the subject of contests of ideas and they are designed by the winning firms. We recall, for example, the "Torino Porta Susa Station" on the Turin-Milan HS/HC line and the "Medio-Padana HS Station" on the Milan-Bologna line.

ICON OF TURIN-MILAN HS LINE

THE DOUBLE METAL UPPER ARCH BRIDGE OVER THE DORA BALTEA RIVER

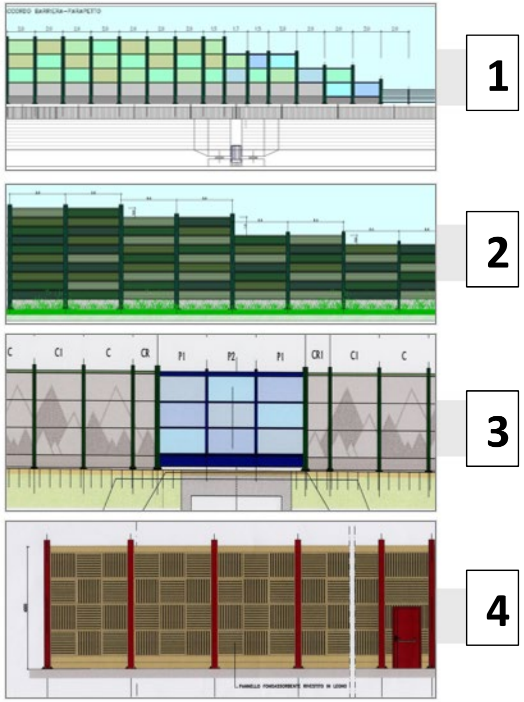
SEZIONE TIPO IN GALLERIA



This is the section adopted on the HS/HC Turin-Milan-Rome-Naples rail line.

Its definition predates the Italian decree DM 28/10/2005 “Safety in Railway Tunnels” which changed the standards of railway tunnels according to their length. In order to comply with that Decree today, many of the tunnels on the line would have to be built with double single-track tubes.

In order to comply with the Decree, “Risk Analyses” have been carried out, so that on the Bologna-Florence “Evacuation Posts” have been built, among other things. There it is possible for travelers to leave trains in a safe condition in case of emergency.



NOISE BARRIERS

MATERIALS:

1 – PMMA

polymethylmethacrylate

2 – ALUMINIUM

3 – CONCRETE

4 – WOOD

TURIN PORTA SUSA STATION

8. Rail equipment

Generally, HS/HC rails equipment is not very different to conventional lines one. Differences are specified in “Basis Specifications”.

- Track type: 60 kg/m UIC 60 E1.
- Standard 1435 mm rail gauge.
- The fixing of the rail to the sleepers are of the direct single-stage elastic type.
- The sleepers are 2.6 m prestressed concrete monoblocs weighing 355 kg each, with wheel-base 60 cm. They are laid on top of a ballast made from crushed bare stone with a minimum compressive strength of 160 MPa.
- Turnouts have sleepers of prestressed concrete or wood, and are of the following types :
  - hydraulic-powered 60 UNI/3000-i/0,022 with movable switch diamond capable of 160 km/h for diverging traffic are used in PJ, PC e PM between running tracks;
  - hydraulic-powered 60 UNI/400/0,074 with movable switch diamond are used in PM between line and stop tracks;
  - electric-powered 60 UNI/250/0,092 are used on passing tracks of PM and in the maintenance yards;
  - electric-powered 60 UNI/250/0,12 are used in the maintenance yards.

9. Technological Systems

In addition to the civil works and equipment, which form the backbone of the railway, the “heart” of the lines is represented by technological installations. They are grouped as follows.

- Energy Subsystem:
  - High Voltage Primary Lines (LP);
  - Electrical Substations (SSE): 2x25 kV AC and direct current 3 kV DC;
  - Double and Simple Parallel Posts (PPD & PPS);
  - Voltage Supply Switch Posts (POC) from 25 kV AC to 3 kV DC;
  - Electric traction box (TE) 3 kV DC;
  - Overhead Line (LC) 2x25 kV AC e 3 kV DC;
  - “Telecomando Enti Periferici Trazione Elettrica” (TP), i.e. Remote Control Peripheral Entities Electric Traction, to remote control electric power plants;
  - Light and Motor Power (LFM) along the line, in yards and buildings.
- Signalling Subsystem:
  - Route Management (GdV)
  - Train spacing (SDT);
  - Hot-box detector (RTB);
  - Electric- and hydraulic-powered turnouts’ control units;
  - Turnouts points Heating Subsystems, in case of cold weather;
  - Train on-board system (provided by train manufacturer).

- Telecommunications Subsystem, (TLC):
    - Long distance data transmission (LD) – optical fibre data transmission network with *Synchronous Digital Hierarchy* (SDH) technology;
    - Train-Ground communication (TT) – GSM-R Mobile Network for mobile phones;
    - Selective and switched telephony;
    - Time synchronisation;
    - Telecommunications network management system.
- Special Systems:
    - Intrusion Detection and Remote Surveillance (AN-TVCC);
    - Antifire (AI);
    - HVAC;
    - Civil Works and Rail Equipment Monitoring;
    - Safety Installations in Railway Tunnels.

10. Energy Subsystem

HS passenger trains and, in the future (expected from the second half of the 2020s, editor's note), fast and heavy freight trains as well, which need more energy, made it essential to revise the electric traction system, in addition to the need to be adapted to European interoperable traffic. The choice was made to adopt the 2x25 kV AC traction system, that in France was already on duty, switching from the 3 kV DC traction system.

Such new system features the following characteristics:

- SSE in-between distance was increased to 50 km thanks to PPDs, which draw return currents from tracks to the substations, making voltage losses lower.
- Voltage Supply Switch Points are situated nearby the junctions, making use of neutral segments of line called POCs, supplied by PPS, which trains cross by inertia without drawing power from the line, to switch from DC to AC supply and vice versa.
- lighter Overhead Line, since higher 25 kV voltage allows the use of smaller power conductors, with a section of 270 mm^2 (150 mm^2 contact wire and 120 mm^2 feeder), instead of 540 mm^2 conductors of 3 kV; as well as lighter supporting poles, with a considerable money saving.
- SSE fed by high voltage (132 or 150 kV) TERNA's or RFI's Power Stations, often built anew. The construction of such was agreed together with designers and local entities during the 'Conferenza di Servizi' and Environmental Impact Studies, considering EM impact too and drawing out paths far from residential areas and buildings.

CARISIO’S DOUBLE PARALLEL POST (PPD) ON TURIN-MILAN HSL

11. Signalling Subsystem

For this subsystem, there has been a real revolution compared to the past, both because of the high speeds involved - which do not allow trackside signals to be safely perceived from the train and which require safe traffic control systems - and because all European traffic should become interoperable.

European Railway Traffic Management System ERTMS/ETCS L2 was adopted, which has become the standard for European HS lines. The main characteristics are:

- ERTMS/ETCS L2 briefly implements an “Automatic Train Control” (ATC) system for the management, control and protection of rail traffic and its signalling on board. The system have no light signals and it is supported by a GSM-R network, which guarantees a theoretical interval between two successive trains of 2 minutes and 30 seconds.
- Such a system made it possible to centralise train traffic management, moving from a distributed management, based on several Fixed Peripheral Posts, to a centralised management, based on a single Central Operating Post (PCO).
- Train Protection is achieved via radio transmission: trains regularly report their position to a “Radio Block Centre” (RBC) of the PCO via GSM-R. On the ground, specific passive beacons or transpornders called “Eurobalises” provide corrections to measurement errors.
- Track circuits are digitally coded, and audio-frequency powered, so that they are independent of the type of electrification of the line. They are used to locate trains, verify their integrity, check for rail breaks and lock turnouts.

12. Integrated Project Management

The engineering and design of a HS line is very complex and presents many interfaces. It is therefore essential to have a functional project management structure that, like an orchestra conductor, can co-ordinate the very different requirements of civil engineer, systems engineer, construction companies and all public and private bodies involved in the approval and implementation of the projects. It all must consider customer’s requirements as well.

Project management is based on three levels:

- *Organizational Breakdown Structure* (OBS): it is the general structure, which involves the customer, ITALFERR and the General Contractor.
- *Product Breakdown Structure* (PBS): it is the project breakdown into technological subsystems.
- *Work Breakdown Structure* (WBS): it is the subdivision at construction level of the works, split into individual civil works, equipment, and the parts of technological installations. This level is very important because it is also linked to the construction companies' payment. The designer, although having important connections to OBS and PBS phases, works mainly in this phase.

The present and future of the design requires an increasingly greater use of the BIM (Building Information Modelling) tool, which uses 3D modelling, allowing a better accuracy of design, costs and better maintenance and management options for the infrastructure.

Based on:

"Linee guida ed esemplificazioni per la progettazione e realizzazione delle linee e della rete ferroviaria di alta velocità a livello di sistema integrato" (*Guidelines and examples for the engineerting, design and realisation of high-speed railway lines and the related network on an integrated system level*)

by Michele Pantaleo, M.Sc. Civ. Eng., summarized by Gilberto Zara, M.Sc. Mech. Eng., in December 2022- April 2023, revised by Simona Gurrì, M.Sc. Mech Eng., Ph.D. candidate and prof. Bruno Dalla Chiara, June 2023