William W. Hay Railroad Engineering Seminar

"Maintaining Adequate Trackbed Structural Support – An Important Railway Infrastructure Issue"

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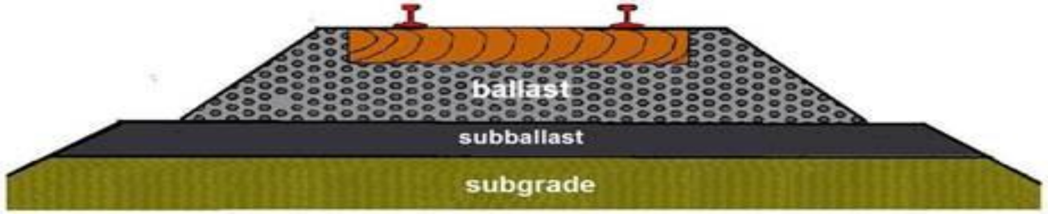
University of Kentucky



Date: Friday, December 5, 2014

Time: Seminar Begins 12:15

Location: Newmark Lab, Yeh Center, Room 2311
University of Illinois at Urbana-Champaign

Sponsored by

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NURail Center

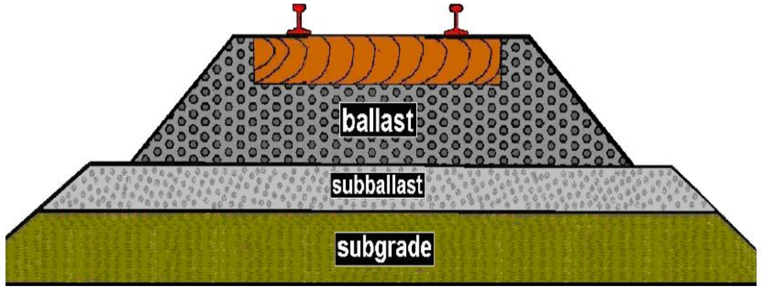
Best wishes to
Jerry for success with
his railroad classes.

5/24/82 W W Hay

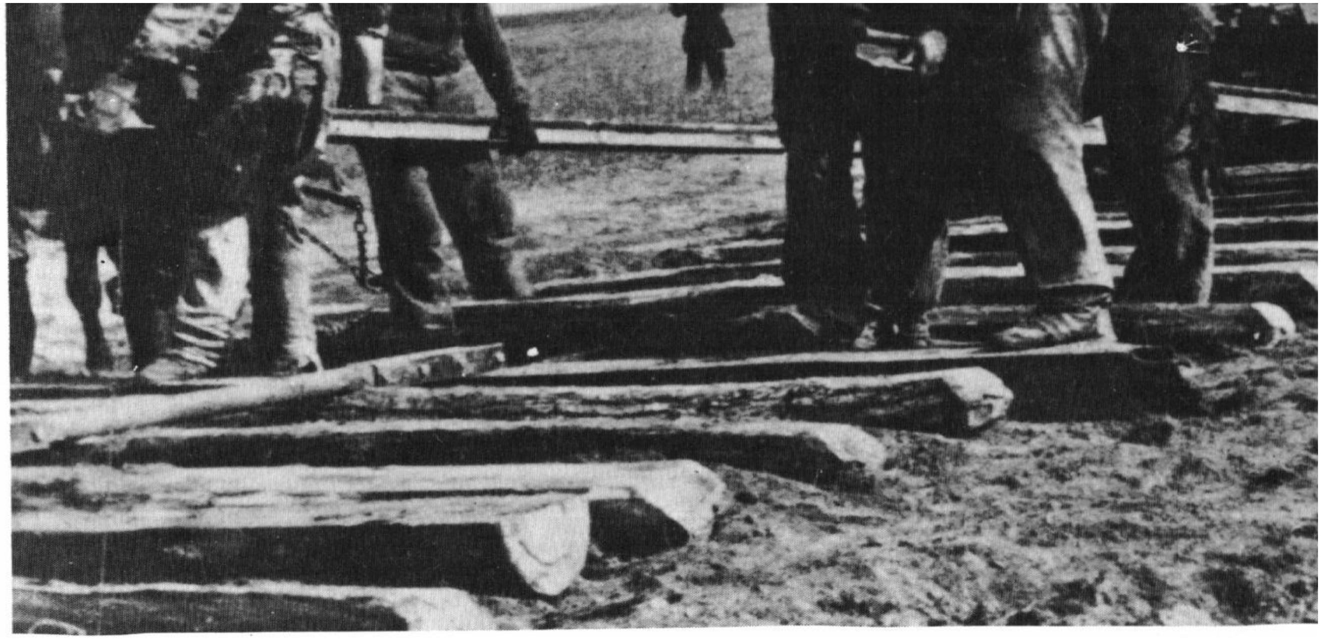
Maintaining Adequate Trackbed Structural Support:
An Important Railway Infrastructure Issue

Outline

- Evolution of Trackbed Designs
- Problems
- Idealized Trackbed/Roadbed Configuration
- Various Structural Design Methods
- Innovative European Practices
- Concluding Comments



Railroad Track and Roadbed Designs in the U. S. -----



Evolved

First

The Track was Laid
on the Natural Ground

Then came the Ballast Rock and Ditches

So the All-Granular Trackbed/Roadbed --- Evolved

And is by far the most prominent type of Track Structure today

Plus larger and better rail

Plus concrete, steel and composite ties

Plus more significant fastenings and OTM

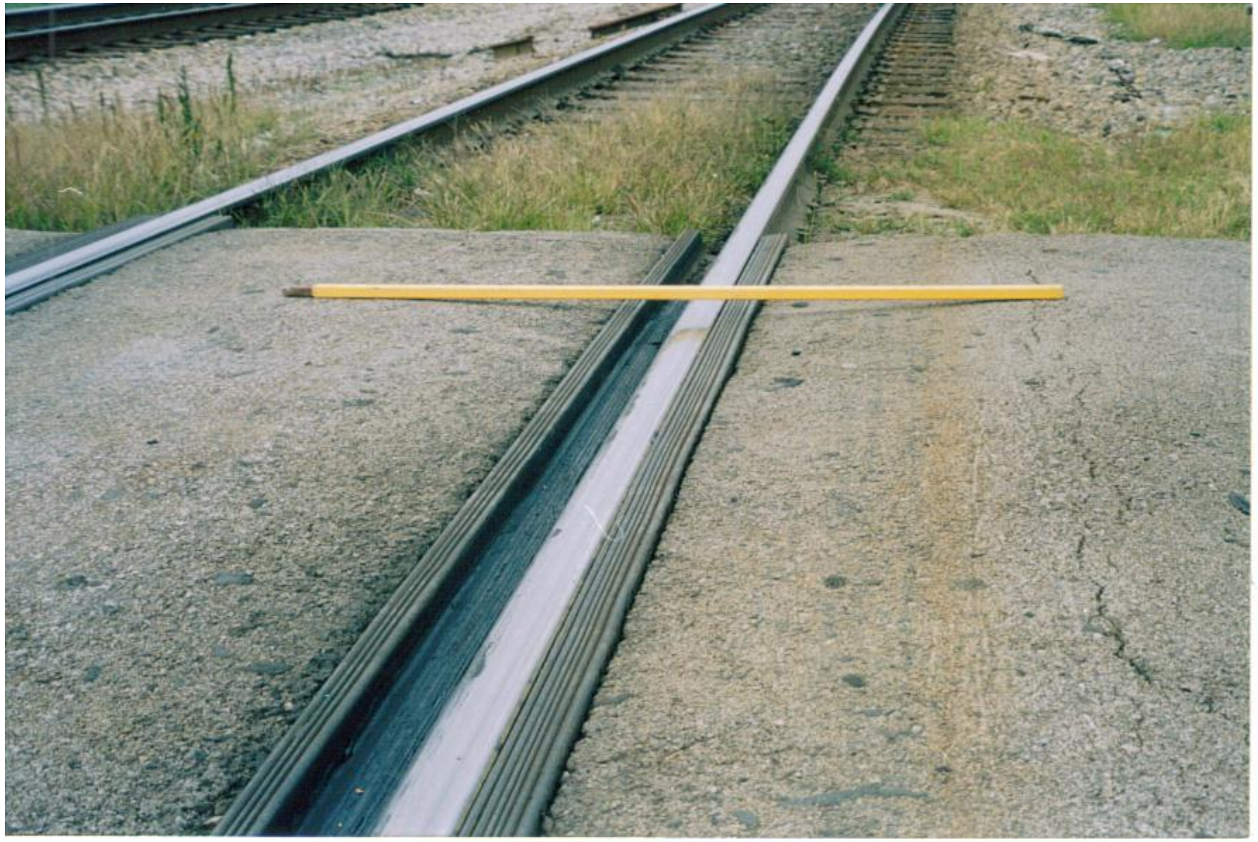
Drainage – Drainage – Drainage ?? OR Support – Support – Support ??

Track Settlement and Pumping

Surface Problem (Cross level)

Profile Trouble Spots

Pumping and Settlement



Settlement

Track Surfacing

Add Ballast

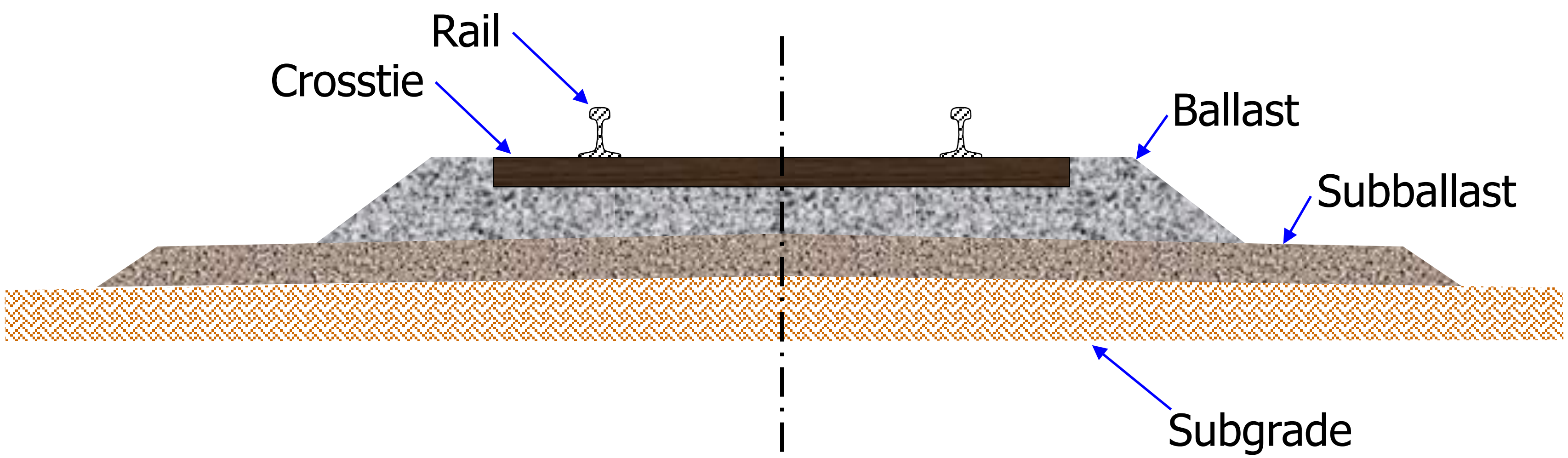
Adjust Ballast

Purpose: Adjust Geometry ---
Horizontally (line) and
Vertically (surface and cross level)

Tamper Pulling Track

Restore Geometry

Idealized Track Cross-Section



- Railroad track and structure are designed to be economical and easy to maintain

Constantly evaluating Alternatives

Benefits compared to Additional Costs

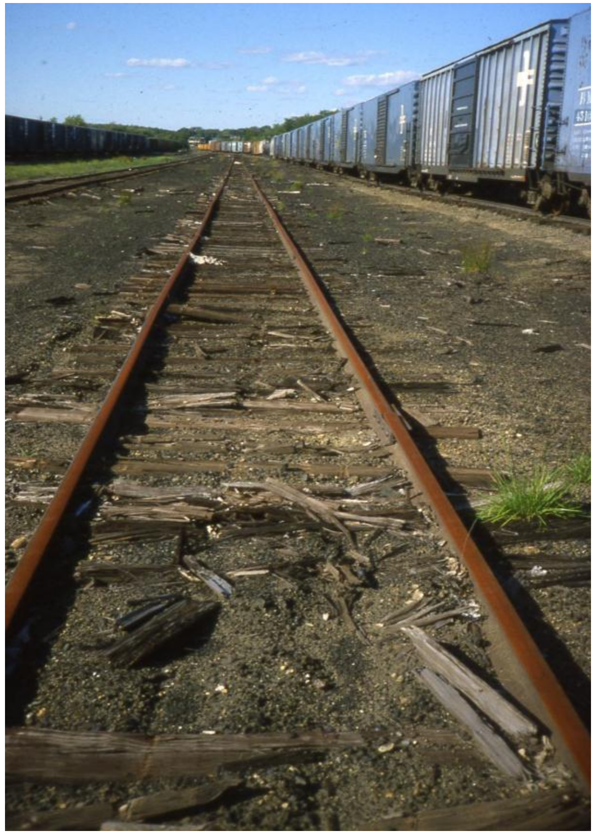
- Basic Requirements
  - Track must support the loadings and guide the train's path

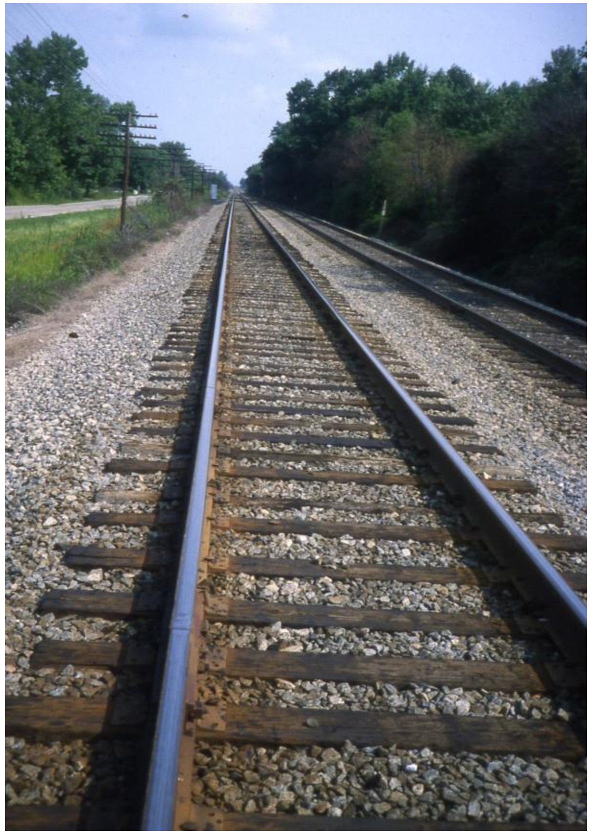
- Track Quality Determines
  - Permissible wheel loadings
  - Safe speed of the train
  - Maintenance of track geometrics
  - Overall safety of operations
  - Dependability/Efficiency of operations
  - FRA Class of Track -- 1,2,3,4,5,6,7,8,9

Class 1 Track
10 mph or less

Class 2 Track
25 mph freight
30 mph passenger

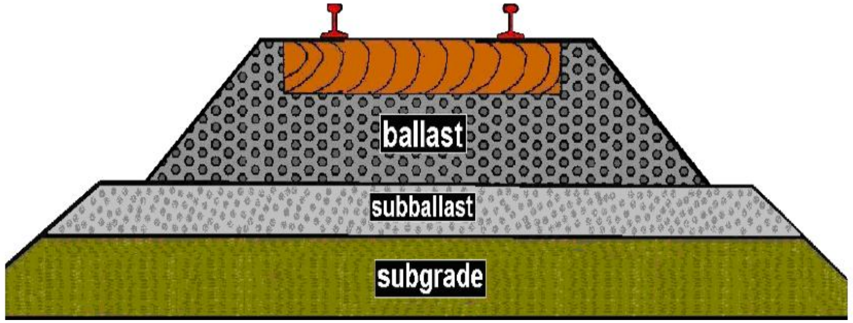
Class 4 Track
60 mph freight
80 mph passenger





Track Functions

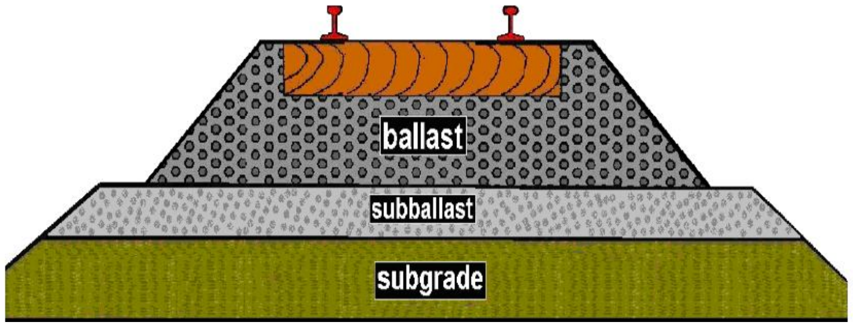
- Maintain vehicles on a fixed guideway
- Provide a high vehicle ride quality
- Withstand and distribute loadings
  - Static (36 tons/axle) or
    (36,000 lbs./wheel)
  - Plus Dynamic (Impact)



Trackbed/Roadbed Functions

Combined as a System

- Ballast
- Subballast
- Subgrade



Support the Track and the Imposed Loadings

Interaction, Vertical Load Distribution, and Deflections

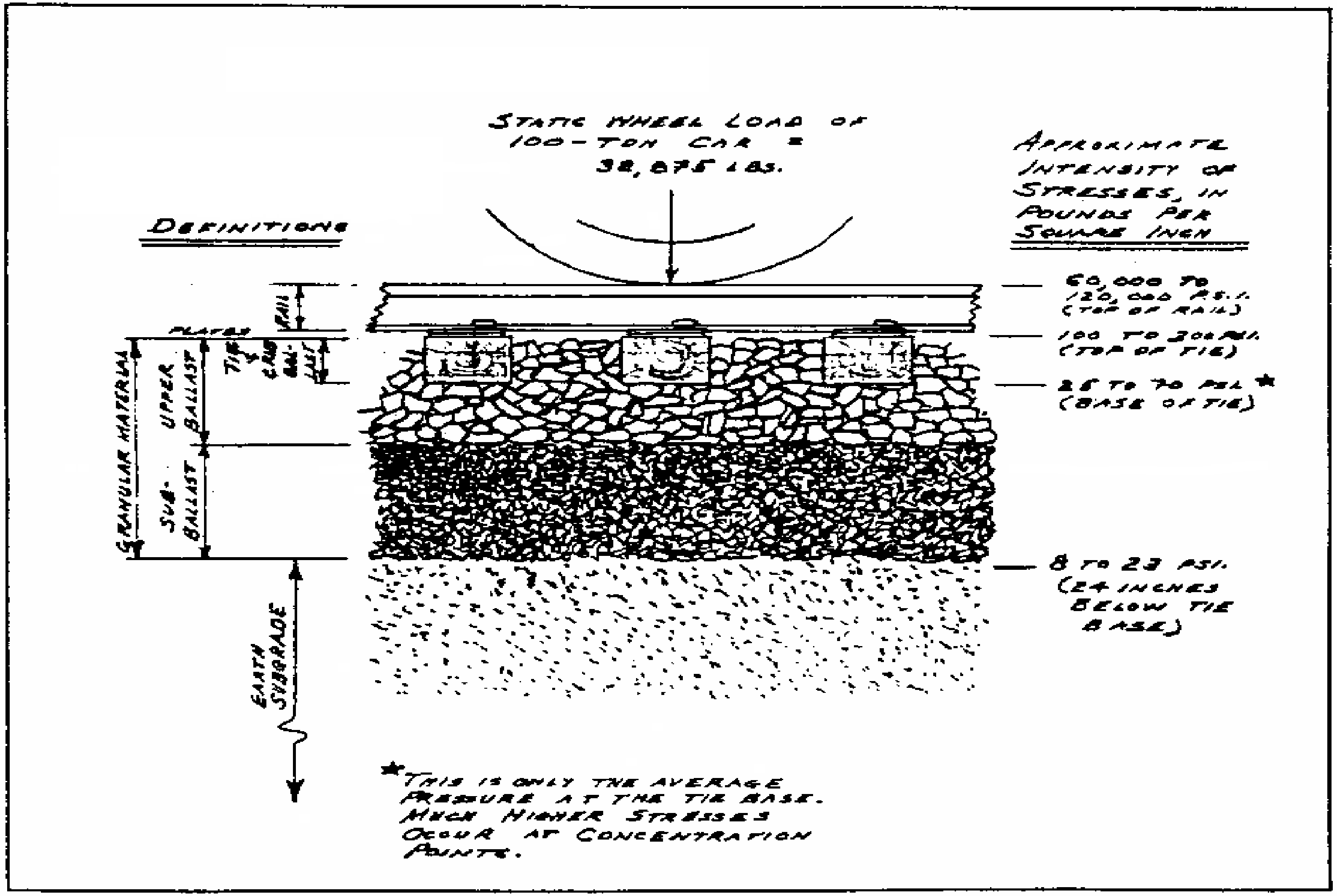
Components do not function independently!

Each component layer must protect the one below.

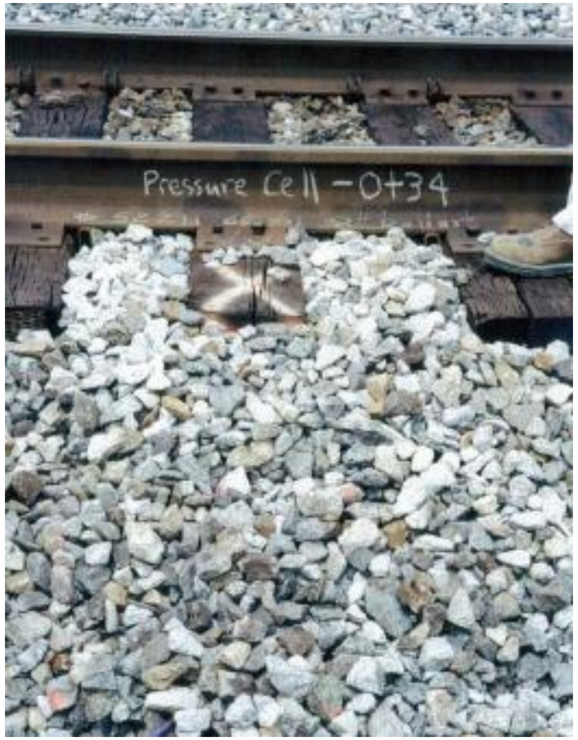
Each component contributes.

It is a System…..

Stress Distribution



Ballast



Supports the Track
Distributes Loadings**
Drains the Track

Provides Resilience
Anchors the Track
Must be Adjustable

Subballast

Similar to highway base material (DGA)

Fine grained – has smaller top size and more fine-size particles than ballast

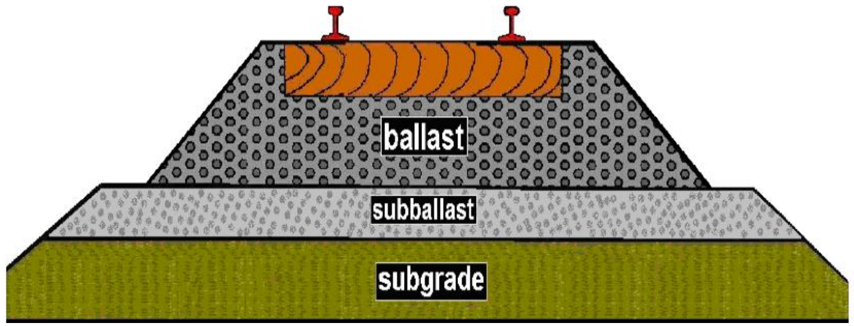
Compacts tight and dense with low % voids

Supports/Confines the ballast
Distributes loadings to subgrade
Separates ballast from subgrade
Waterproofs the subgrade

Use AREMA Recommended Practices

<u>Subgrade</u>

- Supports and distributes the loadings



- Confines the subballast
- Facilitates drainage
- Serves as a working platform for roadbed and trackbed

Can be either <u>foundation</u> or <u>embankment</u>

Subgrade

Use Typical Soils/Geotechnical Technology

Very Important

Subgrade

Subgrades Vary

Must Evaluate

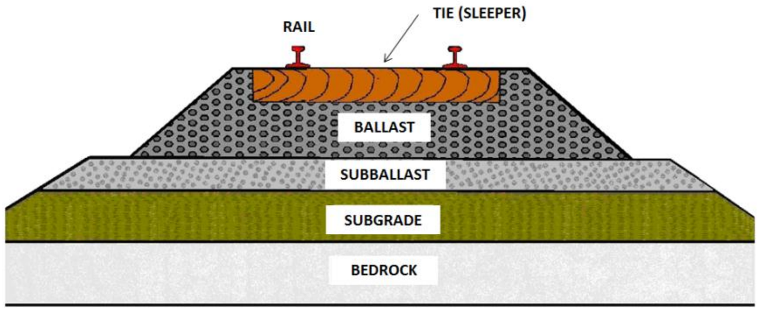
Consider Stabilizing

Top 2 Feet Important

Structural Design

Methods used to design track and cross-section

- Trial and Error – based on experience
- Empirical – based on trial and error
- Empirical/Rational – measure loadings and material properties
- Rational – stress/strain analysis and measurements



Typical All-GranularTrackbed is NOT the permanent way – varies greatly, must be maintained continuously

MANUAL FOR RAILWAY ENGINEERING

- Ch. 1 - Roadway & Ballast
- Ch. 4 - Rail
- Ch. 5 - Track
- Ch. 30 - Ties

- Ch. 7 - Timber Structures
- Ch. 8 - Concrete Structures & Foundations
- Ch. 9 - Seismic Design for Railway Structures
- Ch. 15 - Steel Structures

- Commuter, Transit & High Speed Rail
- Ch. 6 - Buildings & Support Facilities
- Ch. 11 - Commuter and Intercity Rail Systems
- Ch. 12 - Rail Transit
- Ch. 14 - Yards and Terminals
- Ch. 17 - High Speed Rail Systems
- Ch. 18 - Light Density and Short Line Railways
- Ch. 27 - Maintenance-of-Way Work Equipment
- Ch. 33 - Electrical Energy Utilization

- Ch. 2 - Track Measuring Systems
- Ch. 13 - Environmental
- Ch. 16 - Economics of Railway Engineering and Operations
- Ch. 28 - Clearances
- AAR Scale Handbook

www.arema.org

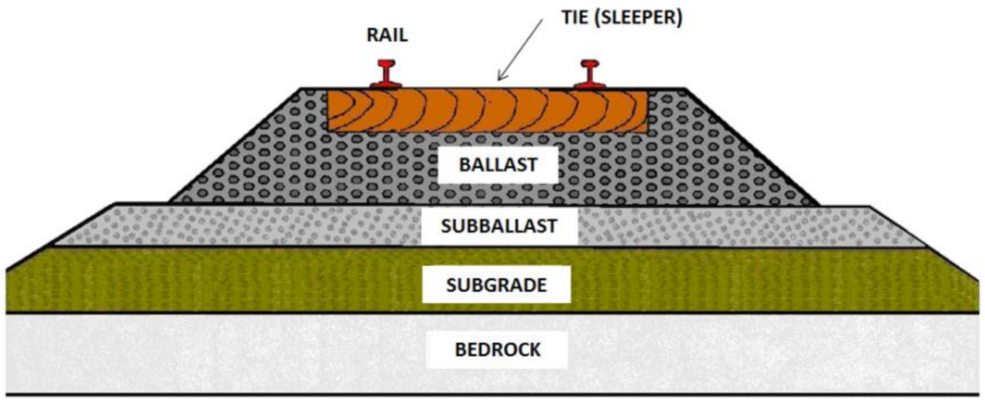
Track Analysis (Pressure Distribution)

- Must determine allowable loads and deformations
- Must determine actual loads and deformations
- Compare and Adjust (component materials and thicknesses)

- Much early work performed by A.N. Talbot and Committee
- Many early researches idealized systems – Winkler, Westergaard, Boussinesq, etc.
- Talbot treated track as a continuous and elastically supported beam
- Computer systems (finite element and layered analysis) have been developed recently
- Geotechnical and Pavement Design Technologies are applied

- Thickness Design
  - Talbot
    - $P_c = 16.8\ P_a / h^{1.25}$

Subgrade Tie



  - Somewhat Arbitrary Standard
  - Mainly Empirical

- Distribution of Pressures
  - For ballast pressure

$$P_a = \frac{2P_{dyn}}{\left(\frac{2}{3}\right)bL} \times \approx 0.40$$

<65 psi

  - Talbot developed empirical formula for subgrade pressure

$$P_c = \frac{16.8P_a}{h^{1.25}}$$

<20 psi

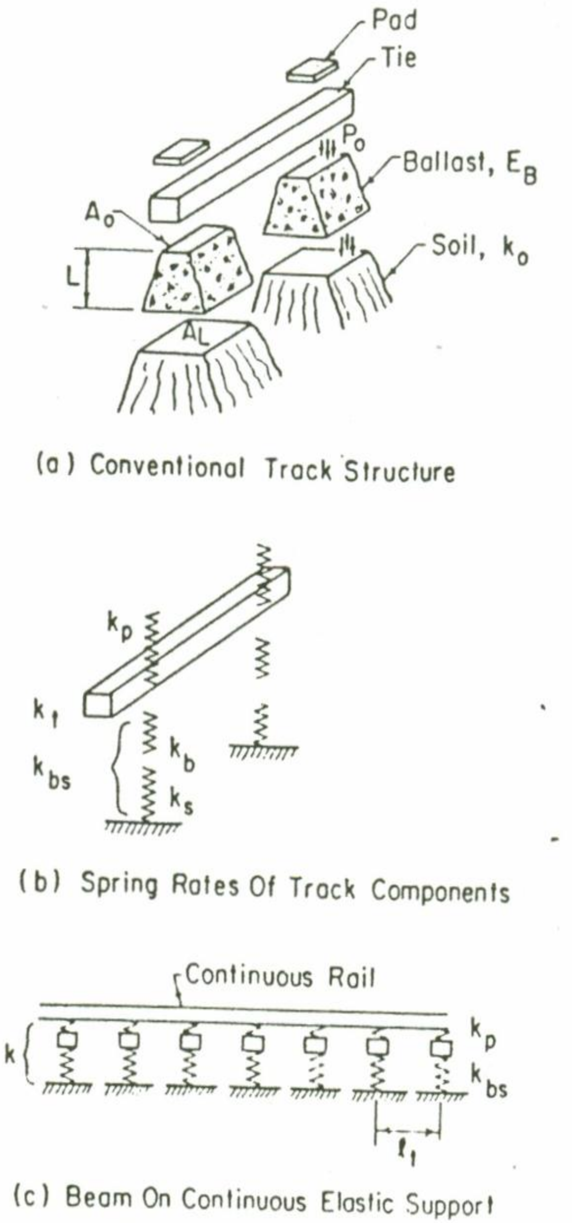


Figure 15.12. Elements of elastic track support models (from H. C. Meacham *et al.*, "Studies for Rail Vehicle Track Structures," Office of High Speed Ground Transportation, Federal Railroad Administration, Report No. FRA-RT-71-45, Washington, D.C., April 30, 1970).

2.11.2.3 Depth of Ballast Plus Sub-ballast

a. The distribution of loads to depth is approximately the same regardless of the granular material. Therefore the combined depth of sub-ballast and ballast is calculated as a single unit to develop the pressure on the subgrade. Talbot developed an empirical formula for vertical pressure exerted by the ballast under the tie at its intercept with the rail at a depth below the bottom surface of the tie.

$$pc = 16.8\ p_a/h^{1.25}$$

where:

p_c = bearing pressure on subgrade including safety factor

p_a = uniformly distributed pressure over tie face

h = depth below face in inches

b. If the tie pressure pa in pounds per square inch and the bearing capacity of the subgrade pc are known, the minimum depth of ballast in inches required to produce a stable structure is:

$$h = (16.8\ p_a/p_c)^{4/5}$$

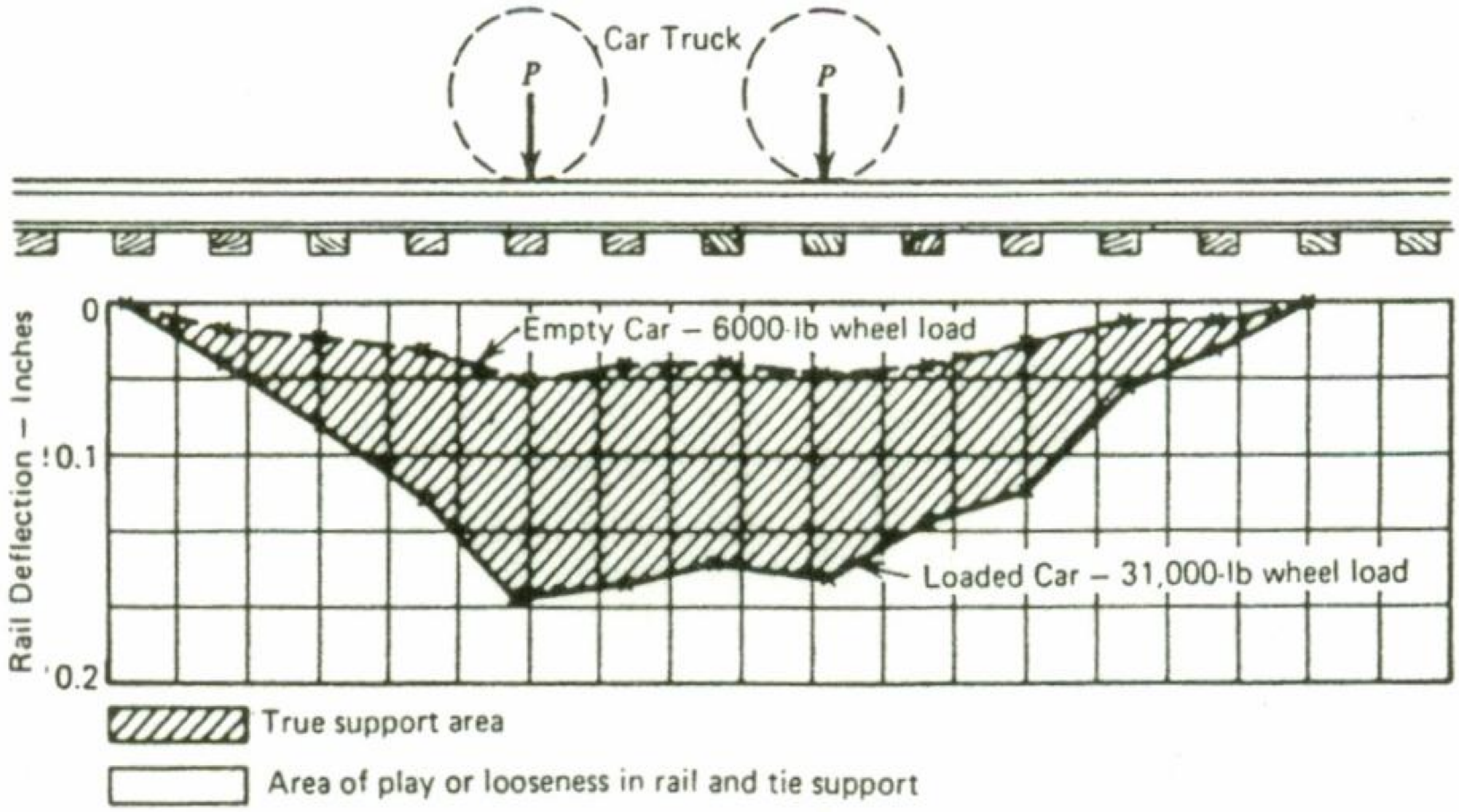
c. Assuming an allowable subgrade pressure of 18 psi (a safety factor of 2) and using the unit tie face pressure developed above of 55 psi, solve for ballast depth:

$$h = (16.8 \times 55/18)^{4/5} = (924.0/18.0)^{4/5} = 23.4 \text{ inches}$$

d. The capacity of the subgrade including the safety factor must always be equal to or greater than the load placed upon it.

Track Stiffness (or Modulus)

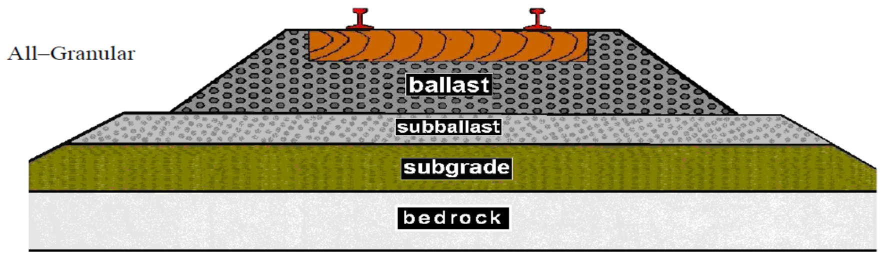
- Up and down movement (pumping) of track under repetitively applied and released loads is a prime source of track deterioration.
- Design of track should keep deflection to a minimum.
- Differential movement causes wear of track components.
- Modulus is defined: load per unit length of rail required to depress that rail by one unit.

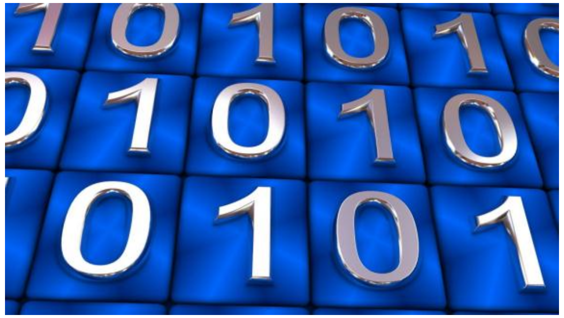


Track Deflections: Loaded and Unloaded

KENTRACK 4.1: A Railway Trackbed Structural Design Program – Rational Method

- Kentrack is a computer program designed to analyze a railroad track segment as a structure
- Uses Bousinessq's Elastic Theory
- Uses Burmister's Multi-Layer System and Finite Element Analysis to perform calculations





Kentrack

- Critical Stresses and Strains are Calculated at Various Interfaces within the Track Structure

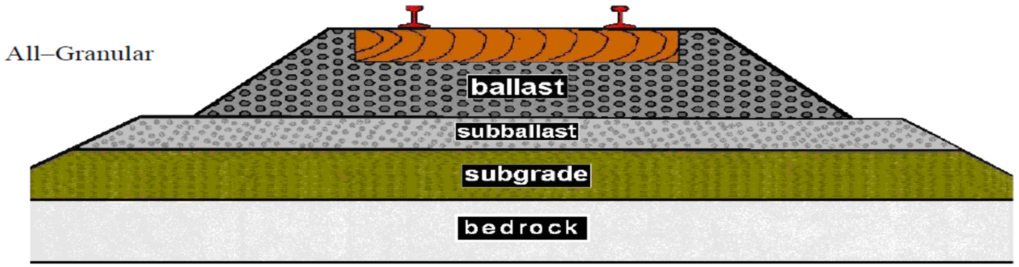
- Design Lives are Predicted for Trackbed Support Layers based on Fatigue Effects (Cumulative Damage Criteria) of Repeated Loadings

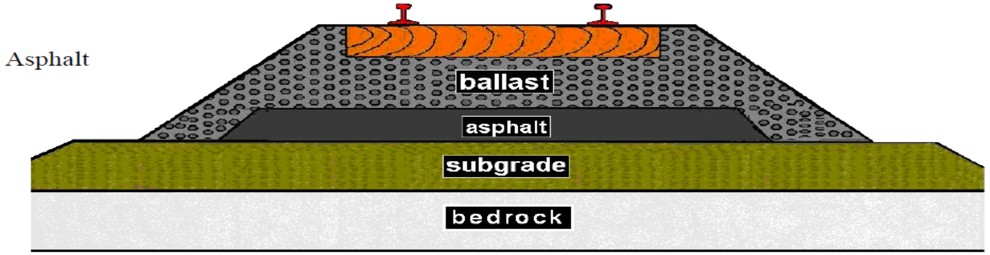
- Uses DAMA Program – Developed for Highway Pavements (Applicability for RR Trackbeds?)

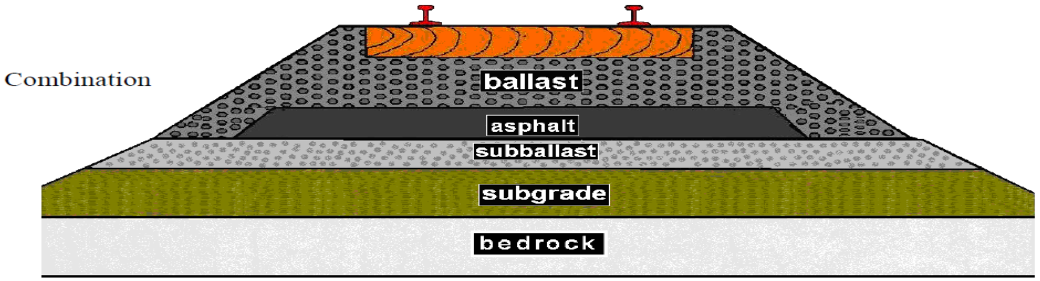
- Applicable of both Unbound (elastic layers) Granular Trackbeds and Bound (elastic and viscous layers) Granular Trackbeds

Trackbed Types

- All-Granular
  - Ballast, Subballast, and Subgrade
- Asphalt Underlayment
  - Ballast, Asphalt and Subgrade
- Combination
  - Ballast, Asphalt, Subballast, and Subgrade







Damage Analysis

Subgrade

- Excessive permanent deformation controls failure
- Deformation is governed by the vertical compressive stress on the top of the subgrade
- $N_d = 4.837 \times 10^{-5} \sigma_c{}^{-3.734} E_s{}^{3.583}$

Asphalt

- Fatigue cracking controls failure
- Fatigue cracking is governed by the tensile strain in the bottom of the asphalt
- $N_a = 0.0795 \times \varepsilon_a{}^{-3.291} E_a{}^{-0.853}$

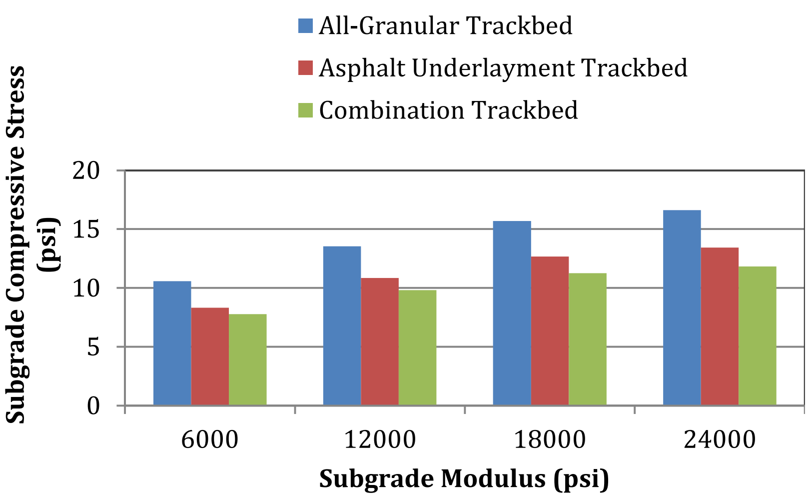
Service Life Prediction

$$L = \frac{1}{\sum_{i=1}^{n} \frac{N_p}{N_a or N_d}}$$

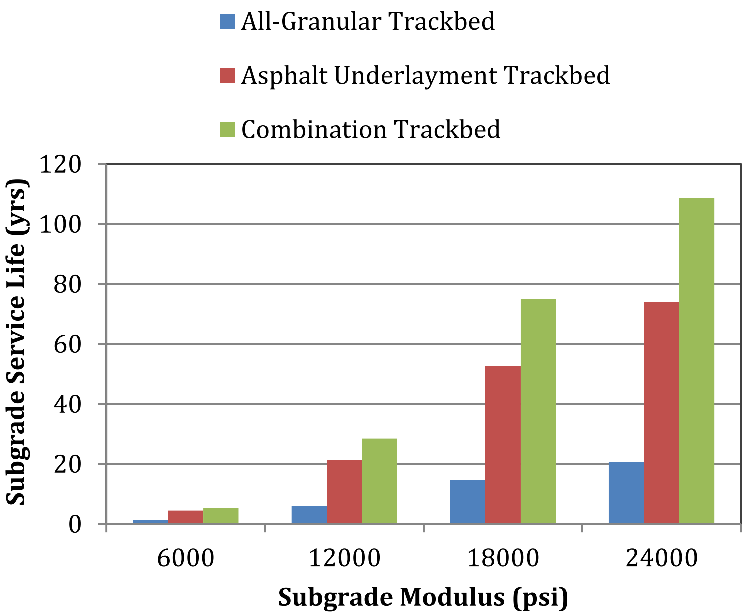
- Subgrade Service Life
- Asphalt Service Life

Effects of Varying Subgrade Modulus – Sensitivity Analysis Example

- A very critical parameter influencing the quality and load carrying capability of the track structure.
- A subgrade with high moduli provides a stiffer foundation that has greater bearing capacity and increases load carrying capability.

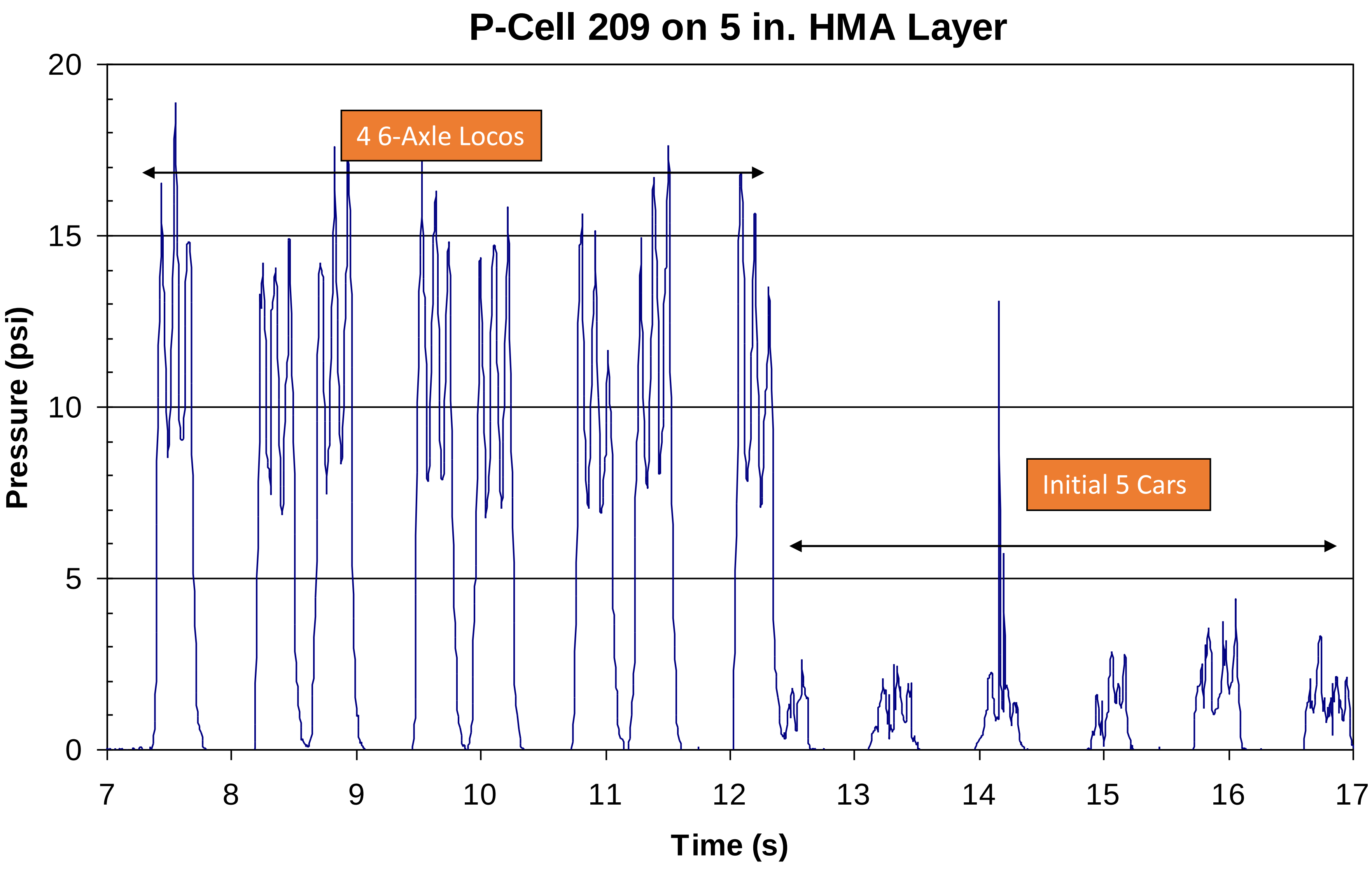


Subgrade Compressive Stress vs. Modulus

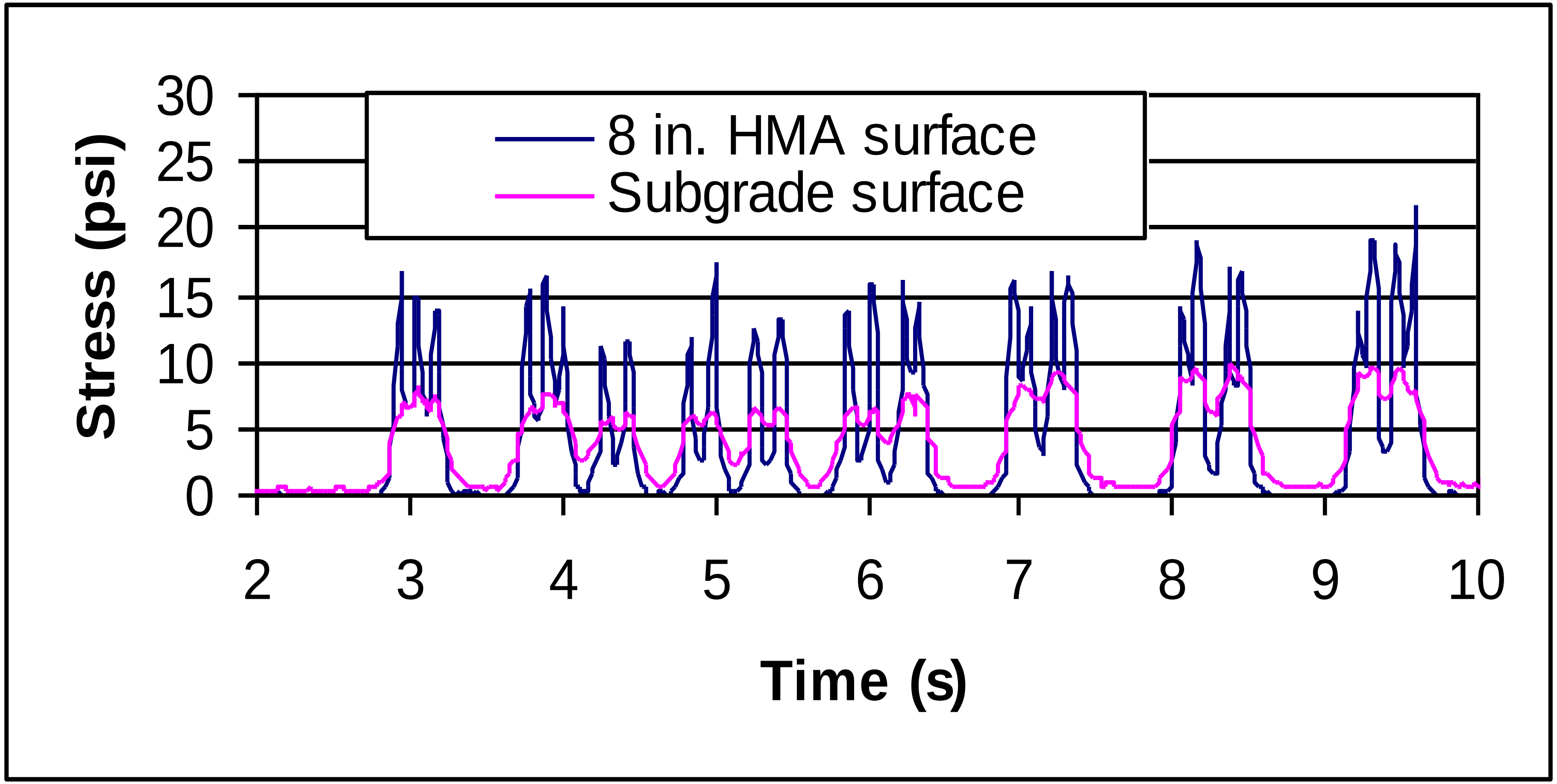


Subgrade Service Life vs. Modulus

Empty Coal Train at Conway



Reduction of Dynamic Stresses*



*Source -- AAR Transportation Test Center – Pueblo, CO

Table 2a. Comparison of the KENTRACK Predictive Values (KPV) Versus In-Track Data (ITD) for the CSX Mainline at Conway, Kentucky

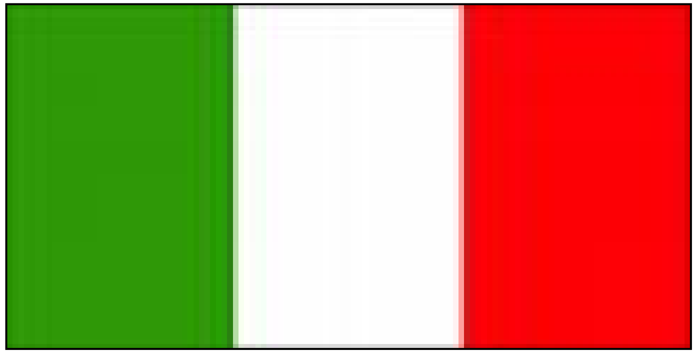
Thickness Ballast/HMA inches	Vertical Compressive Stress on **Ballast** KPV/ITD, psi	Vertical Compressive Stress on **HMA** KPV/ITD, psi	Vertical Compressive Stress on **Subgrade** KPV/ITD, psi
10 / 5	47.9 /	21 / 16	13.6 / -
10 / 8	48.7 /	22 / 15	11.7 / -

Table 2b. Comparison of the KENTRACK Predictive Values (KPV) Versus In-Track Data (ITD) at TTCI in Pueblo, Colorado

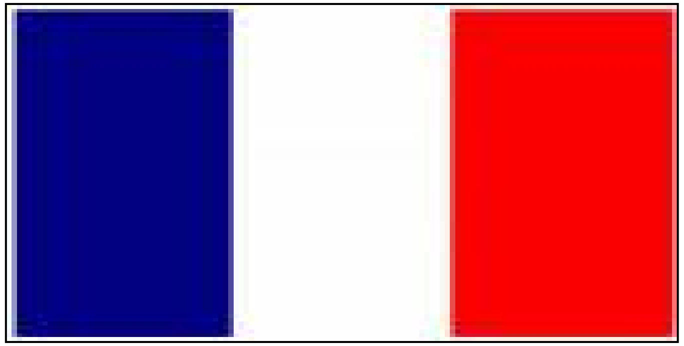
Thickness Ballast/HMA inches	Vertical Compressive Stress on **Ballast** KPV/ITD, psi	Vertical Compressive Stress on **HMA** KPV/ITD, psi	Vertical Compressive Stress on **Subgrade** KPV/ITD, kPa
12 / 4	43.5 / -	11.7 / 14.9	8.3 / 8.0
8 / 8	47 / -	21.9 / 14.9	8.2 / 7.7

International Applications

Italy

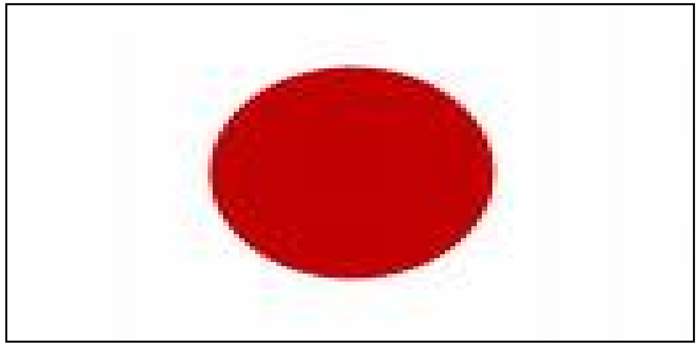


France



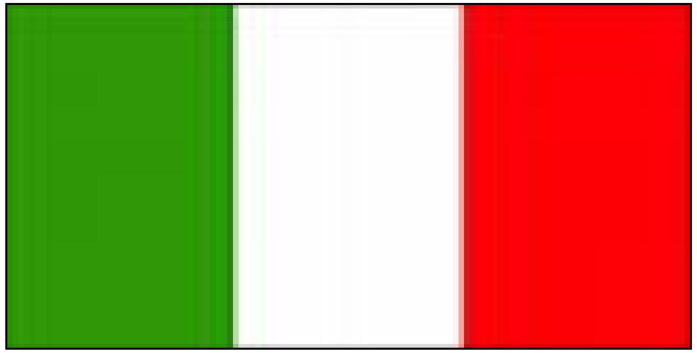
Germany

Japan



Spain

Austria



Widely Utilized On Italian High-Speed Railways

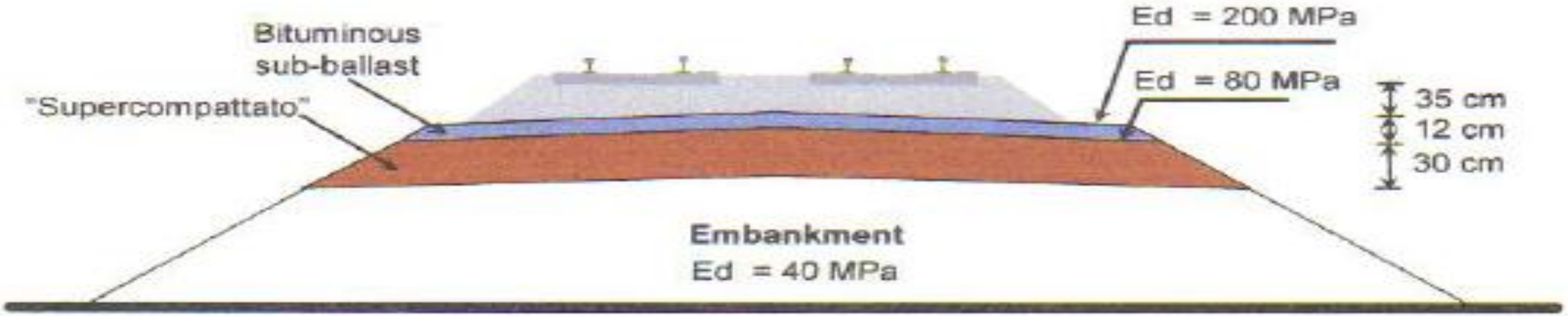
- Rome-Florence: 252 km (1977-1986)
- Debated between cement and asphalt
- Asphalt – designated on all future high-speed passenger lines

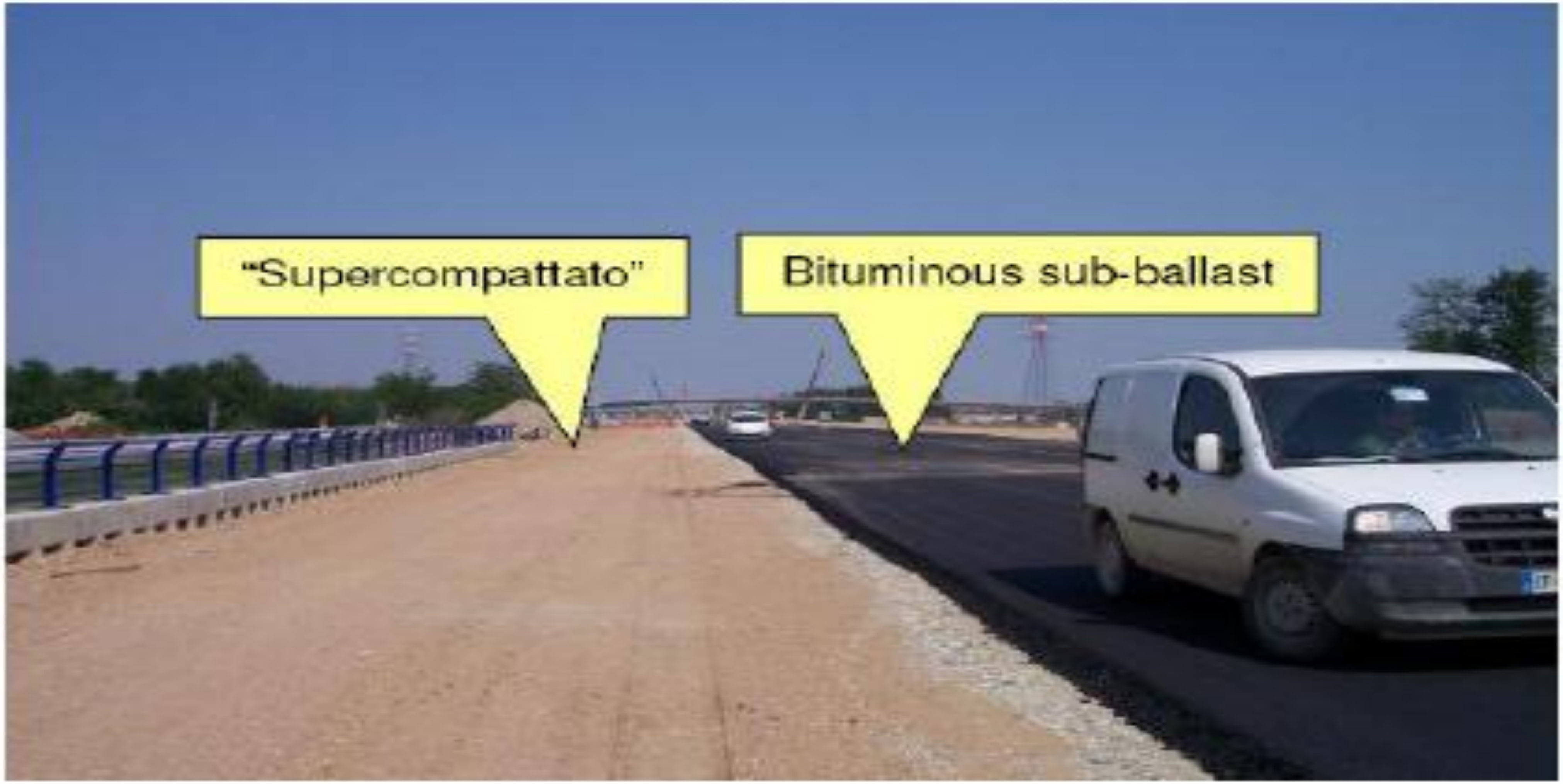
- Prevents rainwater from infiltrating the layers below the embankment
- Eliminates high stress loads and failures of the embankment
- Protects the upper part of the embankment from freeze/thaw actions
- Gradually distributes static and dynamic stresses caused by trains
- Eliminates ballast fouling

Buonanno, 2000

Typical Cross Section

- 12 cm of asphalt with 200 MPa modulus
- 30 cm of super compacted subgrade with 80 MPa modulus
- 35 cm of ballast on top





Italian Trackbed Construction – Improved Subgrade on left, prior to addition of Granular and Asphalt Subballasts on right

- Increased safety and structural reliability due to increased modulus and uniformity
- Reduced life-cycle cost on the infrastructure from reduced subgrade fatigue
- Increased homogenization of the track bearing capacity on the longitudinal profile and better ballast confinement
- Reduced ballast fouling due to improved drainage
- Reduced vibration levels throughout the track therefore reducing noise
- Reduced thickness compared to a conventional granular design

Policicchio, 2008

Advantages of Bituminous Subballast

Teixeira, 2005

Italian Railways Bituminous Trackbed Construction

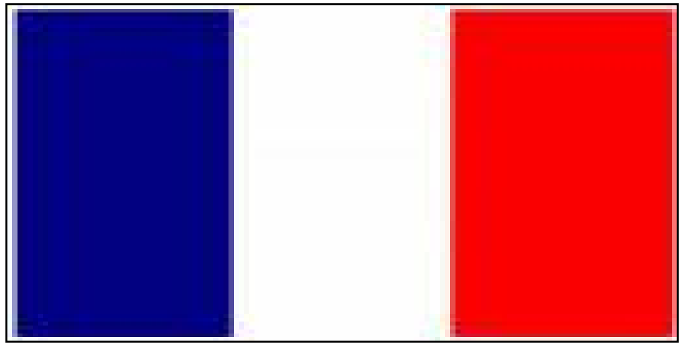
Compacting Subgrade and Placing/Compacting Asphalt

Spreading and Compacting Ballast

Falling Weight Deflectometer for assessing Structural Competency

Station View of Completed Asphalt Trackbed

France



- Paris to Strasbourg high-speed line-- 2007
- 3 km asphalt subballast
- 574 km/hr (357mph) (test)

The test area for the LGV EE
Case Study

Drawn to the LGV EE (www.rff.fr)

- 3 Km Test zone with Asphalt under ballast
- Instrumentation:
  - Temperature Sensors
  - Accelerometers on the sleepers
  - Strain gauges at the base of the layer of asphalt
  - Pressure cells on subgrade support

Construction of the test area - layer of pervious

Comparative Cross-Sectional Profiles

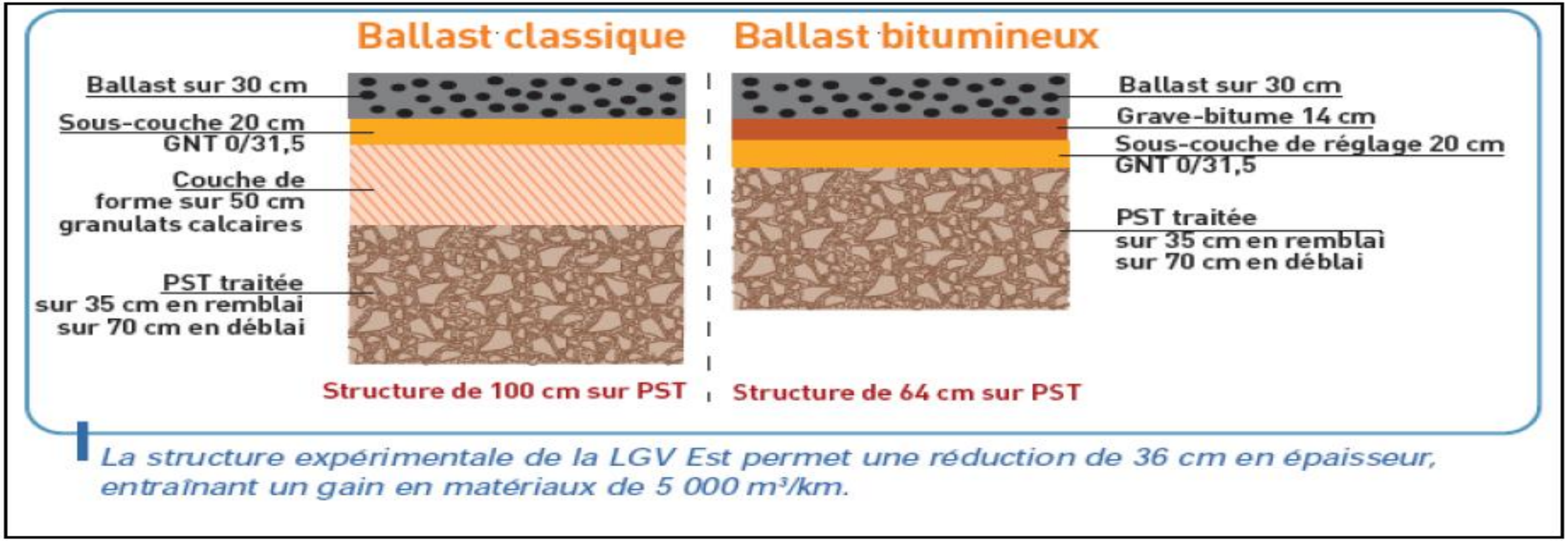


Figure 13. Traditional and Asphalt Cross Sections (Bitume Info, 2005)

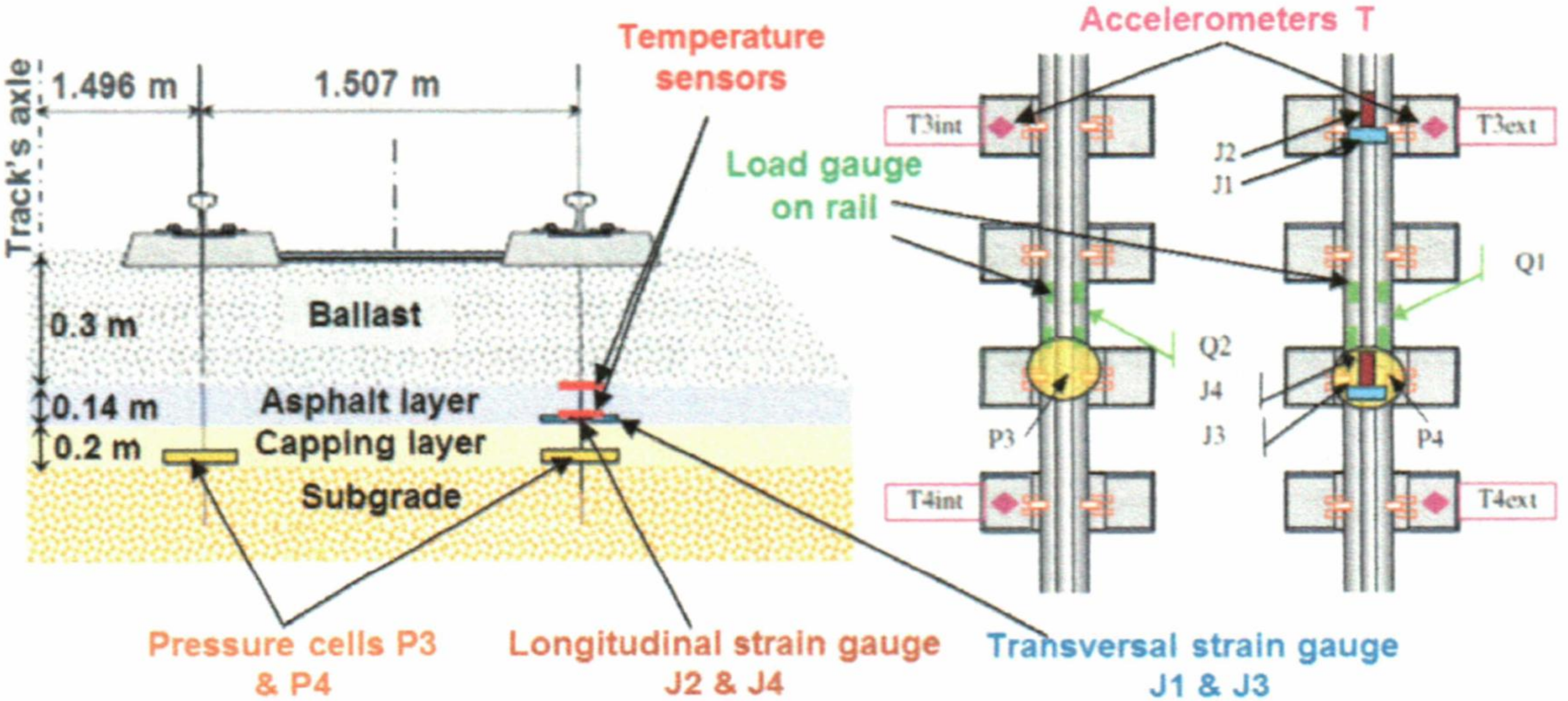
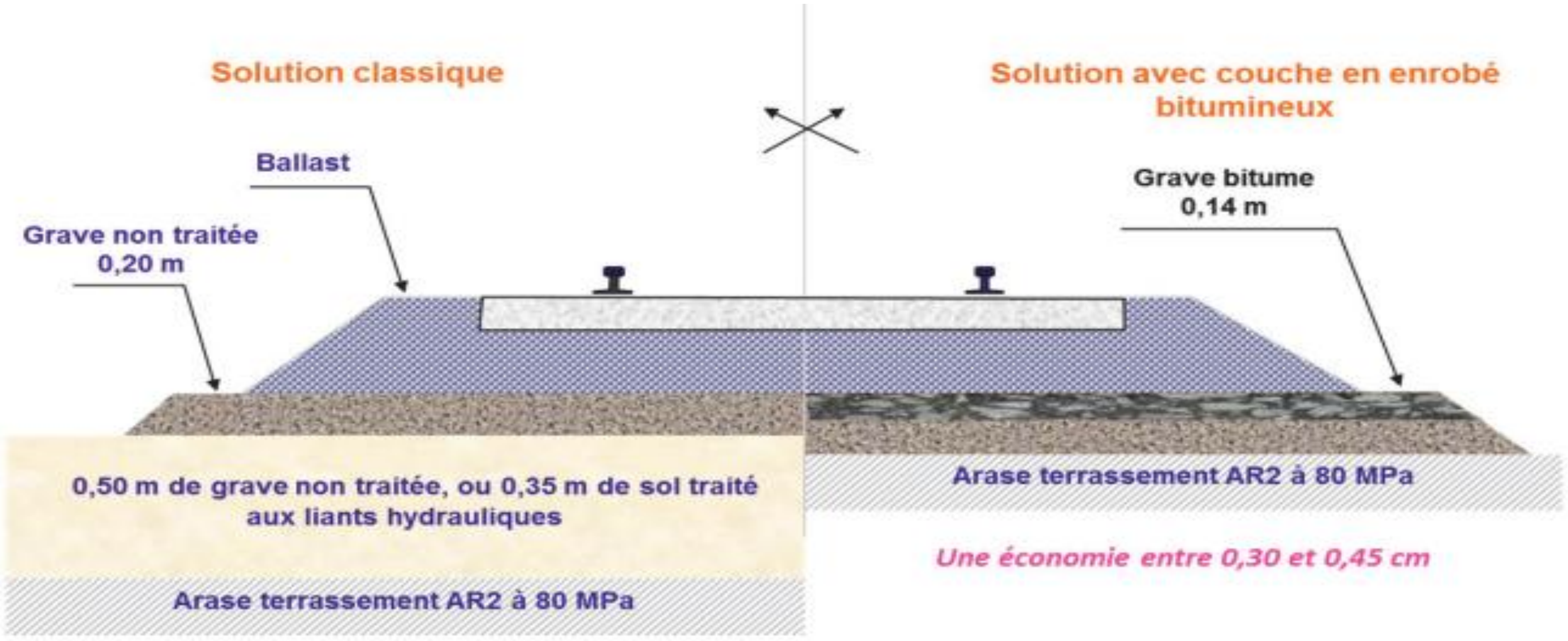


Figure 1. Instrumentation of the EE HSL test zone with bituminous sub-ballast layer: Transversal plan (left) and top plan (right) (Not in scale)


1800-1


CAT
CB-534C
CAT



Matériaux	Module (MPa)	Coefficient de Poisson
Rail : acier	210 000	0,29
Traverse : béton	35 000	0,25
Ballast	130	0,35
Grave-bitume ferroviaire	9 000 (Fatigue $\varepsilon_6 = 110.10^{-6}$)	0,35
Grave non traitée	3 x E_{sol} = 240	0,35
Sol support (Plate-forme)	E_{sol} = 80	0,35

Testing

- Conduct tests for 4 years (2007-2011)
- Temperature sensors continuously recording air temperature
- Pressure Sensors and Strain Gages checked twice a year
- Accelerometers

Context
The coated in the rail

- **Benefits of bituminous mixtures in the railway track:**

- Economies in **Materials**
- **Equipment Traffic** During the yard
- Increase of the **Stability of the structure**
  - ∴ Reduction of **Maintenance efforts**
- Control of the **Vibration**

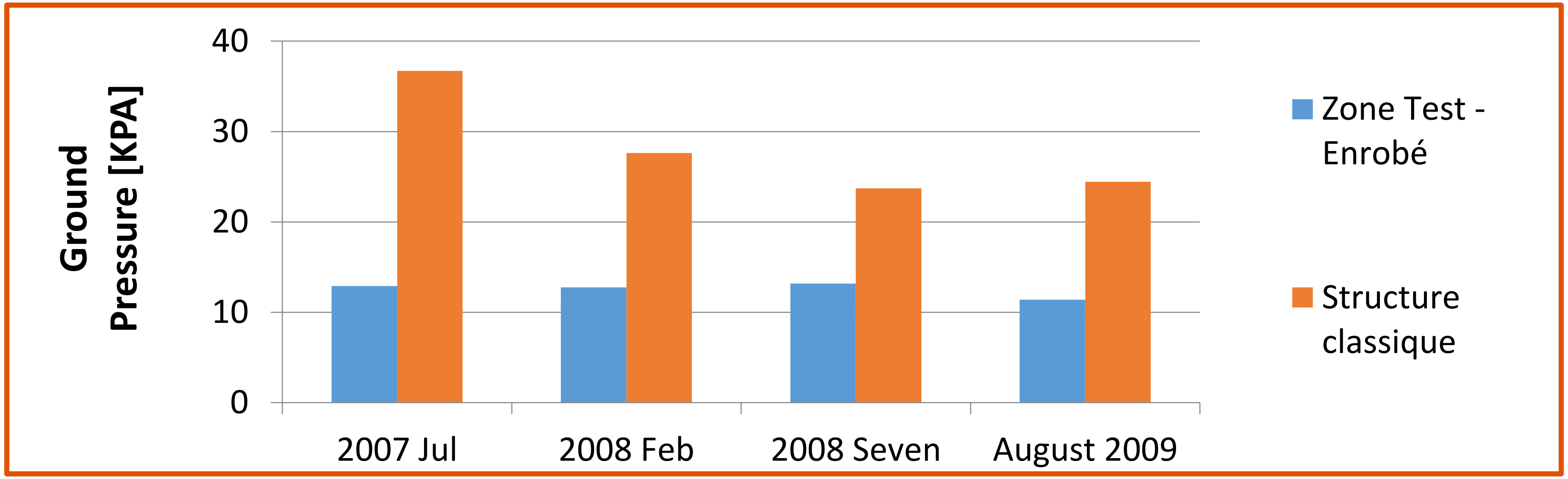
Special features of the rail:

- **High speed** → Dynamic efforts
- **Axle Loads** High
- Exposure to the **Humidity**
- Effort of **Compression** Constant (weight of the superstructure)

Need to characterize the material for these conditions

The test area for the LGV EE
REX

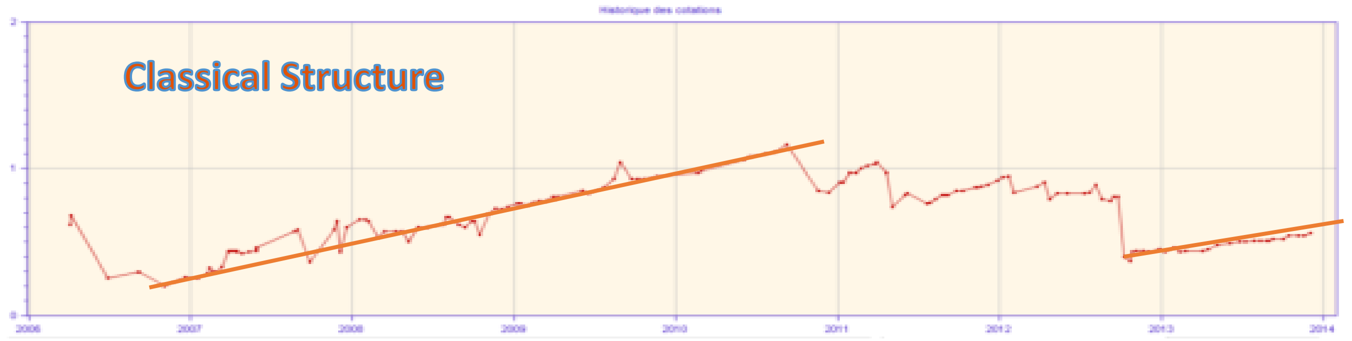
- **Vertical stiffness:**
  - **Comparable Values** To those areas utilize framing techniques
  - **Variation of stiffness** (Standard deviation of the signal EMW) **40% More low** That in the common areas (P. E. LAURENS PSIG-VERS-EVT)
- **Ground Pressure support:**
  - Approximately **50% More low** That in areas a classical structure

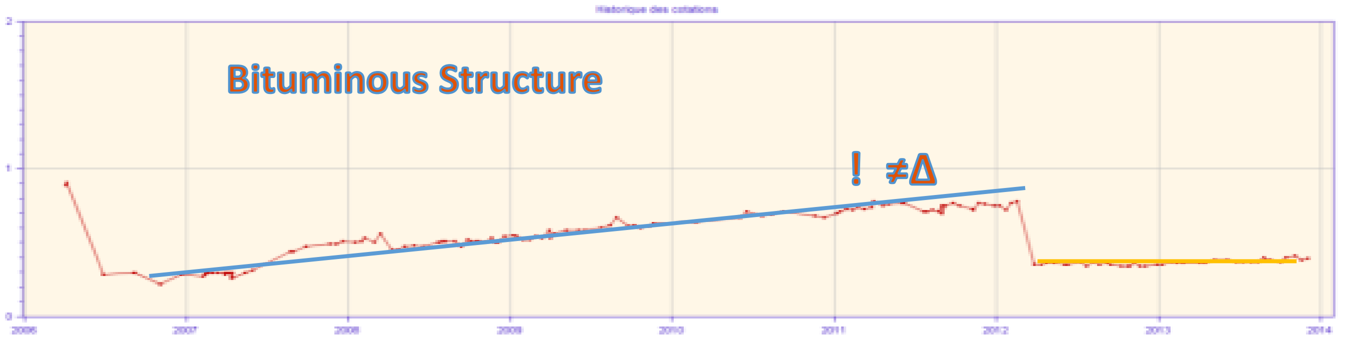


The test area for the LGV EE
REX – Maintenance (2)

- **Bituminous Structure** (Pk 110):
  - More low rate of degradation
  - Best effectiveness of maintenance work
    → Attenuation of the slope after Jam

- **Classical Structure** (Pk 112):
  - Degradation rate constant even after maintenance operations





Comments Relative to French Asphalt Track Section

Reduces overall cross-sectional thickness by 36 cm

Reduces quantity of fill material by 5,000 cubic meters/kilometer

Pressures under asphalt layer are one-half of granular sections

Deflections of asphalt track are one-third of allowable

Sleeper acceleration is not affected

Less maintenance is required on asphalt track

Asphalt track performs well

Based on performance, several more sections are planned

Source:
Bitume Info, 2005 &
Robinette, 2013

Partial Findings

- The use of bituminous layers in structure of railway track allows you to reduce the efforts of maintenance
- The complex module and the Poisson coefficient complex are strongly dependent on the frequency of solicitation and the temperature.
- In terms of rigidity, the trains running at high speed does not seem to be problematic for bituminous mixtures.
- The mold flow model 2S2P1D is a tool of great value for the study of bituminous materials

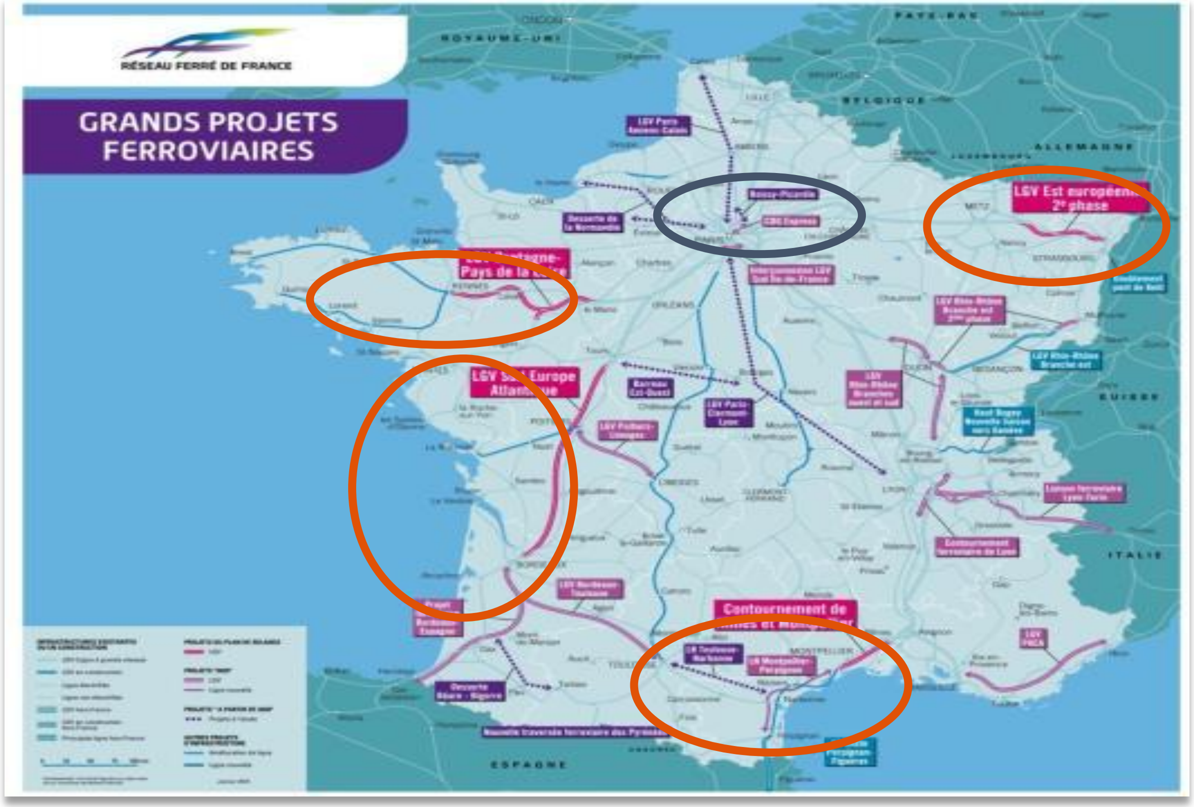
Reference:
Characterization of Thermomechanical Properties of Coated Bituminous Rail
By: Diego Ramirez Cardona
SNCF – French National Railways
October 31, 2014

The Wrapped in the rail network French

- **Rail Experiences with bituminous mixtures:**

  - **LGV is European** Phase 1:
    - 3 Km **Test Area**
  - **Large PProject proponents:**
    - LGV EE phase 2
    - LGV Bretagne Country-de-Loire
    - LGV Atlantic southern Europe-atlantic
    - Workaround

      Nimes-Montpellier



Large rail projects in France (www.rff.fr)

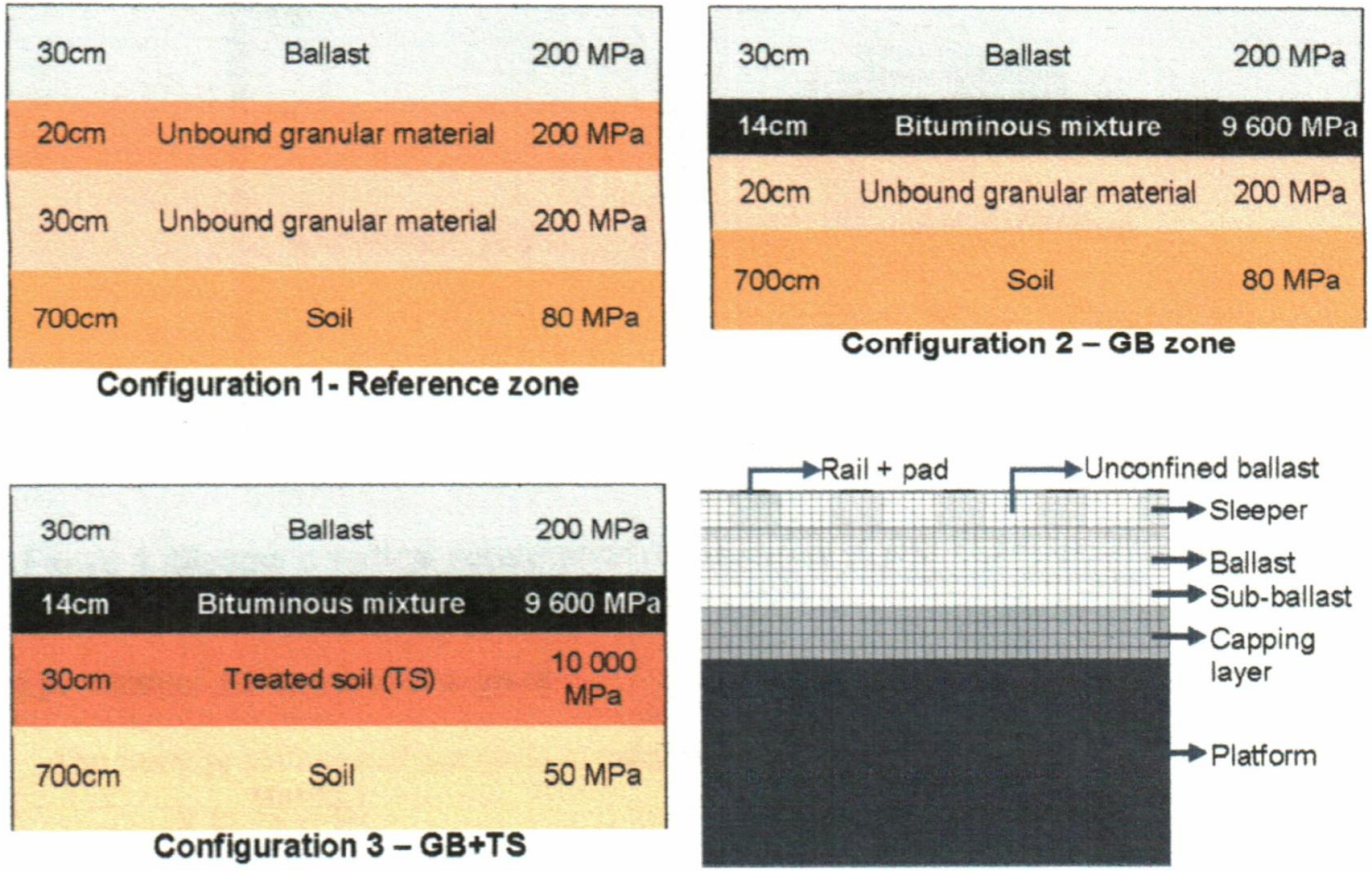


Figure 2. Parameters of the three studied track configurations (Not in scale) and extract of the mesh for FE calculations (Not in scale)

Austrian Railways

Reasons for Implementing Asphalt Layers

How to install an Asphalt Layer?

Targets of an Asphalt Layer

- to allow road vehicles running on the sub-layer during construction phase independently from weather and sub-soil situation

- clear separation of sub- and superstructure during the whole service life

Advantages

- drainage effect for raining water hindering it penetrating the substructure
- avoiding the pumping up of fines into the ballast
- delivering a certain amount of elasticity
- homogenising the stresses affecting the substructure

Long Term Experiences
Jauntal, Carinthia

Austrian Railways Conclusions

Asphalt layers improve the quality of track in defining a clear and long lasting separation between superstructure and sub-structure. This separation results in less maintenance demands of track and (thus) longer service lives.

These benefits must be paid by an additional investment of 10€/m² within the initial construction.

Life cycle cost analyses show that it is worth to implement asphalt layers on heavy loaded lines (> 15,000 gt per day and track), as then the annual average track cost can be reduced by 3% to 5%.

However, implementation of asphalt layers cannot be proposed for branch lines carrying small transport volumes.

Asphalt Layers must be understood as an additional investment in quality, then it pays back its costs. It must not be implemented in order to reduce quality in sub-layers, by for example reducing the thickness of the frost-layers.

Austrian Railways Implementation

Consequently asphalt layers of 8 cm to 12 cm form a standard element for new high capacity and high speed lines in Austria.

Due to the long interruption of operation installing of asphalt layers are not proposed within track re-investment and maintenance operations.

Reference:
Dr. Peter Veit
University of Graz
November 24, 2014

Picture a to c: new Koralm link

Picture d: Schoberpass-line, built in 1991

Concluding Comments

The majority of Railroad Trackbed and Roadbed Designs on the U.S. Railroad System Evolved mainly through Trial and Error; later based on Empirical Measures

Essentially all U.S. Trackbed/Roadbeds are composed of All-Granular Support Layers

Periodic Maintenance (surfacing) of the track is necessary to maintain the required Track Geometric Features

Each Trackbed Support Layer provides specific Qualities; Combined the Layers represent a System

Computer Systems (finite element/layered analysis) can be used to Design and Analyze Layered Track Structures – Kentrack was the featured Rational Procedure herein

Using the Computer System, the Relative Effects of Various Layer Compositions (Properties) and Thicknesses can be Evaluated – Sensitivity Analysis

Concluding Comments (continued)

There is considerable interest presently by selected International Railway Agencies to develop Innovative Trackbed Structural Design Programs

There is considerable interest presently by selected International Railway Agencies to develop Innovative Trackbed Designs and Construction Techniques

Recent Innovative Trackbed Structural Designs and Construction Techniques for Italian, French and Austrian Railways were featured

The Incorporation of a Constituent Layer of Asphalt within the Track Structure and Follow-Up Performance Evaluations for the three Western European Railway Agencies were highlighted

The Asphalt Layer augments or replaces a portion of the Traditional Granular Support Layers providing documented Enhanced Properties to the Track Support Structure

Thank You for Your Attention
Questions ???

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