National University Rail Center - NURail
US DOT OST-R Tier 1 University Transportation Center

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# Develop Railway Engineering Modules in UTK Civil Engineering Undergraduate and Graduate Courses

By

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## DISCLAIMER

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## TECHNICAL SUMMARY

### Title

Develop Railway Engineering Modules in UTK Civil Engineering Undergraduate and Graduate Courses

### Introduction

The importance of railway transport has long been recognized. However, no railway engineering courses have been provided in the UTK civil engineering curricula. The objective of this education project is to develop some railway engineering modules based on the PI's research and teaching experience for many years so that independent railway engineering courses or even programs can be established in the future.

The railroad material characterization modules, such as aggregate, railroad track steel, Portland cement concrete, railroad ties, and asphalt concrete for railroad applications, will be incorporated in the existing civil engineering courses the PI is currently teaching: CE321 – Construction Materials, CE522 - Asphalt and PCC Mix Design and CE525 - Pavement Materials Characterization. The railroad design modules will be incorporated in the PI's pavement design course: CE521 – Pavement Design. More teaching modules will be developed based on the outcomes of the PI's research.

### Description of Activities

The PI developed two teaching modules for railway engineering in PowerPoint slides. The two modules have been partially or fully used in the PI's teaching courses: CE321 – Construction Materials (every semester, undergraduate), CE522 - Asphalt and PCC Mix Design (Spring 2014, graduate), CE691 – Advanced Materials Characterization (Fall 2013, graduate), CE521 – Pavement Design (Summer 2013, Spring 2015, graduate).

### Outcomes

Two railway engineering modules were developed. The first module is "Railroad Paving Materials" and it covers definitions of ballasted and ballastless tracks, types of ballastless tracks, slab track structure, emulsified asphalt cement mortar, and fastening system. The second module is "Railway Trackbeds" and its contents include materials properties, conventional designs, and innovative designs.

### Conclusions/Recommendations

Two railway engineering modules were developed. More will be developed based on results and findings from the PI's railroad research projects .

**Publications/Examples**

The two railway engineering modules developed in PowerPoint slides were attached.

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# Railroad Paving Materials (Ballastless)

## Outlines

- Advantage and Disadvantages of Ballasted Track
- Advantage and Disadvantages of Ballastless Track
- Design Features in Ballastless Track
- Types of Ballastless Track
- Slab Track Structure
- Emulsified Asphalt Cement Mortar (EACM)

  *Requirements and Properties*
- Fastening System

# Ballasted Track

❖ Advantages

✓ Relatively low construction costs

✓ High elasticity

✓ High maintainability at relatively low cost

✓ High noise absorption

# Ballasted Track

❖ Disadvantages

✓ Over time, the track tends to “float”, in both longitudinal and lateral directions, as a result of non-linear, irreversible behavior of the materials.

✓ Limited non-compensated lateral acceleration in curves, due to the limited lateral resistance offered by the ballast.

# Ballasted Track

❖ Disadvantages

✓ Ballast can be churned up at high speeds, causing serious damage to rails and wheels.

✓ Reduced permeability due to contamination, grinding-down of the ballast and transfer of fine particles from subgrade.

# Ballasted Track

❖ Disadvantages

✓ Ballast is relatively heavy, leading to an increase in the costs of building bridges and viaducts.

✓ Ballasted track is relatively high and has direct consequences for tunnel diameters and for access points.

## Ballasted Track

❖ Other reasons for seeking alternative to ballasted track

- ✓ Lack of suitable ballast material
- ✓ Make track accessible to road vehicles
- ✓ Dust from the ballast into the environment

## Ballastless Track - History

❖ Early High-Speed rail built on ballast -- Tokaido Shinkansen from Tokyo to Shin-Osaka, completed in 1964;

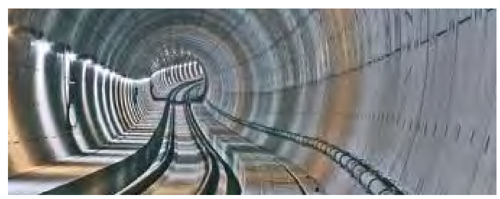
❖ However, with the increase of traffic intensity, damage frequently occurred;

❖ The high-rate economic growth and reduction in working hours, labor shortage and limited interval time for track maintenance created the need to introduced a new low-maintenance track.

❖ In 1965, the former Japanese National Railways (JNR) started a study on slab tracks

# Ballastless Track

- ❖ Advantages
- ✓ Reduced height
- ✓ Dust free
- ✓ Lower maintenance requirement and hence higher availability
- ✓ Increased service life
- ✓ Lower life cycle-cost



# Ballastless Track

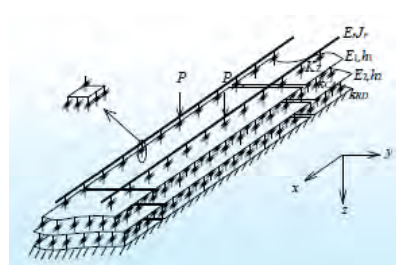
- ❖ Disadvantages
- ✓ Requires high precision laying by automated machines
- ✓ Expert supervision
- ✓ Higher cost, about 1.5-2.0 times conventional ballasted track
- ✓ Derailments can cause costly damage
- ✓ Repair work is more complicated
- ✓ Noise level increases

# Design Principles

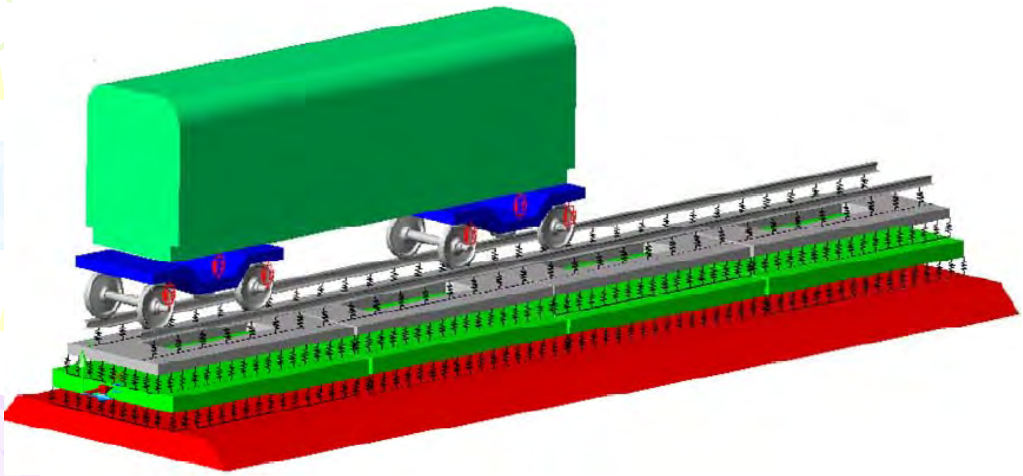
| | |
|---|---|
| Enough Strength and Stability ⇨ | High safety |
| Reasonable design scheme of manufacturing, laying and fine-adjusting of track system ⇨ | Good smoothness |
| Reasonable structure types and durable engineering material ⇨ | Low maintenance |

# Loads on Slab Track

- ❖ Dead load
  - ✓ Structure weight
  - ✓ Shrinkage and creep of concrete
- ❖ Live load
  - ✓ Vertical force
  - ✓ Lateral force
  - ✓ Temperature force
  - ✓ Flexure of bridge
- ❖ Additional load
  - ✓ Brake/traction force
  - ✓ Uneven settlement of subgrade
- ❖ Special load (construction temporary force)



## Dynamic Analysis of Train-Track-Foundation



Train-track-foundation dynamic model

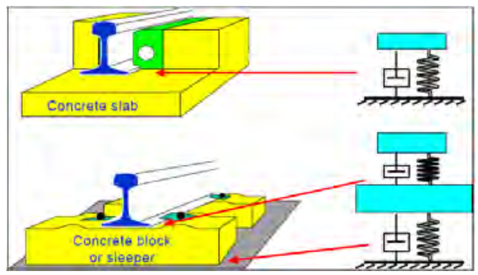
## Track Resilience

- Ballasted tracks
  - Ballast provides half of the resilience.
  - Subgrade provides the other half.
- Slab tracks (ballastless)
  - Slab absorbs little dynamic forces.
  - Limited capability of subgrade for dynamic force absorption
  - Additional resilience needed

# Two Ways to Add Resilience

✓ Extra resilience under the rail with extra thick rail pads.

✓ A second resilient layer under supporting blocks or the sleepers.

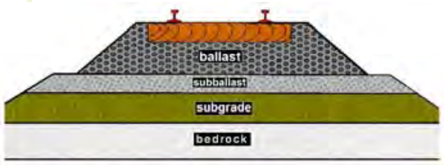



# Supporting layers

Ballastless tracks can be built on

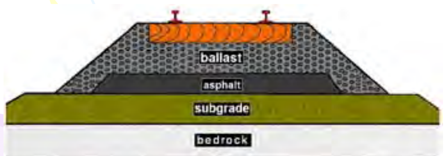
- Asphalt supporting layer
- Concrete supporting layer

# Asphalt Supporting Layers




Classic All-Granular trackbed without asphalt layer


Asphalt Combination trackbed containing both asphalt and subballast layers



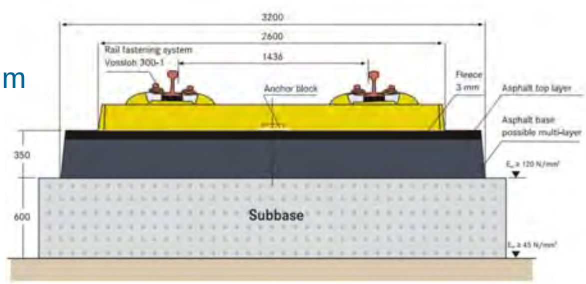

Asphalt Underlayment trackbed without granular subballast layer

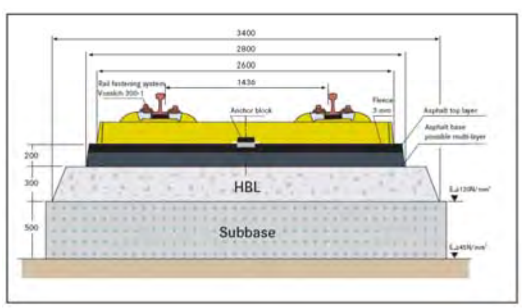

Ballastless trackbed containing thickened asphalt and subballast layers

Courtesy of Dr. Jerry Rose, University of Kentucky

# Asphalt Supporting Layers

German Getrac system



# Concrete Supporting Layers

❖ Systems implemented with concrete supporting layers offer the selection among an optimal diversity of models with homogeneous system structures.

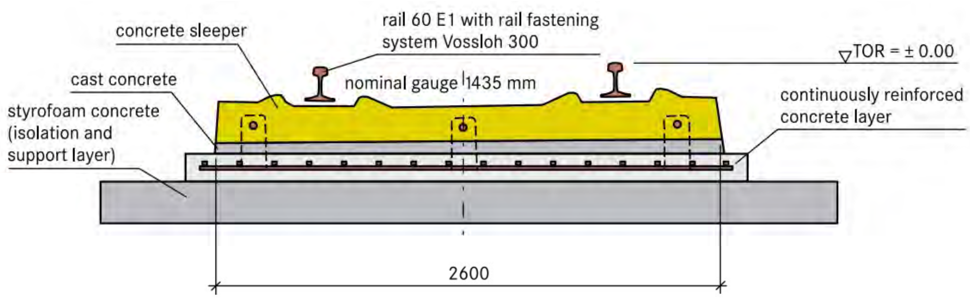
Slab Track System Züblin

RHEDA 2000

# Examples of Concrete Slab Track

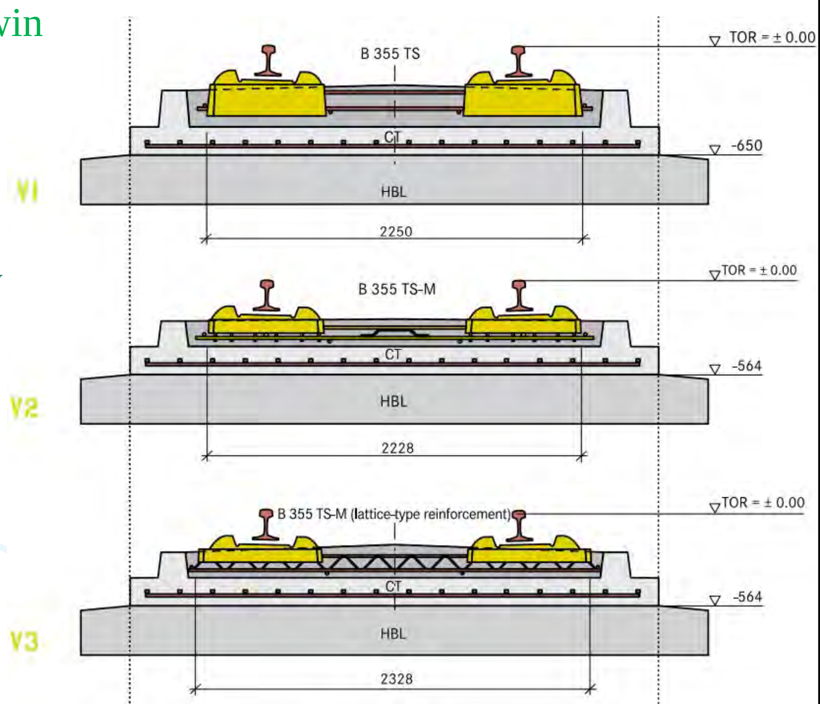
- ❖ Rheda: continous sleeper trough
- ❖ Rheda-Berlin: twin block with untensioned reinforcement
- ❖ Rheada-2000: modified twin block sleeper with braced girder reinforcement
- ❖ Heitkamp Design: concrete trough gravel filling
- ❖ Züblin Design: 10 sleepers inserted into unset concrete
- ❖ Plate track (Shinkansen)

## Rheda: continous sleeper trough

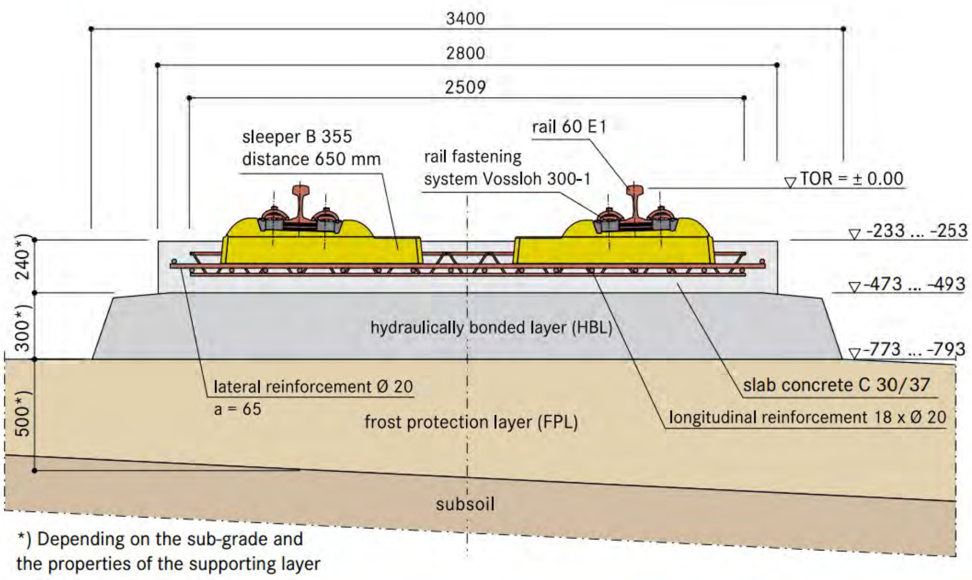



## Rheda-Berlin: twin block with untensioned reinforcement

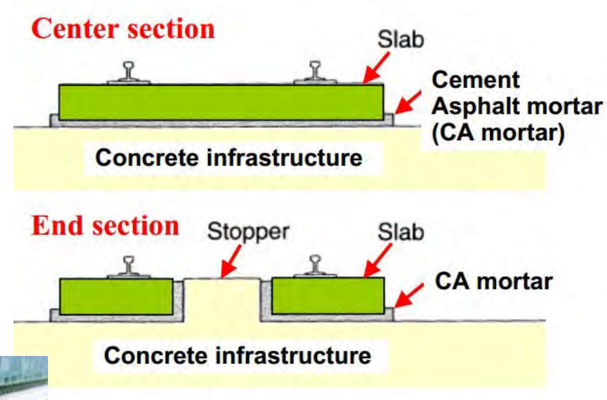
HBL: Hydraulically bonded layer

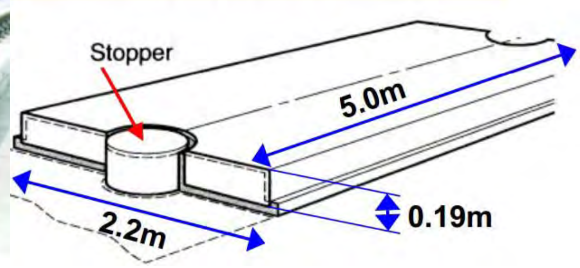


## Rheada-2000: modified twin block sleeper with braced girder reinforcement




## Shinkansen



# Structural Types of Slab Track

- ❖ Cast-in-situ concrete track

- ❖ Precast slab track

# Cast-In-Situ Ballastless Track

- ❖ Longitudinal continuous concrete bed is built on subgrade and in tunnels.

- ❖ Longitudinal discrete concrete bed is built on bridges. A intermediate layer is built btw concrete bed and foundation.

# Precast Slab Track

Slab position restriction


Track geometry adjustment


# Precast Slab Track

Structure

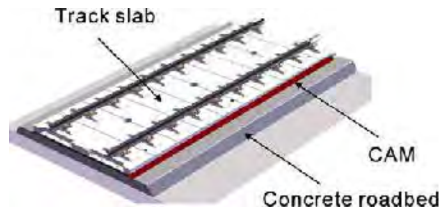
- Precast slab
- Mortar filling layer
- Cast-in-situ support foundation

Advantages of cement asphalt mortar layer

- ✓ Increase construction efficiency
- ✓ Guarantee the quality of slab track
- ✓ Reduce environment and weather impact on construction

# Emulsified Asphalt Cement Mortar (EACM)

❖ Composed of
➢ Cement
➢ Asphalt emulsion
➢ Sand
➢ And several chemical admixtures




❖ Very important for the safety, stability, and comfortable degree of the ballastless slab track.

# Emulsified Asphalt Cement Mortar (EACM)

❖ Characterized by its equally prominent presence of cement and asphalt emulsion with a polymer/cement ratio of more than 0.85.

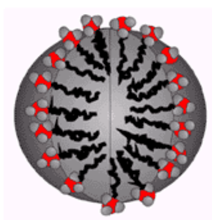
❖ A strong interaction between cement hydration and asphalt emulsion breaking is expected.

# Requirements on Asphalt Emulsion

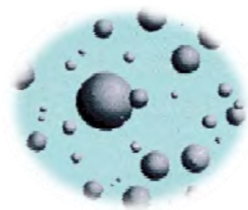
❖ Have a desirable compatibility with cement during mixing

❖ Have good storage stability to guarantee long-distance transportation and long-term storage.

Emulsified Particle



Asphalt Emulsion



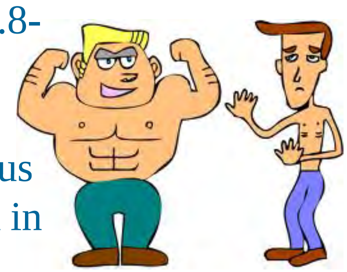
# Two Types of EACM

❖ One with a low elastic modulus and strength used in the Shinkansen slab track and in CRTS I in China

Compresseive strength at 28days: 1.8-2.5MPa

❖ The other with a high elastic modulus and strength used in the Bögl slab track in Germany and in CRTS II in China

Compresseive strength at 28days: >15MPa



| | | Property requirements |
|---|---|---|
| Appearance | | Light brown, homogeneous, no impure substance |
| Particle polarity | | Cationic |
| Engler viscosity (25ºC) | | 5-15 |
| Mass contained on 1.18mm sieve | | <0.1% |
| Storage stability (1d, 25ºC) | | <1.0% |
| Storage stability (5d, 25ºC) | | <5.0% |
| Storage stability (-5ºC) | | No large particles or lumps |
| Compatibility with cement | | <1.0% |
| Evaporation residue | Residue mass | 58-63% |
| | Penetration Number (25ºC, 100g, 5s), 0.1mm | 60-120 |
| | Solubility (trichloroethylene) | >97% |
| | Ductility (15ºC) | ≥50cm |

**Requirements on asphalt emulsion in CRTS I Slab Track**

| | | Property requirements |
|---|---|---|
| Particle polarity | | Anionic |
| Mass contained on 1.18mm sieve | | <0.1% |
| Particle size | | average≤7; fineness modulus≤5 |
| Cement adaptability | | More than 70ml liquid leaks out |
| Storage stability (1d, 25ºC) | | <1.0% |
| Storage stability (5d, 25ºC) | | <5.0% |
| Storage stability (-5ºC) | | No large particles or lumps |
| Evaporation residue | Residue mass | ≥60 |
| | Penetration Number (25ºC, 100g, 5s), 0.1mm | 40-120 |
| | Softening point (ring and ball) | ≥42 |
| | Solubility (trichloroethylene) | ≥99% |
| | Ductility (25ºC) | ≥100cm |
| | Ductility (5ºC) | ≥20cm |

**Requirements on asphalt emulsion in CRTS II Slab Track**

| | Property requirements |
|---|---|
| Temperature of mixture | 5-40ºC |
| Fluidity | 18-26s |
| Workable time | ≥30min |
| Air content | 8-12% |
| The mass per unit volume | ≥1800kg/m$^3$ |
| Compressive strength | 1d, ＞0.10MPa; 7d, ＞0.70MPa; 28d, ＞1.80MPa |
| Elastic modulus at 28d | 100-300MPa |
| Separation | ≤1.0% |
| Expansion rate | 1.0-3.0% |
| Frost resistance | After 300 freeze-thaw cycles, dynamic modulus decreases no more than 60%, and mass lost less than 5% |
| Weatherability | No stripping, no cracking, compressive strength decreases less than 70% |

**EACM Requirements in China CRTS I Slab Track (for low elastic modulus EACM)**

| | Property requirements |
|---|---|
| Temperature of mixture | 5-35ºC |
| Workability | $D_5$≥280mm, $t_{280}$≤16s; $D_{30}$≥280mm, $t_{280}$≤22s; |
| Fluidity | 80-120s |
| Separation | ≤3.0% |
| Expansion rate | 0-2.0% |
| Air content | ≤10.0% |
| The mass per unit volume | ≥1800kg/m$^3$ |
| Flexural strength | 1d, ≥1.0MPa; 7d, ≥2.0MPa; 28d, ≥3.0MPa |
| Compressive strength | 1d, ≥2.0MPa; 7d, ≥10.0MPa; 28d, ≥15.0MPa |
| Elastic modulus at 28d | 7000-10,000MPa |
| Frost resistance | stripping≤2kg/m$^2$, dynamic modulus losses less than 60% |
| Fatigue life (28d) | More than 10,000 |

**EACM Requirements in China CRTS II Slab Track (for high elastic modulus EACM)**

## CRTS II Requirement in China (for high elastic modulus EACM

Symbols in the tables:

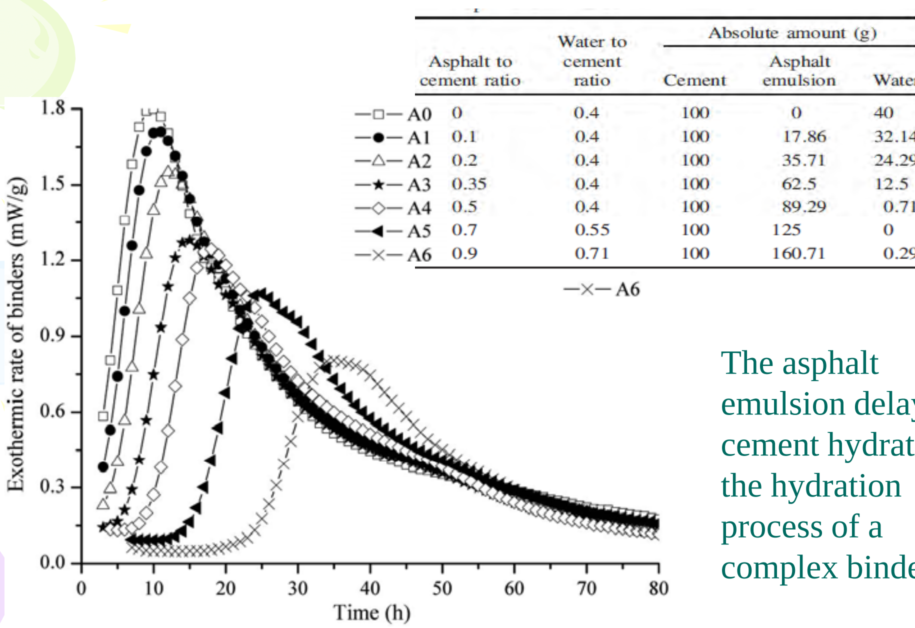
$D_5$ indicates the spread of mortar as slurry when it just prepared;

$D_{30}$ indicates the spread of mortar stored for 30 minutes after mixing preparation;

$t_{280}$ indicates the time when the EACM reaches the diameter of 280mm

## Factors Affecting EACM's Compressive Strength

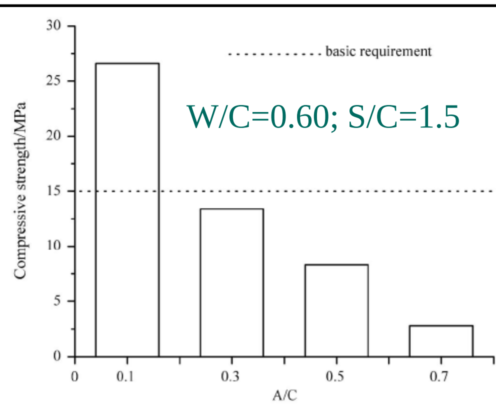
- Ratio of asphalt to cement
  The viscosity of EACM increases with the ratio increases.
- Sand gradation
  The fluidity of EACM decreases as the fineness modulus decreases.
- Ratio of cement to sand
- Water cement ratio
- Admixtures, etc.



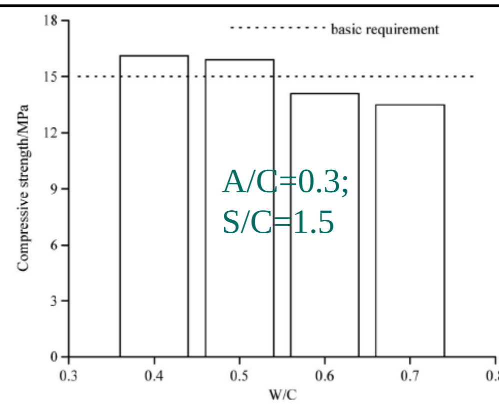

| | Asphalt to cement ratio | Water to cement ratio | Absolute amount (g) Cement | Asphalt emulsion | Water |
|---|---|---|---|---|---|
| —□— A0 | 0 | 0.4 | 100 | 0 | 40 |
| —●— A1 | 0.1 | 0.4 | 100 | 17.86 | 32.14 |
| —△— A2 | 0.2 | 0.4 | 100 | 35.71 | 24.29 |
| —★— A3 | 0.35 | 0.4 | 100 | 62.5 | 12.5 |
| —◇— A4 | 0.5 | 0.4 | 100 | 89.29 | 0.71 |
| —◀— A5 | 0.7 | 0.55 | 100 | 125 | 0 |
| —×— A6 | 0.9 | 0.71 | 100 | 160.71 | 0.29 |

The asphalt emulsion delays cement hydration in the hydration process of a complex binder.

Wang, Yan, Yang, and Kong, 2011

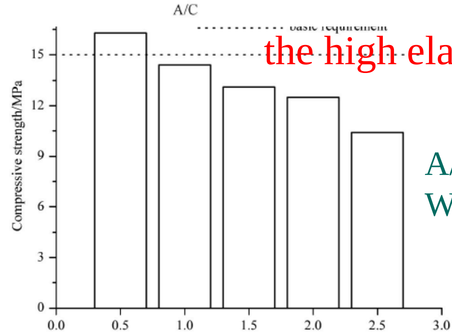



W/C=0.60; S/C=1.5



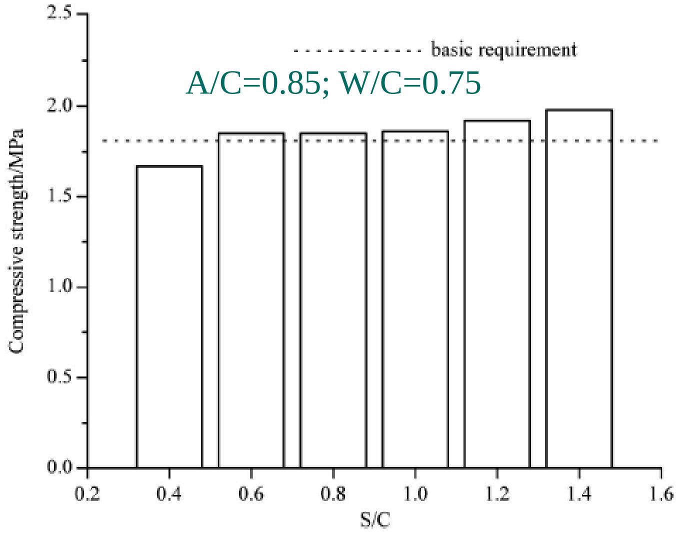

A/C=0.3;
S/C=1.5

the high elastic modulus EACM




A/C=0.3;
W/C=0.65

Wang, Yan, Yang, and Kong, 2011




A slight increase was observed as S/C increased for the low elastic modulus EACM, which may be due to the mechanical friction effect in sand.

Wang, Yan, Yang, and Kong, 2011

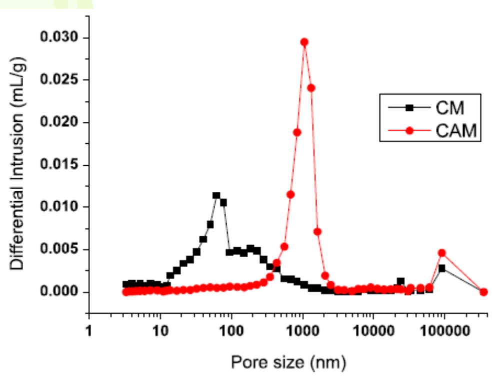
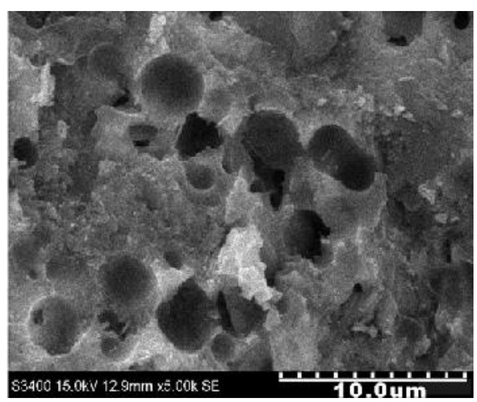



**Fig. 10.** Pore structure of CAM and CM.




The pore size in EACM is mainly around 1000nm, much larger than that in cement paste, 60-200nm

(Hu, Zhang, and Wang, 2012)

## Effect of temperature on compressive strength

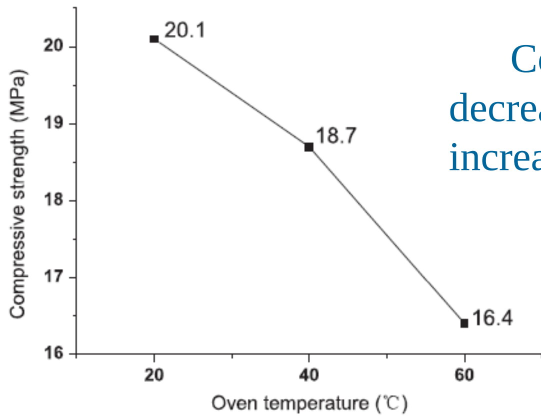



**Fig. 7.** Compressive strength of CAM at different temperatures in dry condition.

Compressive strength decreases as temperature increases.

Asphalt - Viscoelasticity

(Hu, Zhang, and Wang, 2012)

## Effect of temperature when exposed to water

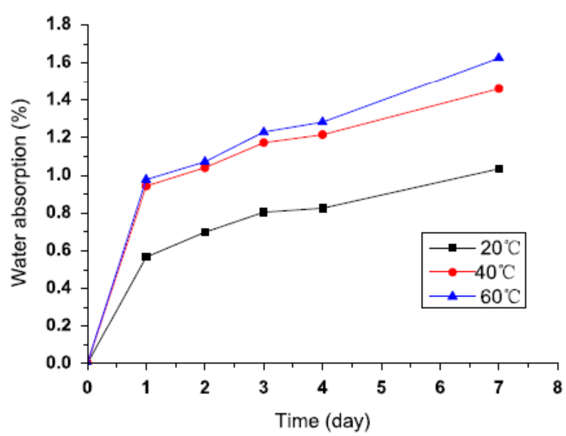
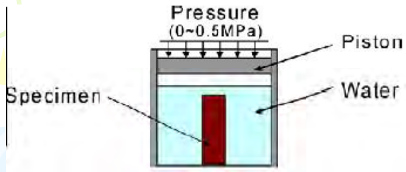



**Fig. 6.** Water absorption of CAM with time at different temperature.

(Hu, Zhang, and Wang, 2012)

# Effect of pressure when exposed to water




- ✓Immerse specimens into the chamber;
- ✓Add one constant pressure for each specimen
- ✓Records water absorption at regular intervals;
- ✓After 16h, cure specimens in the standard curing box (20 ±2$^o$C, RH 60 ±5%) for 7 days;
- ✓Immerse specimens into pressurized water for 5 min for the same pressure;
- ✓Conduct water absorption and compressive strength tests

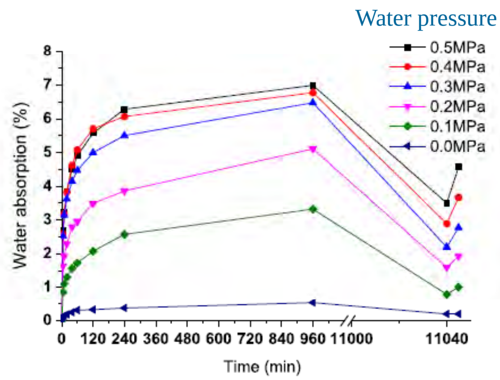
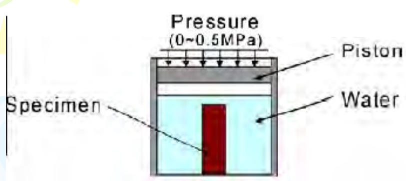



**Fig. 9.** Water absorption of CAM at different time.

(Hu, Zhang, and Wang, 2012)

# Effect of pressure when exposed to water



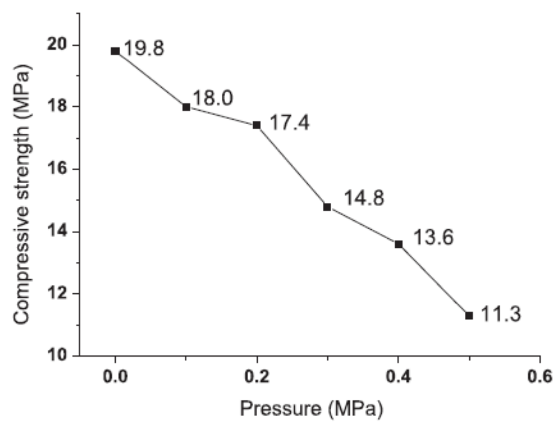




**Fig. 8.** Compressive strength of CAM at different water pressure.

(Hu, Zhang, and Wang, 2012)

## Effect of temperature and pressure when exposed to water

**Conclusions**

❖ Water absorption increases when water temperature and/or pressure increases.

❖ The superposition of temperature and water leads to the performance degradation of EACM.

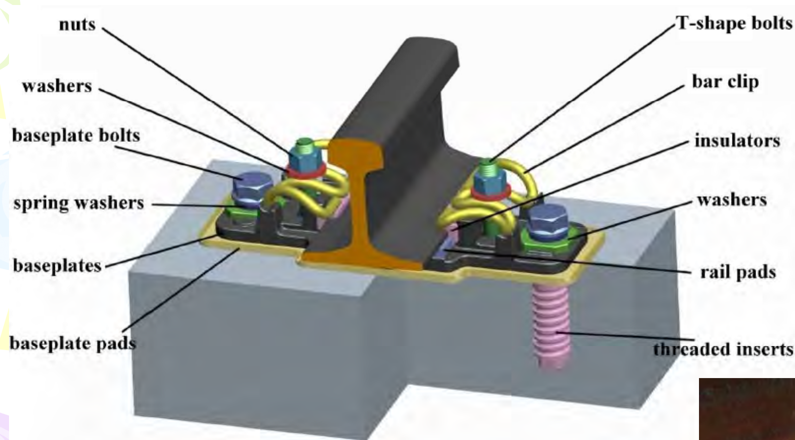
(Hu, Zhang, and Wang, 2012)

# Fastening System for Ballastless Track

❖ Technical Requirements

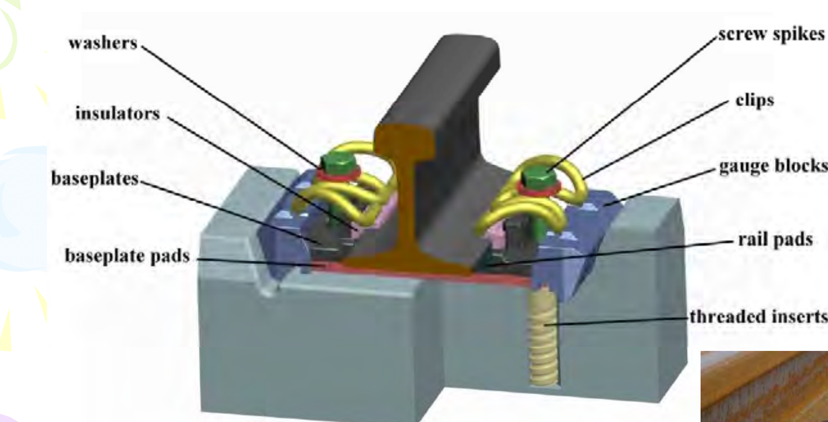
✓ Ability to keep track gauge
✓ Resistance to rail climbing
✓ Damping performance
✓ Insulation performance
✓ Number of components and maintenance
✓ Evenness
✓ Capability of adjusting vertical/lateral position of rails
✓ Versatility
✓ Uniform track stiffness in turnout area

# Fastening System in China



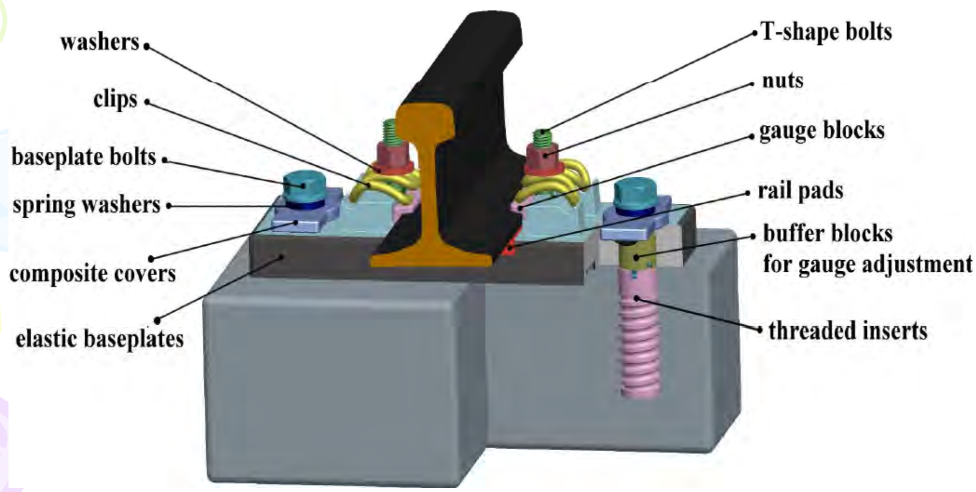

WJ-7

# Fastening System in China




WJ-8

# Fastening System in China




Fastening system in turnout

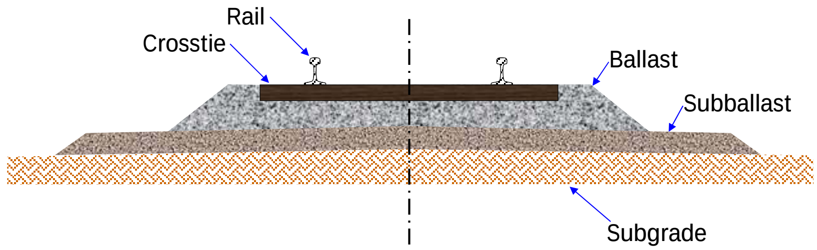
# *Questions?*

# Railway Trackbeds

Materials Properties, Conventional Designs, and Innovative Designs

- Basic Requirements
  - Track must support the loadings and guide the train's path
- Track Quality Determines
  - Permissible wheel loadings
  - Safe speed of the train
  - Overall safety of operations
  - Dependability of operations
  - FRA Class 1,2,3,4,5,6,7,8,9

# Track Cross-Section



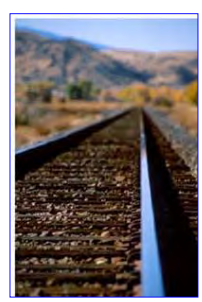

- Railroad track is designed to be economical and easy to maintain

Constantly evaluating Alternatives

Benefits compared to Additional Costs

# Track Functions

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

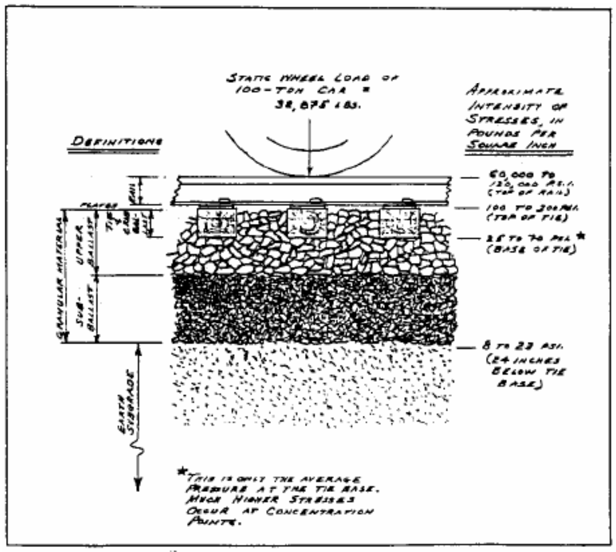


# Interaction, Vertical Load Distribution, and Deflections

Components do not function independently!

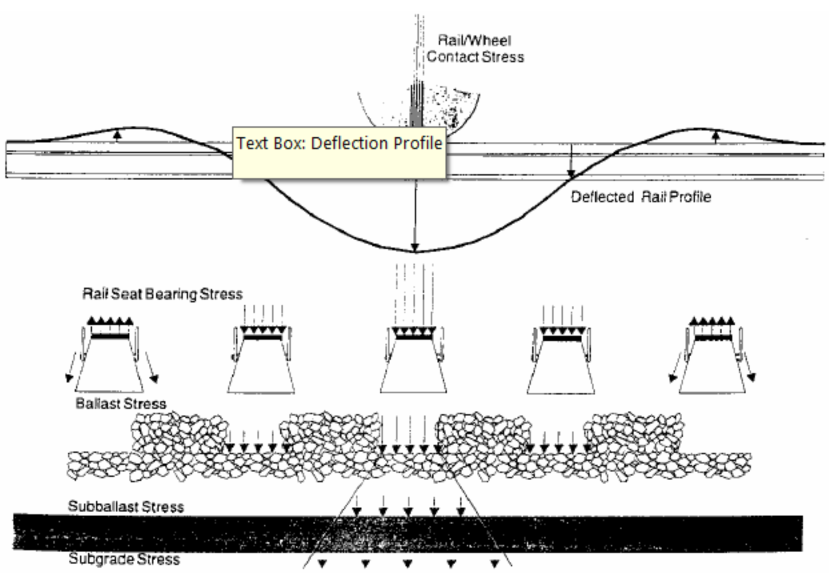
Each component layer must protect the one below.

## Stress Distribution




2

## Deflection Profile

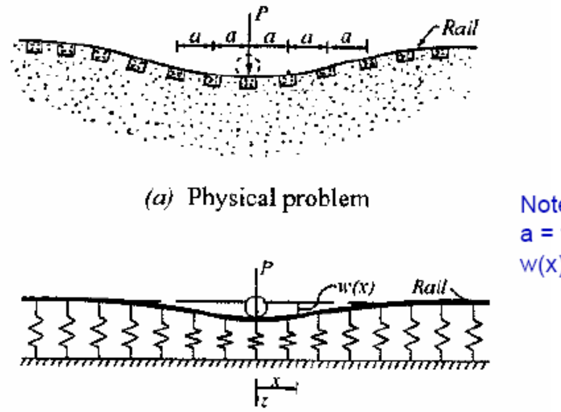



Source: Selig and Waters, Track Geotechnology and Substructure Management, 1994

3

## Classic Approach to Track Analysis and Design

- Continuously supported beam




(a) Physical problem

(b) Analytical model for rail analysis

Notes:
a = tie spacing "s"
w(x) = deflection "y"

Source: Kerr, A.D., Fundamentals of Railway Track Engineering, 2003

## FRA Classes of Track

Part 213 -- Subparts A to F for Class 1-5, Subpart G for Class 6-9

[In miles per hour]

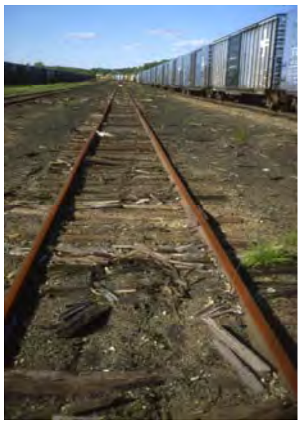
| Over track that meets all of the requirements prescribed in this part for— | The maximum allowable operating speed for freight trains is— | The maximum allowable operating speed for for passenger--trains is— |
|---|---|---|
| Excepted track | 10 | N/A |
| Class 1 track | 10 | 15 |
| Class 2 track | 25 | 30 |
| Class 3 track | 40 | 60 |
| Class 4 track | 60 | 80 |
| Class 5 track | 80 | 90 |

| Over track that meets all of the requirements prescribed in this subpart for— | The maximum allowable operating speed for trains[1] is— |
|---|---|
| Class 6 track | 110 m.p.h. |
| Class 7 track | 125 m.p.h. |
| Class 8 track | 160 m.p.h.[2] |
| Class 9 track | 200 m.p.h. |

Class 1 Track
10 mph or less

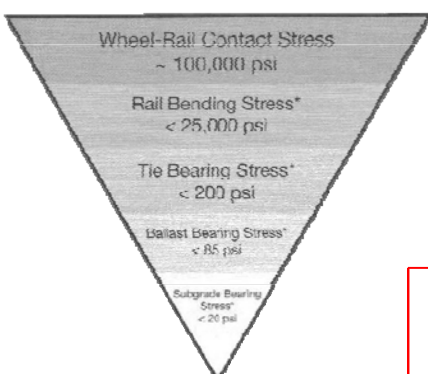
Class 2 Track
25 mph freight
30 mph passenger

Class 4 Track
60 mph freight
80 mph passenger



# Static Wheel Loads

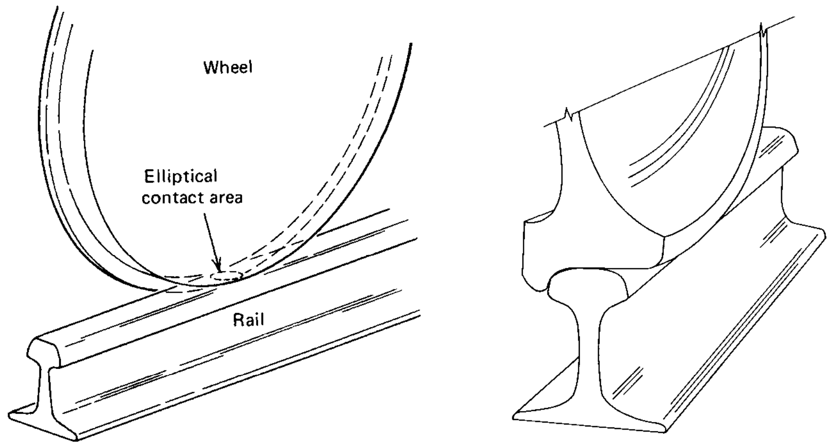
(Wheel Load)(# of wheels) = Gross Weight of Car




| Axle Load | Gross Weight of Cars | |
|---|---|---|
| Axle load (tons) | Gross weight of cars (lbs) | Type |
| 10 | 80,000 | Light rail transit |
| 15 | 120,000 | Heavy rail transit |
| 25 | 200,000 | Passenger Cars |
| 25 | 200,000 | Common European freight limit |
| 27.5 | 220,000 | U.K. and Select European limit |
| 33 | 263,000 | North American free interchange limit |
| 36 | 286,000 | Current Heavy Axle load weight for North American Class 1 |
| 39 | 315,000 | Very limited use; research phase |

Heavy Tonnage Freight

# Wheel/Rail Contact "Patch"

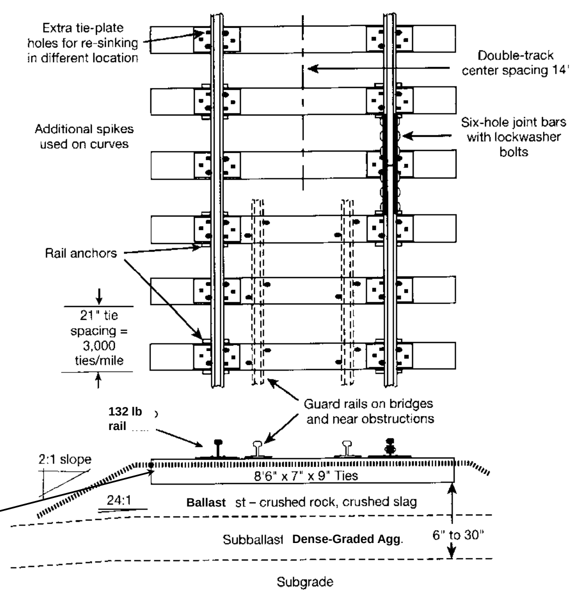



The contact "patch" is about the size of a dime

=0.50 $in^2$

# Track

- Track is a dynamic system of interacting components that distributes the loads and provides a smooth, stable running surface for rail vehicles.
- System must provide *vertical, lateral and longitudinal stability*




9"wide x 7"thick x 9' long

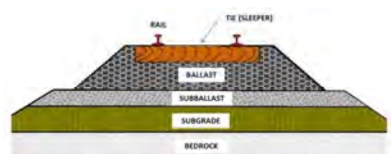
# Track Design and Construction

Desirable Attributes:

- ✓ Balance Stiffness and Resiliency
- ✓ Resistance to Permanent Deformation
- ✓ Stability
- ✓ Adjustability

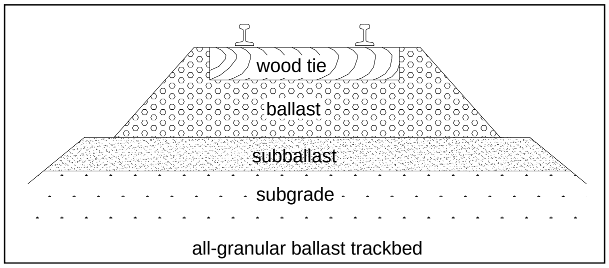

- A profitable RR must have good track.
- Track is apparently a simple structure, has changed little
- Loadings (pressures) must be reduced through the rail, ties, ballast and subballast to within the bearing capacity of the underlying subgrade.

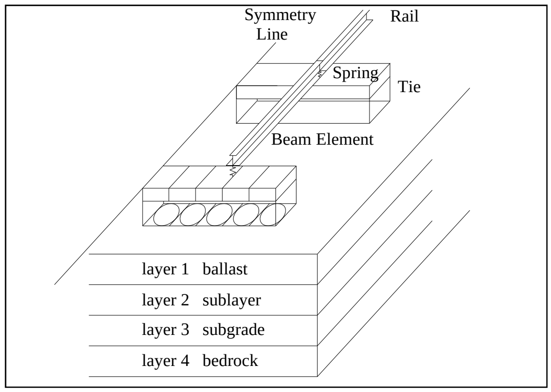
## Methods used to design track and cross-section

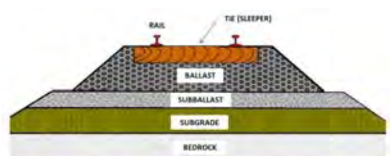



  - Trial and Error
  - Empirical – based on trial and error
  - Empirical/Rational – measure loadings and material properties
  - Rational – stress/strain analysis and measurements

- Trackbed is NOT the permanent way – varies greatly, must be maintained continuously




- Requirements
  - It acts as an elastic, load-distributing structure, thus the load distribution depends on the STIFFNESS and FLEXIBILITY of the track.
  - Assume a 100-ton car: wheel load = 33,000 lbf on rail. Area of contact is assumed to be 0.5 sq in., thus contact stress is 66,000 psi static (dynamic more)
  - Average subgrade will support 20 psi (1.4 ton/sq ft). Thus, the rail, ties, ballast, etc. must reduce 66,000 psi to 20 psi or problems will occur.

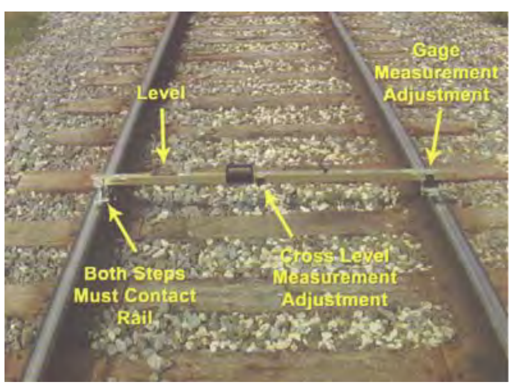
## Trackbed is subjected to a variety of loads and stresses

- Dead loads
- Live loads
- Dynamic loads
- Centrifugal loads
- Lateral loads – hunting and nosing of wheels
- Thermal loads – continuously welded rail (CWR)
- Longitudinal loads – wave action

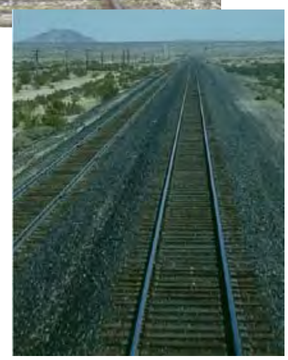

- 263,000 lb/8
  =33,000 lb/wheel
- 286,000 lb/8
  =36,000 lb/wheel
- 315,000 lb/8
  =39,000 lb/wheel
- Axle (ton)=
  (wheel load(lb) X 2)/2000

- Each component distributes the load.
  - STIFFNESS (resistance to deflection)
  - RESILIENCY (elasticity)
  - RESISTANCE TO PERMANENT DEFORMATION
    - Chap 26, pages 593-597, track geometry terms
      - Gage
      - Line
      - Surface
  - STABILITY
  - ADJUSTABILITY
  - GOAL – safe and cost effective

- Gage (or gauge) – transverse distance between the rails measured 5/8 inch from top-of-rail



- Line – adherence of the centerline of the track to the established alignment and to corresponding presence or lack of irregularities or departures



- Surface – adherence to established grade and uniformity of cross-level in the plane across the heads of the two rails and adherence to the established superelevation on curves

# TRACK ANALYSIS

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

# Track Stiffness (or Modulus)

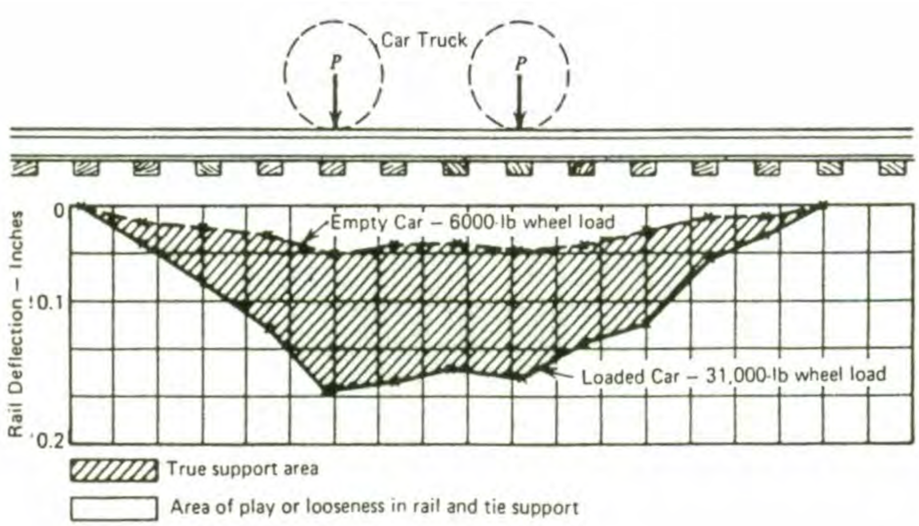
- Up and down movement (pumping) of track under repetitively applied and released loads is a prime source of track deterioration.

- Design of track should keep deflection to a minimum.

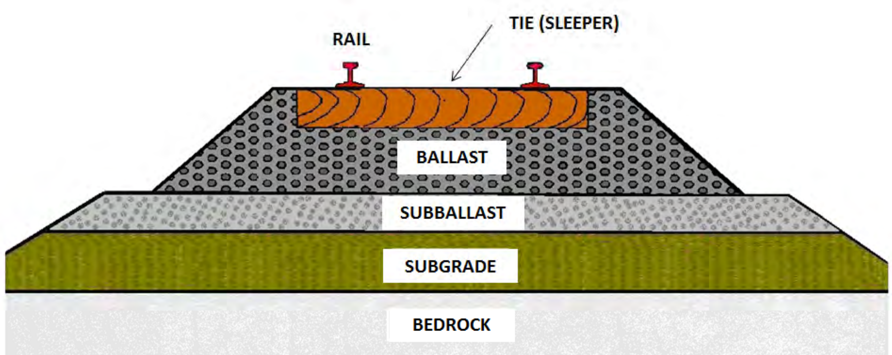
- Differential movement causes wear of track components.

- Modulus is defined: load per unit length of rail required to depress that rail by one unit.

## Track Deflections: Loaded and Unloaded




# Track Components




Typical "All-Granular" Ballasted Trackbed

# Subgrade

Use Typical
Soils/Geotechnical
Technology

Very Important

# Subgrade

Subgrades Vary

Evaluate

Stabilize ???

Top 2 Feet Important

# Subballast

Similar to Highway Base Material (DGA)

Fine Grained

Compacts Tight and Dense

# Ballast


Transmits Loadings
Anchors Track
Drains

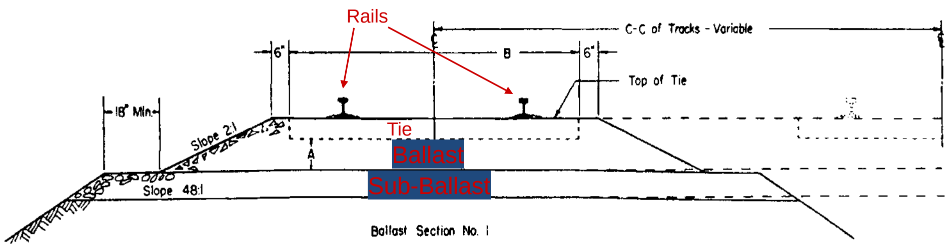
Resilience
Adjustable

- *Ballast* – permeable, granular material placed under and around the ties to promote track stability, hard and angular

# Types of Ballast

- Crushed Granite, Basalt, Traprock & Slag are best
  - high tonnage and mainlines
- Dolomite, Limestone
  - low tonnage line
- Gravel & Sand
  - yard tracks, maybe

# Ballast & Sub-Ballast cross-section*




- Ballast and sub-ballast are the final stages in load distribution
- In addition to distributing vertical loads, ballast has a critical role maintaining longitudinal and lateral stability of track.
- Ballast and sub-ballast must provide adequate drainage.
- Ballast is subject to pulverization from loading and unloading as trains pass over, thereby generating fine particles that clog the ballast

# Ballast Gradations

*Table 1-2-2. Recommended Ballast Gradations*

| Size No. (See Note 1) | Nominal Size Square Opening | Percent Passing | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 3" | 2½" | 2" | 1½" | 1" | ¾" | ½" | d" | No.4 | No. 8 |
| 24 | 2½" - ¾" | 100 | 90-100 | | 25-60 | | 0-10 | 0-5 | – | – | – |
| 25 | 2½" - d" | 100 | 80-100 | 60-85 | 50-70 | 25-50 | – | 5-20 | 0-10 | 0-3 | – |
| 3 | 2" - 1" | – | 100 | 95-100 | 35-70 | 0-15 | – | 0-5 | – | – | – |
| 4A | 2" - ¾" | – | 100 | 90-100 | 60-90 | 10-35 | 0-10 | – | 0-3 | – | – |
| 4 | 1½" - ¾" | – | – | 100 | 90-100 | 20-55 | 0-15 | – | 0-5 | – | – |
| 5 | 1" - d" | – | – | – | 100 | 90-100 | 40-75 | 15-35 | 0-15 | 0-5 | – |
| 57 | 1" - No. 4 | – | – | – | 100 | 95-100 | – | 25-60 | – | 0-10 | 0-5 |

Note 1: Gradation Numbers 24, 25, 3, 4A and 4 are main line ballast materials. Gradation Numbers 5 and 57 are yard ballast materials.

Similar to ASTM Specifications for Aggregate

### 2.11.2.5 Sub-ballast Materials

a. Material most commonly available for use as sub-ballast are those aggregates ordinarily specified and used in construction for highway bases and subbases. These include crushed stone, natural or crushed gravels, natural or manufactured sands, crushed slag or a homogeneous mixture of these materials. Other natural on site materials conforming to proper engineering standards and specifications as may be defined by individual railway companies may be used.

b. The sub-ballast shall be a granular material so graded as to prevent penetration into the subgrade and penetration of track ballast particles into the sub-ballast zone. Applying the filter principle used in drainage to the grading of the subgrade material will determine the grain size distribution of the sub-ballast. Most state highway specifications include standard gradations for dense graded aggregate (DGA) and aggregate base course (ABC). These gradations may meet the requirements for use as sub-ballast. Other standard gradations may also meet these requirements.

c. Prepare the gradation curve for the sub-ballast by plotting the grain size distribution for the subgrade on a semi-logarithmic paper, using the logarithmic scale for the grain sizes and the natural scale for percent passing. Determine the grain-sizes at 15%, and 50% points on the chart. Use these values with relevant ratios from Table 1-2-3 to compute the limiting grain sizes at the 15% and 50% passing lines on the chart. The maximum grain size of the sub-ballast must not exceed the maximum grain size of the track ballast. No more than 5% of the sub-ballast should pass the No. 200 sieve. Construct lines connecting the minimum and maximum points to set limits for the sub-ballast material. See example Figure 1-2-5.

**TABLE 21.2 Grading Specifications for Densely Graded Aggregates and Subballasts**

| Sieve Size | 2 in. | 1 in. | $\frac{3}{8}$ in. | No. 10 | No. 40 | No. 200 |
|---|---|---|---|---|---|---|
| Percentage Passing (Optimum) | 100 | 95 | 67 | 38 | 21 | 7 |
| Permissible Range Percentage Passing | 100 | 90-100 | 50-84 | 26-50 | 12-30 | 0-10 |

Track
Settlement and
Pumping

Surface Problem
(Cross Level)

## Profile Trouble Spots

## Fouled, Muddy, Pumping Track

# Types of Ties (Sleepers)

Timber

Concrete

Composite (Polymeric)

Steel

# Wood Railway Ties

- Common Size
  – 9 in. wide
  – 7 in. thick
  – 8.5 – 9 ft. long
- Purposes
  – Hold the 2 rails transversely secure to correct gage
  – Bear and transmit axle loads with decreased pressure
  – Anchor the track

# Typical Concrete Tie

- ~ 3 times heavier than wood ties,
- More expensive than wood ties
- Pre-cast, Pre-Stressed, fastenings embedded

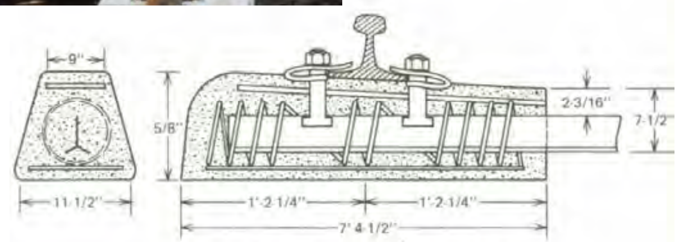
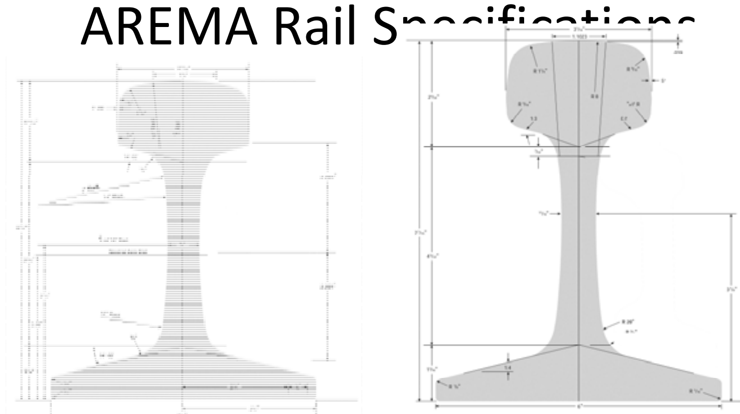



Figure 23.4. Two-block (RS-type) tie.

## Concrete Slab Track – Direct Fixation

## Bolted Rail /Joints versus Continuously Welded Rail (CWR)

## AREMA Rail Specifications



- Rail specifications are maintained by AREMA
- Rail size is measured in lbs./yard of length
- Most common new rail is 115 lb., 136 lb., & 141 lb.
- Type – Standard, Intermediate*, Premium

48

# Types of Steel Rail

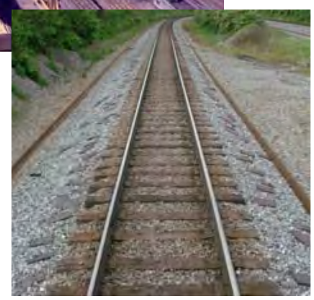
- Standard Medium Carbon 
- Head Hardened 
- Fully Heat Treated 
- Also Hi Si, CHRO/MOLY and Bainitic

Intermediate Hardness Rail ???????

# Rail Stamping

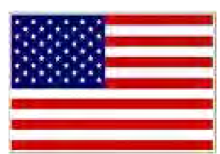
## Continuously Welded Rail (CWR)

- 1440 ft. sections
- Advantages
  Many
- Disadvantages
  Few



## United States Applications

Since 1981



- Short Maintenance—Road Crossings, Turnouts, Rail Crossings, Tunnels, Bridge Approaches, WILDS, etc.
- Capacity Improvement—Double Tracking, Line Changes, etc.



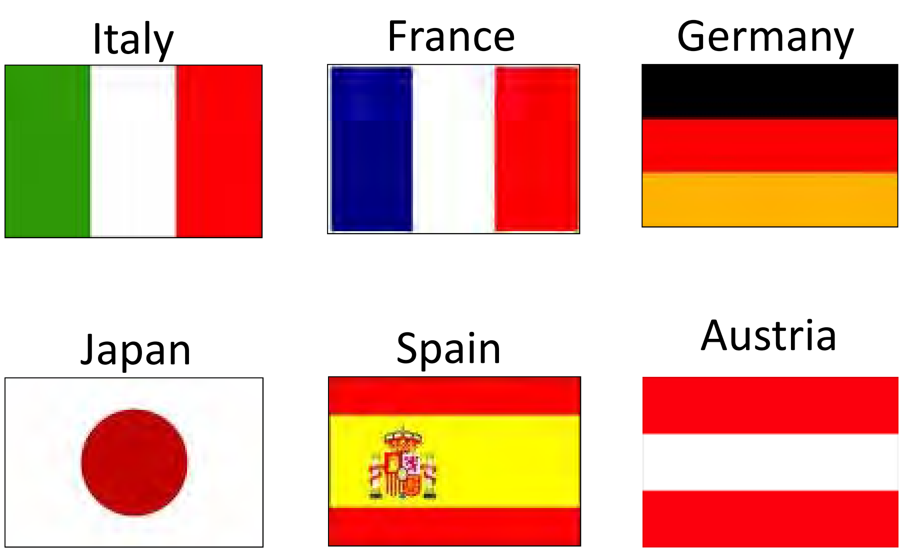






SW Durham Rd.
May 15-16, 2010

## International Applications



# Italy

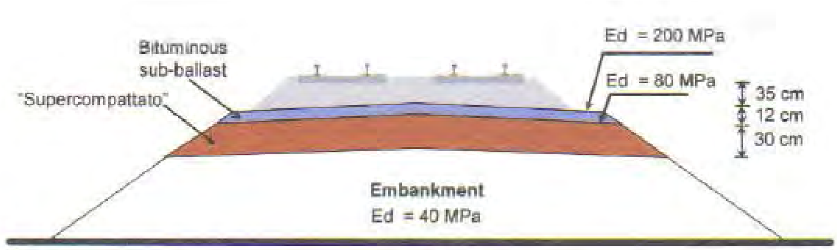
- Rome-Florence: 252 km (1977-1986)
- Debated between cement and asphalt
- Asphalt – designated on all future high-speed passenger lines


- Prevents rainwater from infiltrating the layers below the embankment
- Eliminate high stress loads and failures of the embankment
- Protect the upper part of the embankment from freeze/thaw actions
- Gradually distribute static and dynamic stresses caused by trains
- Eliminate 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




- 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

Teixeira, 2005


# Japan


- Widely Used
- High Speed/Regular
- Firm Support for Ballast
- Reduce Load Level on Subgrade
- Facilitate Drainage

Momoya and Sekine, 2007

## New Railway Roadbed Design

**Yoshitsugu MOMOYA**
Assistant Senior Researcher, Track Structures and Geotechnology, Track Technology Division

When laying track on earth structures, roadbed performance is extremely important for controlling track settlement and dynamic deflection. In order to meet roadbed performance demands in Japan, concrete roadbed is used for slab track (Fig. 1), and asphalt roadbed is used for ballasted track (Fig. 2); this structure is also standard for the Shinkansen bullet train. The roadbed design methods are described in the "Design Standard for Railway Structures (Earth Structures)." In the January 2007 revision to this design standard, a performance based design method was introduced.

As the previous Design Standard for Railway Structures (Earth Structures) was based on specifications, the thickness of each layer of the roadbed design was specifically defined. With the performance based design method, however, it has become possible for the designers to design roadbed thickness to satisfy roadbed performance requirements. Specifically, by considering the fatigue life related to the number of trains, a method of designing thickness according to the importance of a particular section of track is described. Also, while the previous design concept was not consolidated with regard to a concrete roadbed for slab track or an asphalt roadbed for ballasted track, with this revision the roadbed design methods have been grouped together systematically.

With the new design standard, the earth structure performance rank for the relevant track is determined by the relative importance of the section of track and the track type. When designing the roadbed, a type of roadbed is selected to suit each of the various performance ranks. For performance rank I, concrete roadbed or asphalt roadbed for ballastless track is selected; for performance rank II, asphalt roadbed for ballasted track is used; and for performance rank III, crushed stone roadbed for ballasted track is selected. After the type of roadbed has been selected in this way, the roadbed structure design is carried out.

In the case of a concrete roadbed (Fig. 3), the following effects of train loads are checked for: displacement of the roadbed, breakage of the reinforced concrete base, fatigue damage, cracking, contraction, and thermal stresses. For asphalt roadbeds, the following effects of train loading are checked: displacement of the roadbed and fatigue damage of the asphalt mixture layer. In particular, in the case of an asphalt roadbed for ballasted track (Fig. 4), fatigue failure had not been considered in the previous design; however, this time a design method based on fatigue life has been introduced.

In this way, by systemizing roadbed design thinking to suit the design standard revision, and with the introduction of the performance-based design method, flexible design to suit the importance of the track section has now been made possible.

- Performance Rank I: Concrete roadbed or asphalt roadbed for ballastless track
  - Concrete base thickness = 190 mm
  - Asphalt base thickness = 150 mm
  - Stone base thickness = 150 mm
- Performance Rank II: Asphalt roadbed for ballasted track
  - Ballast thickness = 250-300 mm
  - Asphalt base thickness = 50 mm
  - Stone base thickness = 150-600 mm
- Performance Rank III: Crushed stone roadbed for ballasted track

# Ballastless Cross Section

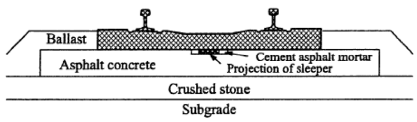



**Fig. 1** The first test track of solid bed track on asphalt pavement

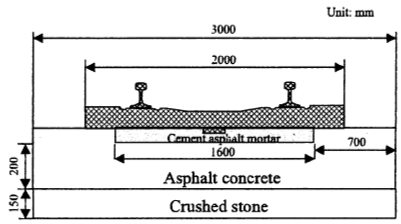



**Fig. 7** Cross section of the improved solid bed track on asphalt pavement

- Mainly used for viaducts and tunnels
- Proposed a low noise solid bed track on asphalt pavement

# Ballasted Cross Section

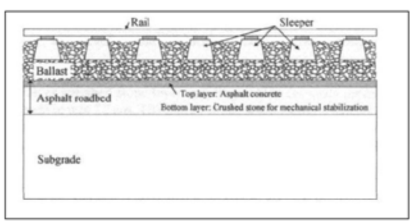



Figure 12: Performance Rank II Cross-Sectional Profile (Momoya and Sekine, 2007)

- Asphalt Thickness:
  5 cm
- Well-Graded Crushed Stone Thickness:
  15-60 cm

# France


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

# Comparative Cross-Sectional Profiles

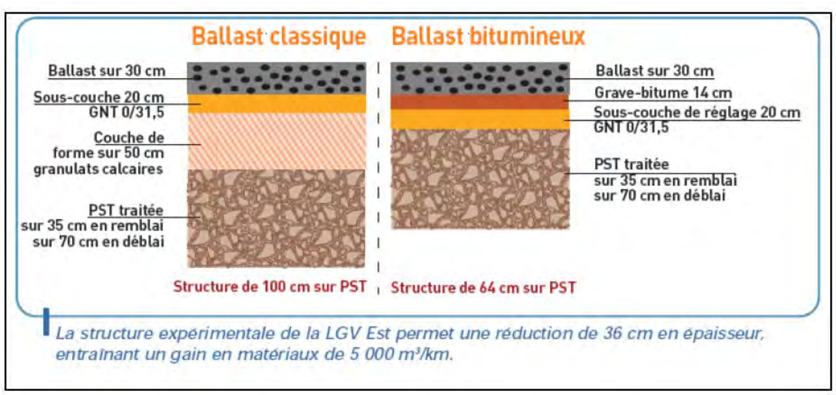



Figure 13. Traditional and Asphalt Cross Sections (Bitume Info, 2005)

Figure 14. Asphalt Placement and Compaction (Faure, 2005)

- Reduces overall cross-sectional thickness by 36 cm
- Reduces quantity of fill material by 5,000 cubic meters/ kilometer

Bitume Info, 2005

# Testing

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

# Spain

- Madrid – Valladolid
- Barcelona – French Border

Figure 15. Bituminous subballast sections built on the high-speed line Madrid-Valladolid, section between Segovia and Valdestillas (left) and on the high-speed line Barcelona-French Border, section Sils-Riudellots (right). Source: Teixeira (2009).

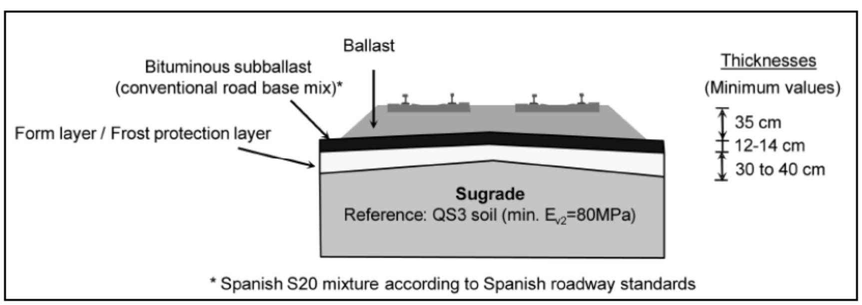



Figure 16. Track design with bituminous sub-ballast for Spanish high-speed lines standards. Source: Teixeira et al. (2009)

# Germany

- Utilize several alternatives to conventional ballast design
- German Getrac A1/A3 – ballastless slab consisting of asphalt
- Concrete ties are anchored to the asphalt

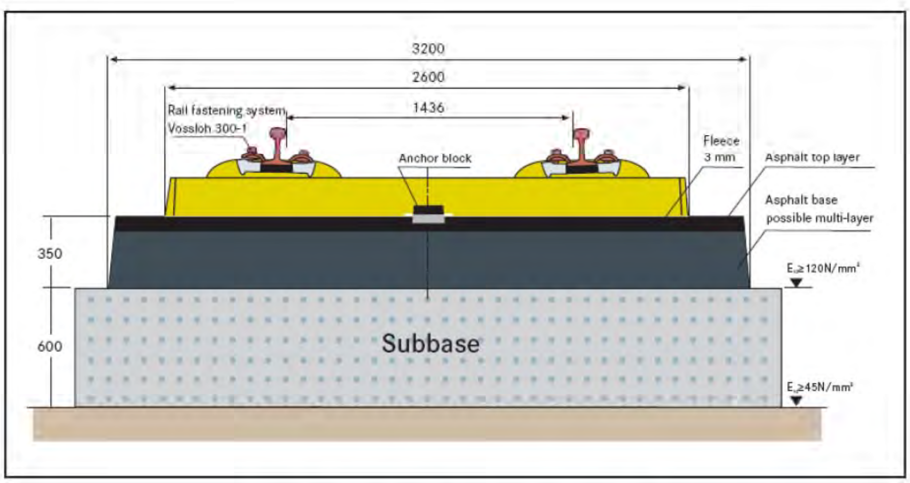



Figure 18. German Getrac A1 Cross Sectional Profile

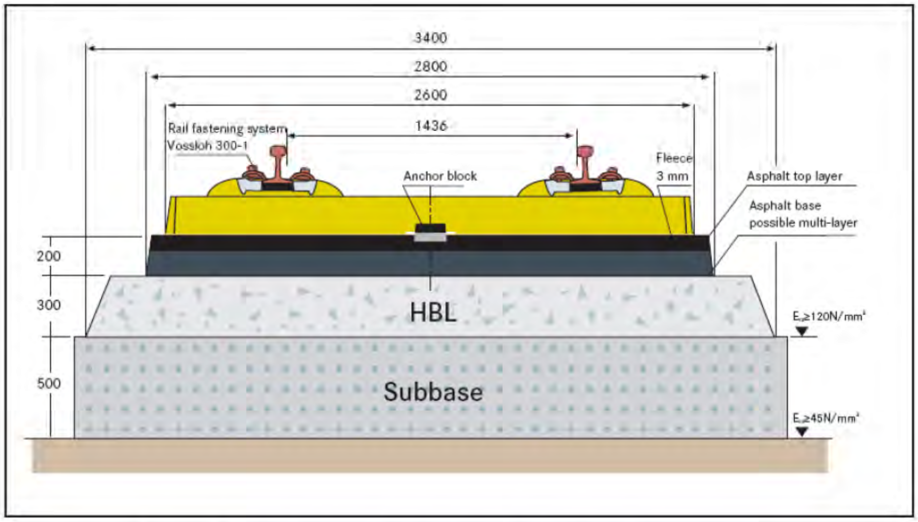



Figure 19. Getrac A1 Cross Sectional Profile with Hydraulically Bound Layer

Figure 21. Paving with Asphalt

Figure 22. Installation of Concrete Ties

Figure 23. Finished Getrac A3 Track at Brandleite Tunnel

# Austria


# 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


## 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.

# 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.

Picture a to c: new Koralm link

Picture d: Schoberpass-line, built in 1991