State-of-the-Art on the Use of Bituminous Subballast on European High-Speed Rail Lines

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Technical University of Lisbon (IST)
INDEX

1.  CURRENT HIGH-SPEED TRACK DESIGN TRENDS AND CHALLENGES (SPANISH CASE STUDY).

2.  THE USE OF BITUMINOUS SUBBALLAST IN THE ROME-FLORENCE LINE

3.  SPANISH STUDIES ON THE INTEREST OF USING A BITUMINOUS SUBBALLAST

4.  CURRENT APPLICATION OF BITUMINOUS SUBBALLAST IN EUROPE
European HS Network

Situation as at 02.2008

Information given by the Railways

- $v \geq 250 \text{ km/h}$
- $180 < v < 250 \text{ km/h}$
- Other lines

1st generation
FIRST GENERATION OF HIGH-SPEED BALLASTED TRACKS

FRANCE
- TGV only; Reduced Nº structures; Fast construction
- Low stiffness of the fastening system
- High stiffness of the setting bed

GERMANY
- Mixed traffic; High Nº structures; Slow construction
- Very high stiffness of the fastening system
- Very high stiffness of the setting bed

ITALY
- Mixed traffic; High Nº structures; Slow construction
- Average stiffness of the fastening system
- Very high stiffness of the setting bed

SPAIN
- Mixed traffic; Reduced Nº structures; Very fast construction
- Very high stiffness of the fastening system
- High stiffness of the setting bed
CURRENT HIGH-SPEED TRACK DESIGN IN EUROPE

HIGH-SPEED BALLASTED TRACK STRUCTURE IN EUROPE

RAIL UIC60

RAILPAD VERTICAL STIFFNESS
30 kN/mm to 500 kN/mm

SLEEPER (TWIN BLOCK or MONOBLOCK)

Weight: Effective area:
245 kg 0.24m²

300-400kg 0.30-0.40m²

SLEEPER SPACING: 0.60 - 0.63m

SETTING BED

BALLAST: Size distribution (mm) → 25/50, 23/63, 30/60
Minimum thickness (cm) → 30 to 40 cm

SUB-BALLAST: GRANULAR-ONLY LAYER (except Italy)
Minimum thickness (cm) → 20 to 70 cm

Required Bearing Capacity: 80 to 120 MPa (top of sub-ballast)
Typical Maintenance problems (track geometry) are due to bearing capacity variations (known since the beginning).

How much does these problems cost? Is it worth to fix it?
Very few studies published concerning the Influence of track structural configuration on track maintenance needs in high-speed lines

ANALYSIS OF THE MAINTENANCE NEEDS OF A HIGH-SPEED LINE (during 15 years)

**Database (CENIT-UPC):**

Madrid-Sevilla → 942 km of single track

- Maintenance works records during the first 15 years of operation (1992-2007)
- Dynamic and geometric track inspection records in the first 15 years of operation (1992-2007)

-180 records-
TRAFFIC IN THE MADRID-SEVILLE LINE (ROLLING STOCK)

**AVE TRAINS:** Max. wheel load → 17,2t
Unsprung mass: 3,94 ton /motored bogie; 3,66 ton / trailing bogie

**TALGO 200 TRAINS:**
Max. wheel load → 22,5 t
Unsprung mass → 5,6 ton /motored bogie
2,6 ton / trailing bogie
TRAFFIC IN THE MADRID-SEVILLE LINE (SPEED)

Mora

Maintenance Centre

Calatrava

Hornachuelos

Kilometer

Speed (Km/h)

0
50
100
150
200
250
300
350

0
15
30
45
60
75
90
105
120
135
150
165
180
195
210
225
240
255
270
285
300
315
330
345
360
375
390
405
420
435
450
465

Ave Speed (km/h)
Talgo Speed (km/h)

Paulo F. Teixeira (2009) - State-of-the-Art on the Use of Bituminous Subballast on European High-Speed Rail Lines -
Nowadays about 50 trains /day (25,000 gross ton/day/direction): Modest traffic when compared to other European high-speed lines.
Madrid-Sevilla High-speed line Maintenance costs

TRACK SYSTEM (40% of total maintenance costs):

41% - Tamping, profiling, stabiliz.

Mean cycles?
### Dados recompilados (operações de ataque de via pesado)

<table>
<thead>
<tr>
<th>Ano operação</th>
<th>VIA 1</th>
<th>VIA 2</th>
</tr>
</thead>
<tbody>
<tr>
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<td>15</td>
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<tr>
<td>16</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### TRACK GEOMETRY MAINTENANCE WORKS

- **Hornachuelos**
- **Calatrava**

**Densidade de bateos (km bateados/km de linha/mes)**

- **CALAT+HORN**
- **Polinómica (CALAT+HORN)**

<table>
<thead>
<tr>
<th>Data</th>
<th>VIA 1</th>
<th>VIA 2</th>
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</thead>
<tbody>
<tr>
<td>01/01/92</td>
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<td></td>
</tr>
<tr>
<td>01/01/94</td>
<td></td>
<td></td>
</tr>
<tr>
<td>01/01/96</td>
<td></td>
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<td>01/01/98</td>
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<tr>
<td>01/01/00</td>
<td></td>
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<tr>
<td>01/01/02</td>
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<tr>
<td>01/01/04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>01/01/06</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
GENERAL EVOLUTION OF THE MAINTENANCE OPERATIONS

Track length annually tamped (km)

```

CALATRAVA
147x2 = 294 km
95
95
= 32%

HORNACHUELOS
154x2 = 308 km
170
170
= 55%

MAINTENANCE BASE SECTION | TRACK KILOMETRES | AVERAGE TRACK LENGTH TAMPED ANNUALLY (KM)* | LENGTH TAMPED / TRACK LENGTH
---|---|---|---
CALATRAVA | 147x2 = 294 km | 95 | 95
HORNACHUELOS | 154x2 = 308 km | 170 | 170
```

On condition

Traffic

Speed

Maintenance

Greater tamping needs in Hornachuelos section?

High embankment height in the Hornachuelos section

<table>
<thead>
<tr>
<th>LINE SECTION CORRESPONDING TO MAINTENANCE BASE AT</th>
<th>EMBANKMENT HEIGHT (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt; 1</td>
</tr>
<tr>
<td>CALATRAVA</td>
<td>70%</td>
</tr>
<tr>
<td>HORNACHUELOS</td>
<td>60%</td>
</tr>
</tbody>
</table>

18%
MAINTENANCE WORKS

INFLUENCE OF THE EMBANKMENT HEIGHT

Average Values for each Track

Average Value of the whole line

A. López Pita, P. Teixeira, Ubalde L. et al. (JRRT, 2007).
MAINTENANCE WORKS

INFLUENCE OF THE HETEROGENEITIES

Difficult to correlate – depends on maintenance work policy
REQUIRED TRACK GEOMETRIC QUALITY

UIC 518 standards:

- **QN1 quality level**: Correction of the defects as part of ordinary track maintenance work.
- **QN2 quality level**: Program maintenance in the short runs to remove defects.
- **QN3 quality level**: Acceptable, but undesirable (high priority for correction).

For $200 < V_{\text{máx}} < 300 \text{ km/h}$

<table>
<thead>
<tr>
<th>SPECIFIC DEFECTS</th>
<th>QN1 (mm)</th>
<th>QN2 (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LONGITUDINAL LEVELING ALIGNMENT</td>
<td>4.0</td>
<td>8.0</td>
</tr>
<tr>
<td></td>
<td>4.0</td>
<td>6.0</td>
</tr>
<tr>
<td>AVERAGE DEFECTS IN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LONGITUDINAL LEVELLING ALIGNMENT</td>
<td>1.0</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>0.7</td>
<td>1.0</td>
</tr>
</tbody>
</table>

GENERAL EVOLUTION OF TRACK QUALITY

- Madrid-Seville (1992-2002): 90% of the track above QN2 level
ANALYSIS OF THE GEOMETRICAL QUALITY

Standard deviation (NL 3-25m) - Longitudinal levelling

VÍA 1

VÍA 2

No hay viaducto ni transición
Viaduct
Transition

No viaduct or transition

Valor medio de la desviación estándar de la señal medida en tramos de 200 m (mm)

2001 2002 2003 2004 2005
enero julio

2005 2006

TOTAL

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**ANALYSIS OF DYNAMIC TRACK INSPECTION RECORDS**

150 inspections in the period 1992-2002 (15 per year)

- **a\(_{vv}\):** vertical accelerations on vehicle body
- **a\(_{TV}\):** transversal accelerations on vehicle body
- **a\(_{VA}\):** vertical accelerations on axle box
- **a\(_{LB}\):** lateral accelerations on the bogie

---

<table>
<thead>
<tr>
<th>ACCELERATION (m/s(^2))</th>
<th>RECOMMENDED ACTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>a(_{vv})</td>
<td></td>
</tr>
<tr>
<td>&lt; 1</td>
<td>Normal level of control</td>
</tr>
<tr>
<td>From 1 to 2</td>
<td>Thorough level of control</td>
</tr>
<tr>
<td>a(_{TV})</td>
<td></td>
</tr>
<tr>
<td>&lt; 1.5</td>
<td></td>
</tr>
<tr>
<td>From 1.6 to 2</td>
<td></td>
</tr>
<tr>
<td>a(_{VA})</td>
<td></td>
</tr>
<tr>
<td>30 &lt; a(_{VA}) &lt; 50</td>
<td>Programmed correction</td>
</tr>
<tr>
<td>2 &lt; a(_{lb}) &lt; 4</td>
<td>Immediate correction</td>
</tr>
<tr>
<td>a(_{lb})</td>
<td></td>
</tr>
<tr>
<td>&gt; 6</td>
<td></td>
</tr>
<tr>
<td>&gt; 70</td>
<td></td>
</tr>
</tbody>
</table>

“exceedance level density”

Nº of times the intervention level was exceeded / km / nº of inspections
Distribution of “exceedance level”

Percentage of exceedings (dynamic auscultation)

- Mora Section
- Calatrava Section
- Hornachuelos Section
- Whole Track 2

Lateral accelerations – Bogie
Transversal accelerations – vehicle body
Vertical accelerations – vehicle body
Vertical accelerations – axle box

70%
ANALYSIS OF DYNAMIC TRACK INSPECTION RECORDS

Distribution of “exceedance level” along the time in one section

- Need to correlate with maintenance operations and track section features (presence of switches, expansion equipment, viaducts, embankments,...)

![Graph showing distribution of exceedance level over time](image.png)
Distribution of “exceedance level” along the time in one section → DISPERSION

Need to correlate with maintenance operations and track section features (presence of switches, expansion equipment, viaducts, embankments,...)
## Division of the line into 10m sections → infrastructure characteristics

(switches and expansion device were filtered)

<table>
<thead>
<tr>
<th>TRACK SECTION CONSIDERED</th>
<th>EXCEEDANCE LEVEL DENSITY (EXCEEDANCE Nº/KM OF TRACK/INSPECTION)</th>
<th>RELATIVE RATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Track section without any switches, expansion devices, bridges or embankments</td>
<td>0.075</td>
<td>100</td>
</tr>
<tr>
<td>Track section on embankment, without any switches, expansion devices or bridges</td>
<td>0.094</td>
<td>125</td>
</tr>
<tr>
<td>Track section on bridge</td>
<td>0.159</td>
<td>194</td>
</tr>
<tr>
<td>Track section at beginning of bridge-natural infrastructure transition</td>
<td>0.259</td>
<td>315</td>
</tr>
<tr>
<td>Track section over culvert</td>
<td>0.487</td>
<td>594</td>
</tr>
</tbody>
</table>

- If we consider the overall transition section (40m) → track deterioration is 6 times higher than in plain track...
How much can we save if we fix those problems?
HIGH SPEED TRACK DESIGN FOR LOW MAINTENANCE COSTS

Intermediate level of improvement of high-speed track design

Increasing track superstructure elasticity (low-stiffness pads, USPs..)

Improving track substructure bearing capacity

Slab track

Maintenance costs

Construction costs

Conventional high-speed track

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Degradation (ballast settlement) \( \delta = f (\sigma_b, \gamma) \)

- **Conventional track**: rail UIC 60, sleeper B 70, rail pad Zw 687a (spring coefficient 500 kN/mm)

- **Improved track**: rail UIC 60, sleeper B 75, high resilient rail fastening system (spring coefficient 27 kN/mm)

**Main lines**: Hannover–Würzburg

Stuttgart - Mannheim (1991)

**Increased resiliency due to maintenance behaviour**

**Test sections**: Comparison of the long term behaviour between ballastless and ballasted track

**Vibration velocity**

**Frequency**

**ICE V = 250 km/h**

**W. Stahl (2004)**
Puissance dissipée dans la voie sous une roue de $8 \times 10^4$ N de charge roulant à 300 km/h.

Cas d'un rail d'inertie $I = 0.2 \times 10^4$ m$^4$ (rail UIC 50).

Cas d'un rail d'inertie $I = 0.4 \times 10^4$ m$^4$ (rail "lourd").

LGV PSE $\begin{cases} I = 0.3 \times 10^4 \text{ m}^4 \text{ (rail UIC 60).} \\ k = 4.8 \times 10^7 \text{ N/m}^2 \end{cases}$

French TGV trials (Sauvage and Fortin, 1982)
Optimization of Track Vertical Stiffness for High-Speed Lines (Track Superstructure Design)

\[ K = \frac{Q}{y_m} \]

- \( K \): vertical stiffness of the track, kN/mm
- \( Q \): quasi-static load, kN
- \( y_m \): maximum deformation of the rail surface, mm

\( K = f[k \text{ (rail)}; k \text{ (sleeper)}; k \text{ (pad)}; k \text{ (ballast + subgrade)}] \)

Non significant

Structural requirements
- Natural foundation: Good bearing capacity
- Bridges and tunnels: Rigid

\( k \text{ (pad)} \) optimal?

Operation costs

\[ K (\text{optim.}) = f(\text{traffic-characteristics, speeds and volume-, dynamic loads, maintenance policy, energy costs}) \]

Standard high-speed track

\[ K \approx 70 \text{ to } 80 \text{ kN/mm} \]

Track stiffness

Optimal railpad vertical stiffness \( (k_{pad}) \)

\[ k_{pad} \approx 60 \text{ kN/mm} \]

Source: Teixeira / López Pita, 2003
Stiffness of the ballast support (HSL):

\[ E_{v2} > 80 \text{ a } 120 \quad \text{to} \quad E_{v2} > 180 \text{ MPa (granular cement)} \]

\[ E_{v2} > 200 \text{ MPa (bituminous)} \]
INDEX

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2. THE USE OF BITUMINOUS SUBBALLAST IN THE ROME-FLORENCE LINE

3. SPANISH STUDIES ON THE INTEREST OF USING A BITUMINOUS SUBBALLAST

4. APPLICATION OF BITUMINOUS SUBBALLAST IN EUROPE
The use of bituminous sub-ballast appears as an alternative to the granular layer treated with cement proposed by some contractors, due to:

- **Increase on work performance** on the construction of the layer
- **Easy to run through the platform** with heavy vehicle once built, no matter what climatic conditions were found
- **The lack of granular material on the construction area**
  
  **Savings on the transport of material**
  (bituminous layer needed aprox. 40% less granular material)
USE OF BITUMINOUS SUB-BALLAST IN ITALY

⇒ The technical solution proposed by contractors was accepted by the technical department of FS

⇒ 3 trials were built:

⇒ 5 km en el tramo Figline-Firenze (□)

⇒ 3 km en el tramo Barsano-Città de Pieve (▲)

⇒ 11,2 km en el tramo Settebagni-Stimigliano (○)

⇒ Good practical results ⇒ Bituminous sub-ballast was accepted as an option for the next sections of the Rome-Florence line and future lines
LONG TERM BEHAVIOUR

- Good structural behaviour short and long term (although lack of studies comparing the behaviour of bituminous subballast vs granular subballast).

- Overall track renewal already performed in the first sections:
  - Still no evidence of track fatigue limit
  - Bituminous subballast was in better state than expected (ballast protection)
  - No major technical problem when replacing the ballast layer
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4. APPLICATION OF BITUMINOUS SUBBALLAST IN EUROPE
Could the use of bituminous sub-ballast improve current HS ballasted track design?

Could this solution be feasible for future Spanish high-speed lines?

A) What should be the design characteristics to meet Spanish HS standards?
B) In what terms these solutions can reduce track maintenance needs?
C) In what conditions it is more cost-effective than using a granular sub-ballast?
A) TRACK DESIGN WITH BITUMINOUS SUBBALLAST

Multilayer (KENTRACK)

Linear elasticity and Non linear elasticity

FEM (Ansys, CESAR)  Elasto-plasticity
A) TRACK DESIGN WITH BITUMINOUS SUBBALLAST

- **Algorithm** (Bachiller, 2004) to calculate the **dynamic overloads** produced by the different high-speed vehicles, considering the following parameters:

  - Geometric quality of the track (longitudinal level)
  - Track vertical stiffness
  - Distribution of masses of the vehicle
  - Maximum running speed (up to 350 km/h)

- **Fórmula de Prud’Homme ampliada**

  - **DEFECTOS DEL CARRIL**
    - Parámetros del aspecto (m³):
      - $A = 0.46e-6$
      - $B = 0.3$
    - Desviación típica de los defectos: $\sigma = 0.90$ mm

  - **CARACTERÍSTICAS DEL SISTEMA**
    - Masa no suspendida (Kg): $M_s = 2.050,00$
    - Masa semisuspendida (Kg): $Ms = 1.210,00$
    - Eje motor
    - Eje remolque: $m = 2.000,00$
    - Eje remolque: $1.525,00$
  
  - **Suspensión**
    - $K_s (kN/m)$
    - $C_s (kN/m)$
    - $f (Hz)$
    - $e (%)$
    - 1ª: $600,00$  $4,00$  $1.04$  $2.19$
    - 2ª: $2300,00$  $5,00$  $5.94$  $4.74$

  - **Características de la VÍA**
    - Rigidez vertical de la vía (l/mm)
    - $f (Hz)$
    - $e (%)$
    - $h = 6$  $38.12$  $20.00$

  - **Masa no suspendida $M_s$**
  
  - **Masa semisuspendida $Ms$**

  - **Masa suspendida $M_s$**

  - **$\omega_1 = \sqrt{K_1 / M_s}$** frecuencia propia
  - $\xi_1$ factor de amortiguamiento

  - **$\omega_2 = \sqrt{K_2 / M_s}$** frecuencia propia
  - $\xi_2$ factor de amortiguamiento

- **Defectos aleatorios del carril $S(\Omega)$**

- **ACEPTAR**
A) TRACK DESIGN WITH BITUMINOUS SUBBALLAST

VEHICLES CONSIDERED IN THIS STUDY

1. **AVE 101** - Alstom – Vmáx = 300 km/h
   (Madrid – Sevilla)
A) TRACK DESIGN WITH BITUMINOUS SUBBALLAST

VEHICLES CONSIDERED IN THIS STUDY

2. **AVE 102** - TALGO / BOMBARDIER – $V_{\text{máx.}} = 350 \text{ km/h}$

(Madrid – Barcelona)
A) TRACK DESIGN WITH BITUMINOUS SUBBALLAST

VEHICLES CONSIDERED IN THIS STUDY

3. AVE 103 - SIEMENS – Vmáx. = 350 km/h
   (Madrid – Barcelona)
A) TRACK DESIGN WITH BITUMINOUS SUBBALLAST

RESULTS for: Subgrade vertical stress level

A thickness of 12cm a 14cm can be considered, at least, equivalent to the 30cm granular layer required on the spanish high-speed standards.
A) TRACK DESIGN WITH BITUMINOUS SUBBALLAST

- Road traffic design (construction period)
- Subballast fatigue

Bituminous sub-ballast (12 cm – 14 cm) will fulfill the usual HS track requirements.
A) TRACK DESIGN WITH BITUMINOUS SUBBALLAST

Bituminous subballast (conventional road base mix)*

Form layer / Frost protection layer

Ballast

Sugrade
Reference: QS3 soil (min. $E_{v2}=80\text{MPa}$)

* e.g. Spanish S20 mixture – according to Spanish roadway standards

Thicknesses (Minimum values)

- 35 cm
- 12-14 cm
- 30 cm

* e.g. Spanish S20 mixture – according to Spanish roadway standards
B) POSSIBLE INTEREST OF BITUMINOUS SUBBALLAST

POSSIBLE ADVANTAGES RELATED TO TRACK MAINTENANCE COSTS AND LIFE CYCLE

- Track mean settlement
- Differential settlements (vertical stiffness variations)
- Subgrade life cycle

OTHER ADVANTAGES...

- Construction process (no damages during the construction period) and quality control
B) POSSIBLE INTEREST OF BITUMINOUS SUBBALLAST

TRACK MEAN SETTLEMENT

Source: Selig & Waters, 1994
B) POSSIBLE INTEREST OF BITUMINOUS SUBBALLAST

Vertical accelerations in ballast for v=300km/h

Comparing Vertical accelerations inside tracks with Granular and Bituminous Sub-ballast for speeds of 300 and 350 km/h

Vibration attenuation at very high speeds

P. Ferreira - IST (2007)
B) POSSIBLE INTEREST OF BITUMINOUS SUBBALLAST

-Experimental results-

Ground vibration speed (mm/sec)

Without bituminous sub-ballast: 0.6 to 1
With Bituminous sub-ballast: 0.3 to 0.4

Source: Buonanno (2000)
Buonanno & Mele (2000)

Undergoing experimental measurements in France (TGV Est) and Italy (Torino-Novara)
B) POSSIBLE INTEREST OF BITUMINOUS SUBBALLAST
Bearing capacity homogenization

Source: Bergreen (Banverket)
B) POSSIBLE INTEREST OF BITUMINOUS SUBBALLAST

Rome-Florence high-speed line
- Analysis of track geometry record (4 years) -

Study (2005-2006):
CENIT-UPC & UNIROMA (DITS)

- 2 equivalent sections with 40km length each
  - One with bituminous sub-ballast
  - One with cement-treated granular sub-ballast
- Same traffic
- Same superstructure
- Evaluate possible benefits of bituminous sub-ballast

Source: CENIT-UPC / UNIROMA (DITS)
B) POSSIBLE INTEREST OF BITUMINOUS SUBBALLAST

Rome-Florence high-speed line
- Analysis of track geometry record (4 years) -

⇒ Difficult to find solid conclusions in plain track

Source: CENIT-UPC / UNIROMA (DITS)
B) POSSIBLE INTEREST OF BITUMINOUS SUBBALLAST

Rome-Florence high-speed line
- Analysis of track geometry record (4 years) -

Granular sub-ballast treated with cement

Bituminous sub-ballast

Source: CENIT-UPC / UNIROMA (DITS)

Bituminous sub-ballast seems to be positive to reduce the effects of abrupt vertical stiffness variations
B) POSSIBLE INTEREST OF BITUMINOUS SUBBALLAST

- Track long-term behaviour depends on the evolution of formation quality

LONG-TERM BEHAVIOUR

Granular sub-ballast
Subgrade

Bituminous sub-ballast
Subgrade

- Bituminous sub-ballast offers better protection against environmental conditions along subgrade lifetime:
  - Water proof
  - Helps maintaining moisture content (Rose et al., 2003)
  - Longer life cycle of the subgrade
  - Quantitative estimation of this impact need some field tests results
B) POSSIBLE INTEREST OF BITUMINOUS SUBBALLAST

SUBGRADE LIFE CYCLE

⇒ Moisture content near optimum moisture content with bituminous sub-ballast (Long-term monitoring at 2 sites, after 15-16 years)

Source: Rose, Brown et al., 2000

FIGURE 8 Relationship between measured in situ moisture contents and optimum moisture contents from the standard Proctor compaction test for the roadbed or subgrade samples.
Variation of moisture content and track settlement

(CODE-BRIGHT)

IST - UPC
In synthesis, it is expected that track maintenance costs should be lower by using a bituminous sub-ballast.

Need to balance benefits in Maintenance with higher investments…
Is that so? How much?

ANALYSIS OF THE INVESTMENT (CONSTRUCTION) COSTS
(In Spain)
Evaluation of costs for granular sub-ballast

Source: Current tracks under construction / recently built

RESULTS (Synthesis)

⇒ Cost highly sensitive to distances from quarry

(local availability of material is a key factor)

Evaluation of costs for bituminous sub-ballast

Source: Current roadways under construction / recently built

RESULTS (Synthesis)

⇒ Cost sensitive to prices of bitumen (petroleum)
3. ANALYSIS OF THE INVESTMENT (CONSTRUCTION) COSTS

Evaluation of costs for granular sub-ballast

Evaluation of costs for bituminous sub-ballast

Granular layer Cost
(€/m³)

Bituminous layer cost

Bitumen content

-30% -20% -10% 0% 10% 20% 30%

4,00%
4,25%
4,50%
4,75%
5,00%

Bitumen cost
For transport distances higher than 70 to 80 km, bituminous layer gets less expansive…
3. ANALYSIS OF THE INVESTMENT (CONSTRUCTION) COSTS

Provgnosis of costs for future High-Speed lines to be built in Spain …

Density of quarries

“Factibility indicator” of finding suitable granular material
3. ANALYSIS OF THE INVESTMENT (CONSTRUCTION) COSTS

\( \Rightarrow \) Prognosis of costs for future High-Speed lines to be built in Spain ...

\( \Rightarrow \) Indicator calibrated with data of lines under construction \( \Rightarrow \) range of transport distance per region
3. ANALYSIS OF THE INVESTMENT (CONSTRUCTION) COSTS

SAVINGS IN BALLAST MATERIAL…

- Around 200 m³ per km of track → approximately 5% of sub-ballast cost…

SYNTHESIS OF INVESTMENT COSTS

- Confirmed that the use of bituminous might be a cost-effective possible solution (depending on local availability of granular material)

Ballast savings = (Slope with bituminous sub-ballast) - (Slope with granular sub-ballast)

Slope with bituminous sub-ballast (3%)
Slope with granular sub-ballast (5%)

BALAST

hb

SUBGRADE
INDEX

1. CURRENT HIGH-SPEED TRACK DESIGN TRENDS AND CHALLENGES (SPANISH CASE STUDY).

2. THE USE OF BITUMINOUS SUBBALLAST IN THE ROME-FLORENCE LINE

3. SPANISH STUDIES ON THE INTEREST OF USING A BITUMINOUS SUBBALLAST

4. CURRENT APPLICATION OF BITUMINOUS SUBBALLAST IN EUROPE
CURRENT APPLICATION OF BITUMINOUS SUBBALLAST IN EUROPE

• In National design Standards:
  • Switzerland (conventional lines)
  • Czech Republic (conventional lines)
  • Italy (new high-speed lines)

• Under evaluation (test sites) - to be included in future national standards?
  • France (high-speed)
  • Finland
  • Spain (high-speed)
THE USE OF BITUMINOUS SUBBALLAST IN ITALY

- 1.200 km
- 1.900.000 m³ of bituminous material
LAYOUT OF RAILWAY EMBANKMENT

BALLAST

GRASS SOIL $E \geq 20\text{MPa}$

STRONG COMPACTED LAYER cm 30
$E \geq 80\text{MPa}$
$G = 98\%\text{ AASHTO Mod}$

EMBANKMENT
$E \geq 40\text{MPa}$
$G = 95\%\text{ AASHTO Mod}$

DRAIN SOIL LAYER cm 50 $E \geq 20\text{MPa}$

RECLAIMED SOIL

GEOTEXILE

ASPHALT LAYER $h = 12\text{cm}$

EDITING: Arch. M. Icardo
**THE USE OF BITUMINOUS SUBBALLAST IN ITALY**

**Thickness**  
H 12 cm

**Stone Aggregate**
- **Large fraction**
  - LA coefficient < 30%
  - Crushed 90 % min
  - Imbibition coefficient ≤ 0.015 %
- **Fine fraction**
  - Natural sand vol./crusher ratio 1 / 2
  - Equivalent in Sand < 70
- **Filler**
  - Through ASTM 200 sieve = 70 %

**Bitumen**
- **Type** 50 / 70
- **Percentage** 4.1 – 4.7
  - Best possible percentage to establish on the basis of Marshall tests
- **Filler / bitumen volumetric ratio** 1.5 / 2

**Mix**
- **Marshall stability** min 1,000 daN
- **Marshall slippage** 2 - 4 mm
- **Marshall rigidity** min 250 daN/mm²
- **Loss of stability** max 25% (Comparison between stability in original samples and samples placed in water for 24 hours at 60°C)
- **Residual gaps** 3 - 6 %
- **Resistance to indirect traction** > 8 daN/cm²

**Fig. 19 - Grading envelope for asphalt conglomerate**
TECHNICAL VISIT: LINE MILANO-TORINO (NOVARA, MAY 2004)

SUBGRADE + HIGHLY COMPACTED SOIL LAYER ("SUPERCOMPATATTO")
TECHNICAL VISIT: LINE MILANO-TORINO (NOVARA, MAY 2004)

LAYING THE BITUMINOUS MIX
TECHNICAL VISIT: LINE MILANO-TORINO (NOVARA, MAY 2004)

COMPACTATION
State-of-the-Art on the Use of Bituminous Subballast on European High-Speed Rail Lines

Paulo F. Teixeira (2009)
INFRAESTRUCTURE AFTER LAYING THE BITUMINOUS LAYER (1/2)

“Supercompattato”

Bituminous sub-ballast
CURRENT TRIAL SECTIONS IN SPAIN

Barcelona-french Border HS line

Sils-Riudellots
CURRENT TRIAL SECTIONS IN SPAIN
CURRENT TRIAL SECTIONS IN SPAIN

2 different bituminous mixes

S25  D20
State-of-the-Art on the Use of Bituminous Subballast on European High-Speed Rail Lines

Paulo F. Teixeira (2009)
FIRST APPLICATIONS IN SPAIN

Tramo de vía entre Segovia y Valdestillas donde se aprecia la capa de balasto sobre una capa asfáltica que sustituye al subbalasto
CEDEX – Spanish National Laboratory -
- Full scale Experimental tests -
CURRENT TRIAL SECTION IN FRANCE

TGV Est

High-speed line

30 cm ballast
20 cm unbound gravel base course
50 cm limestone capping layer
Cement treated upper earthworks layers

30 cm ballast layer
14 cm asphalt treated base material
20 cm unbound gravel regulating layer
Cement treated upper earthworks layers

CURRENT TRIAL SECTION IN FRANCE
CURRENT TRIAL SECTION IN FRANCE
CURRENT TRIAL SECTION IN FRANCE

Zone d’expérimentation grave-bitume

Référence
Déblai
Remblai
Aniveau

Accéléromètres sur traverses : 4 fois 10 accéléromètres (1/blochet)
Capteurs de pression sous traverses : 2 fois 2 capteurs de pression (1/blochet)
Jauges de contraintes dans la grave bitume : 8 jauges
Mesure de charge de roue (identification + localisation)
State-of-the-Art on the Use of Bituminous Subballast on European High-Speed Rail Lines

Thanks for your attention !!!

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