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

NURail Project ID: NURail2012-UKY-E01

Rail Engineering and Education Symposium Materials

By

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05-26-2016

Grant Number: DTRT12-G-UTC18 (Grant 1)

DISCLAIMER

Funding for this research was provided by the NURail Center, University of Illinois at Urbana - Champaign under Grant No. DTRT12-G-UTC18 of the U.S. Department of Transportation, Office of the Assistant Secretary for Research & Technology (OST-R), University Transportation Centers Program. The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. This document is disseminated under the sponsorship of the U.S. Department of Transportation's University Transportation Centers Program, in the interest of information exchange. The U.S. Government assumes no liability for the contents or use thereof.

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TECHNICAL SUMMARY

Title

Rail Engineering and Education Symposium Materials

Introduction

The objective of this project is to develop curricular materials for the Rail Engineering and Education Symposia held in the summers of 2012 and 2014.

Description of Activities

The main approach to accomplish the activity is to develop and deliver power point facilitated lectures. Two topics are included: Introduction to Railway Infrastructure and KENTRACK 4.0 Railway Trackbed Structural Design and Analysis Program and Tutorial. The intended target group is college-level educators. Students are generally civil engineering instructors seeking advanced knowledge of rail engineering for use in their own classes. The main deliverables are the two accompanying power point presentations (2014 revised versions). Several other education-oriented papers and presentations were prepared and delivered as described below (list of activities).

Outcomes

The major results of this project are two modules prepared and delivered at both 2012 and 2014 REES symposia. Included in the appendices of this report are the latest versions of these two presentations as well as a list of other education related papers and presentations produced.

Conclusions/Recommendations

The REES materials have been made available on the NURail and Kentucky Civil Engineering Department web sites. Dr. Rose is available to deliver REES lectures based on updates of these modules in 2016 and in the foreseeable future.

Publications/Examples

Appendix A: REES 2014 Module on Introduction to Railway Infrastructure

Appendix B: REES 2014 Module on KENTRACK 4.0 Railway Trackbed Structural Design and Analysis Program and Tutorial

Appendix C: List of other education related papers and presentations produced

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Appendix A: REES 2014 Module on Introduction to Railway Infrastructure

Introduction to Railway Infrastructure

Jerry G. Rose, PE
University of Kentucky
Department of Civil Engineering

- Roadway and Track
- Drainage Structures
  - Bridges
  - Culverts and Pipes
- Tunnels
- Terminals/Yards and Ports
- Buildings
- Environmental Facilities
- Signal Structures and Detectors
- Communications Structures

Major Rail-Related Agencies/Groups

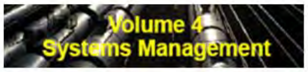
- **AREMA** – American Railway Engineering and Maintenance-of-Way Association
  - Technical society, individual professional members, primarily publishes Recommended Practices and other technical literature
- **AAR** – Association of American Railroads
  - Composed primarily of Railroad Companies that represent the industry in many ways, mainly large Class I railroads
- **ASLRRA** – American Short Line and Regional Railroad Association
  - Similar to AAR for Short Line and Regional RR Companies
- **FRA** – Federal Railroad Administration
  - Part of USDOT, mainly promulgates and enforces railway safety regulations
- **STB** – Surface Transportation Board
  - Part of USDOT, mainly and economic regulatory agency

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

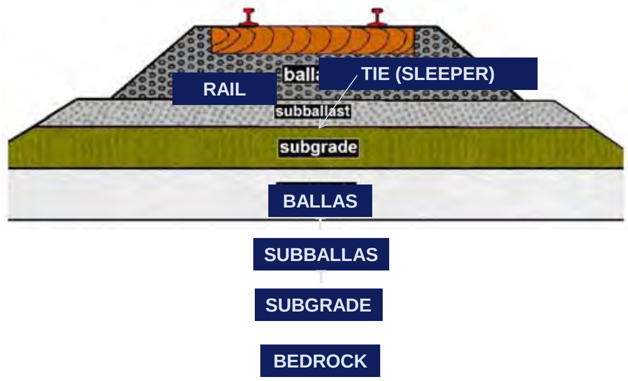
www.arema.org

Engineering Department's 4 Sub Departments

ENGINEERING

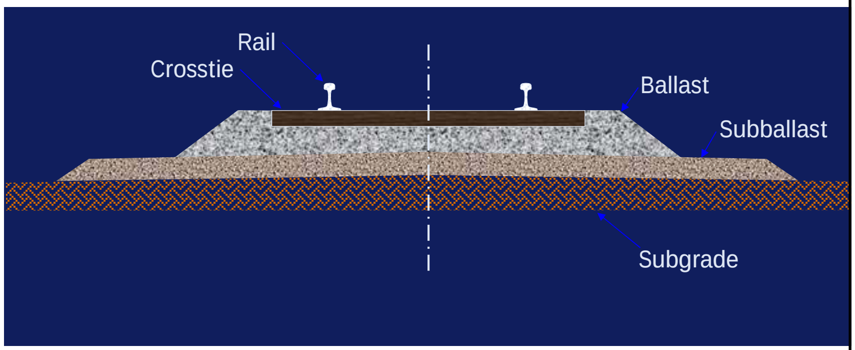
- Engineering Cost & Systems (EC&S)
- Design & Construction (D&C)
- Communications & Signals (C&S)
- Maintenance of Way & Structures (MW&S)

I. Roadway and Track



- Introduction
  - Track Supports and Guides
- Track Quality Determines
  - Permissible Wheel Loadings
  - Speed of Operation
  - Safety
  - Dependability of Operations
  - FRA Class 1-5 & 6-9

Track Cross-Section



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

Constantly evaluating
Alternatives
Benefits compared to Additional
Costs

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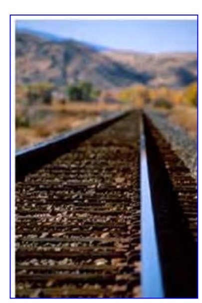
Track Functions

- Guide vehicles
- Provide a high vehicle ride quality
- Withstand and distribute loadings
  - Static (36 tons/axle)
  - Dynamic (Impact)



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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 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.

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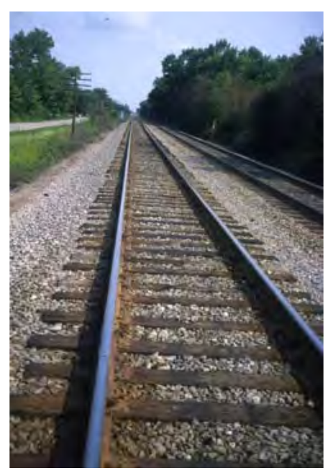
Class 1 Track

Class 2 Track

Class 4 Track



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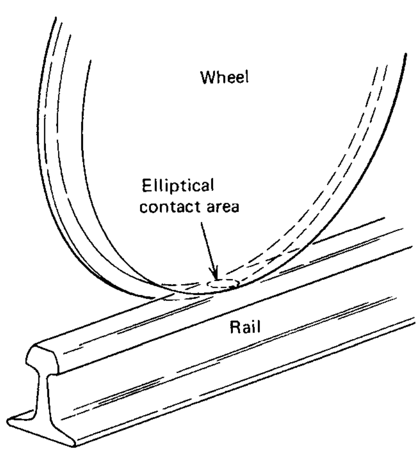
Static Wheel Loads

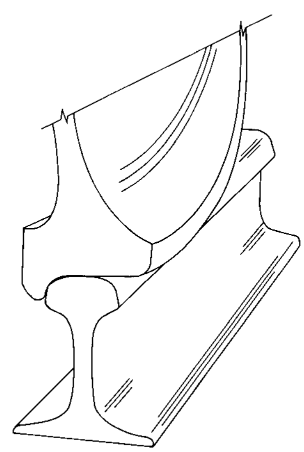
(Wheel Load)(# of wheels) = Gross Weight of Car

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"



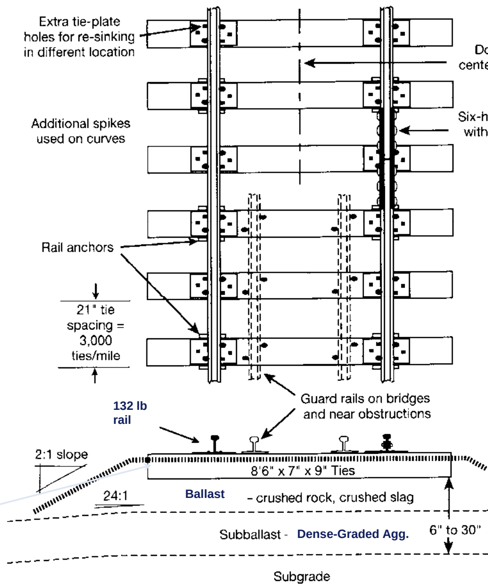


The contact "patch" is about the size of a dime

=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*

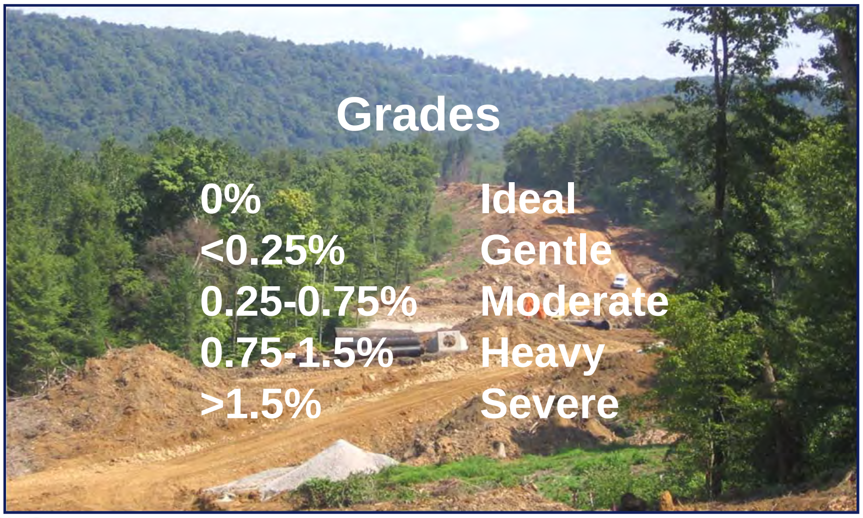


9"wide x 7"thick x 9' long

Track Design and Construction

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

Clearing, Site Preparation, and Installation of Erosion/Sediment Control



Mass Excavation and Installation of Drainage Structures

Roadbed (Subgrade) Fine Grading and Sub-ballast Placement

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Finished Roadbed – Ready For Track

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Track Construction

Unloading Ballast

Skeleton Track Ready for Ballast

Tamper Pulling Track

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Complete – Ready for Service

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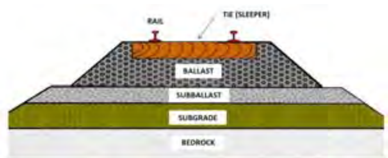
Methods used to design track and (structural) cross-section

- 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

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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

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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

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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.

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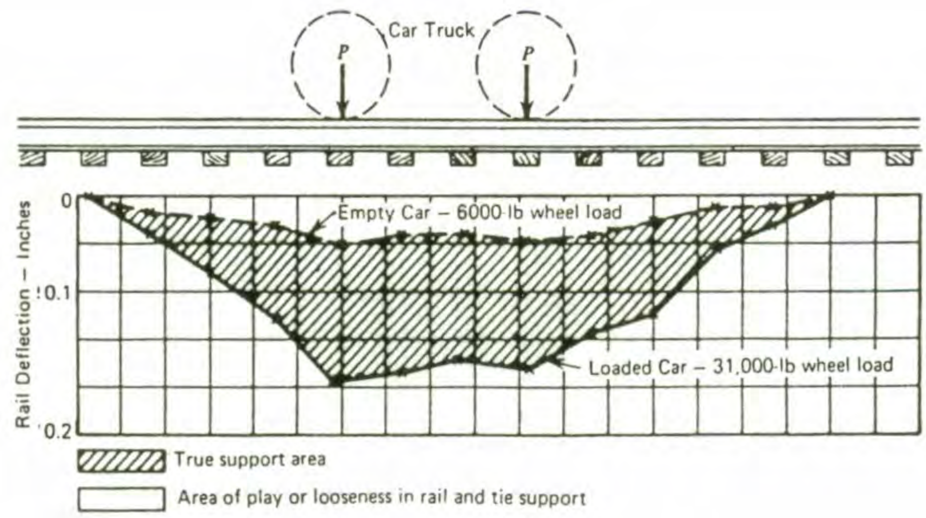
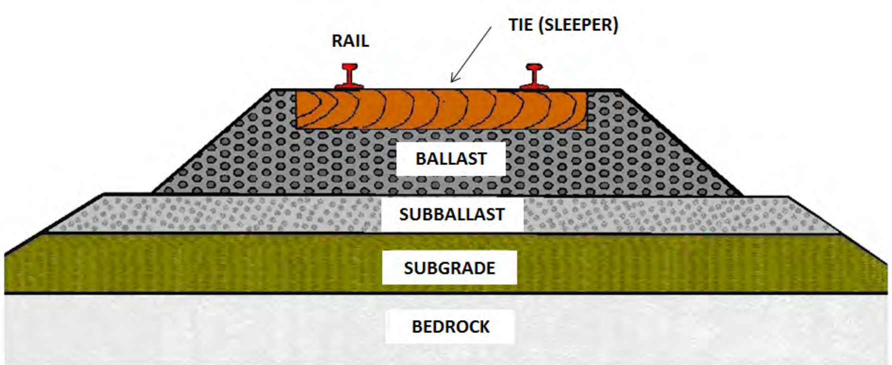


Track Deflections: Loaded and Unloaded

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 -- smaller size than ballast and more fine-size particles
- Compacts tight and dense with low % voids
- Separates and Waterproofs

Use AREMA Recommended Practices

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

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Types of Ballast

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

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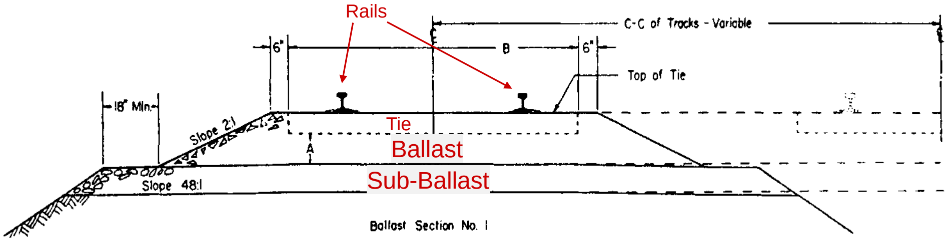
Ballast & Sub-Ballast cross-section*



- 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

* AREMA recommended practice.

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 (Wood)

Prestressed Concrete

Composite (Polymeric)

Steel

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Concrete
(gaining popularity and use)

Wood
(common)

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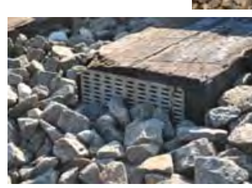
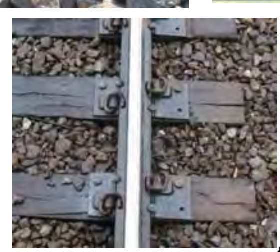
Wood Railroad Ties

- 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

Protections Against Mechanical Wear

- Tie plates
- Anti-Splitting devices
- Keep tie dry (rail seat)
- Use plate holding spikes or premium fasteners





Wood Tie Replacement Process

- Ties first marked for replacement
- Automated
- Accomplished by a "tie gang"

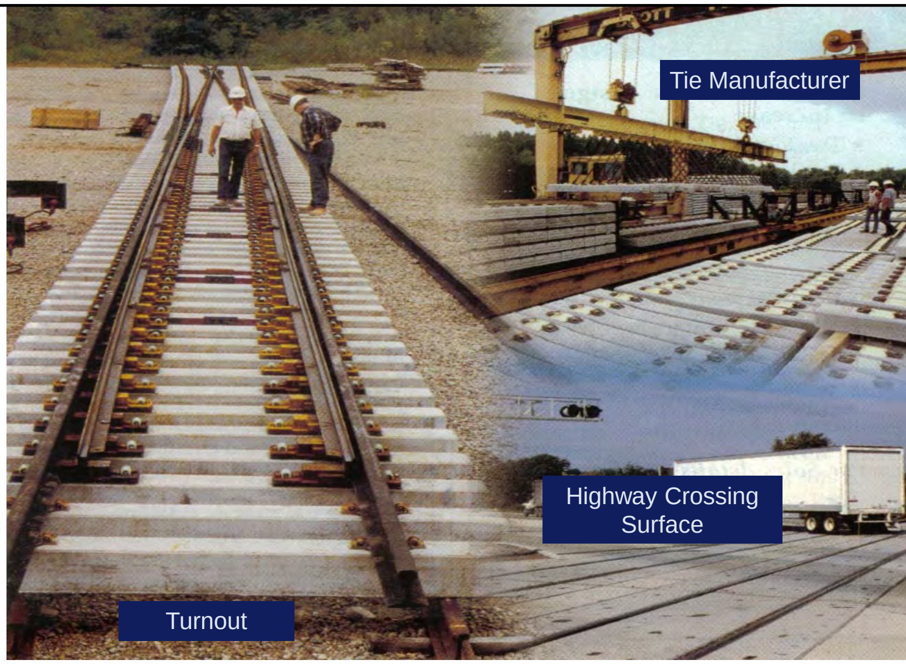
Production

800 per mile

4 miles per day

Typical Concrete Tie

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



Some Problems with Concrete Ties

Epoxy Repair of Concrete Tie Rail Seat Deterioration

Wear and Abrasion

Alternate Concrete Tie

Two-Block
or
Bi-Block

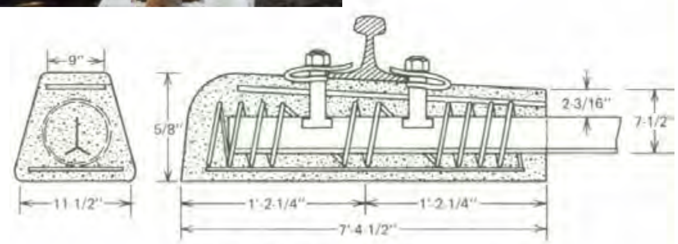
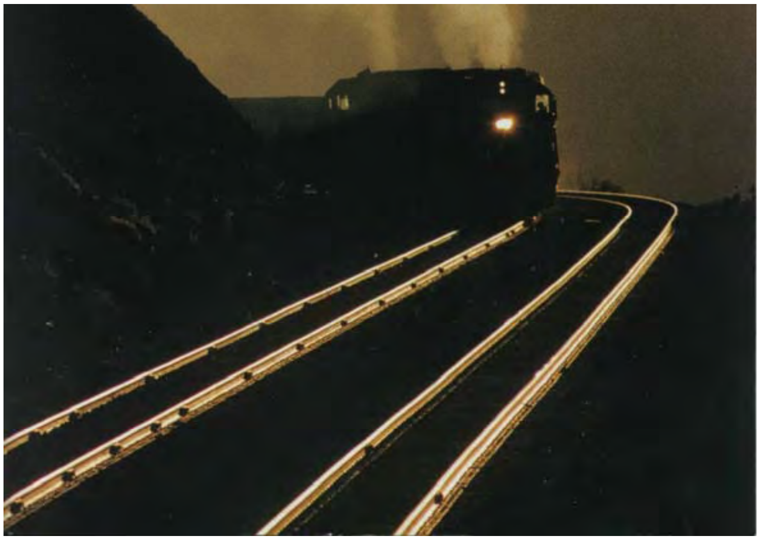


Figure 23.4. Two-block (RS-type) tie.

Concrete Slab Track – Direct Fixation

Bolted Rail /Joints versus Continuously Welded Rail (CWR)



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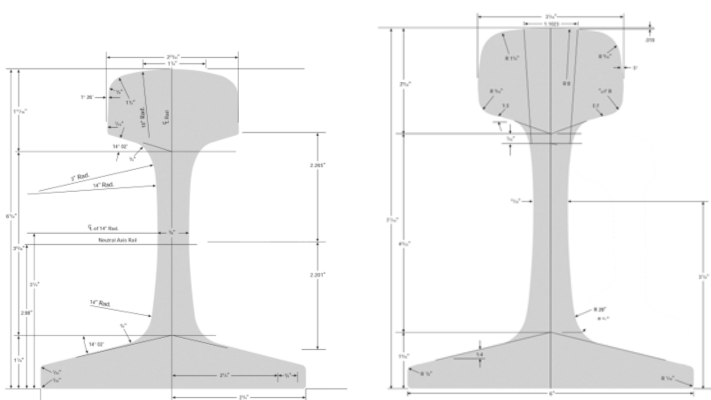
AREMA Rail Specifications



- 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

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52

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Types of Steel Rail

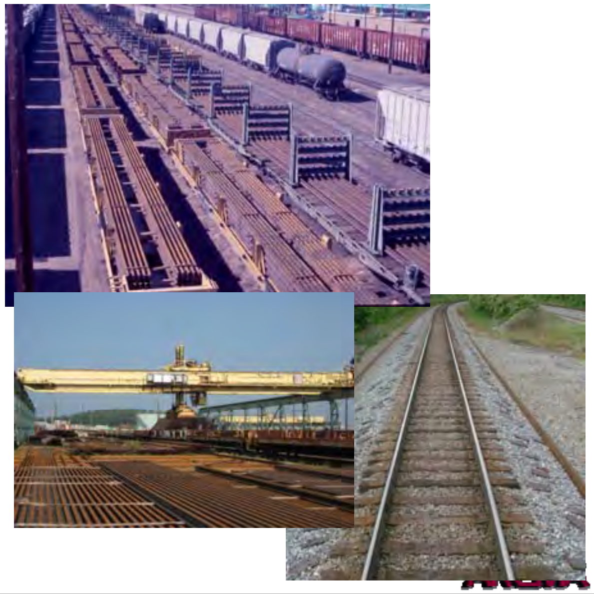
- Standard Medium Carbon 
- Head Hardened 
- Fully Heat Treated 
- Also Hi Si, CHRO/MOLY and Bainitic

Intermediate Hardness Rail ???????

Rail Brand Identification

Continuously Welded Rail (CWR)

- 1440 ft. sections
- Advantages
  Many
- Disadvantages
  Few



Largest and Premium Rail for:

- Heaviest Volumes
- Heaviest Loadings
- Highest Speeds

- High Degree Curves & Steep Grades
- Where Safety is a Priority

Current Rail Steel Technology

- Three U.S. Steel Mills roll rail – Arcelor-Mittal in Steelton, PA, Steel Dynamics in Columbia, IN, and Evraz Rocky Mountain Steel in Pueblo, CO
- Rail is imported from eight or more countries, very little exported from U.S. except small amount in Western Hemisphere
- Typical Weights rolled are 115/119, 132/133, and 136/141
- Primary Objectives – produce lower wear rates
  provide higher fatigue resistance
- Rail Hardness has increased over time
- Pearlitic is the primary steel used in rail manufacture, some interest in developing Bainitic steel for rail

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Current Rail Steel Technology (cond't.)

- Rail is produced in Three Strength/Hardness levels or grades
  Standard Strength/Hardness – Brinell Hardness of ~ 300
  Intermediate Strength/Hardness – Brinell Hardness of ~ 350 to 360
  Premium Strength/Hardness – Brinell Hardness of ~ 390
- Very little Standard Strength/Hardness Rail produced today
- More Intermediate and Premium Rail produced today
- Hardness is about maxed out, so attempting to improve fatigue resistance
- Cleanliness has been improved with vacuum degasing and inspection
- Can Alloy* or Heat-Treat Steel to get Intermediate and Premium grades
  *sometimes problems with welding alloy steel

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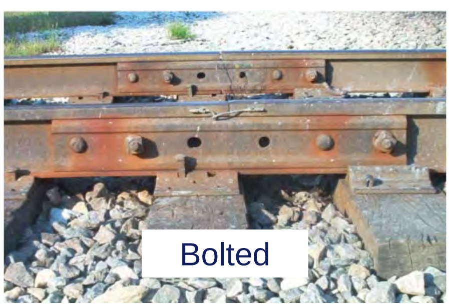
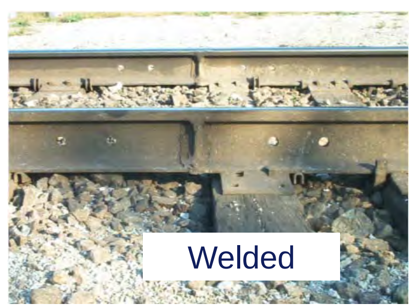
CWR Maintenance

- Need Adequate Ballast Restraint
- Should Anchor Slightly Above Mean Annual Temperature
- Don't Disturb in Hot Temp.
- Broken Rail in Cold Temp.
- Buckled Track in Hot Temp.

Rail joints – Bolted vs. Welded

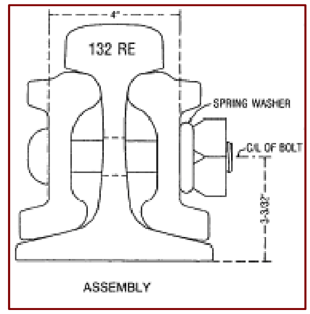




- No more “clickety clack”
- Most North American mainline track is now made of “continuously welded rail” (CWR)
- Eliminates dynamic loads at joints
- Improves ride, reduces maintenance requirements and extends roadbed and other track component life

Rail Joints

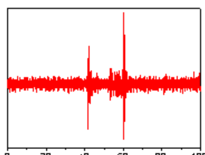
- Properly align rail ends
- Provide structural support
- Allow thermal movement of rail



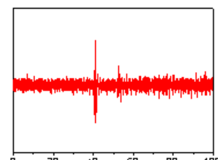
Improving the Life of Rail

- Curve Reduction
- Rail Lubrication
  - Top of Rail
  - Gage Face
- Rail Grinding
- Improved Rail Quality
- Defect Detection

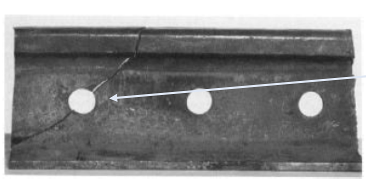
Rail Testing



- •Magnetic Induction
- •Ultrasonic



Rail Defects and Failure



Kind of Defect	Per Cent of Total
Head / Web Separation	43 %
Bolt Hole Break	29 %
Vertical Split Head	21 %
Base Break	4 %
Split Web	1 %
Sudden Rupture	1 %
Horizontal Split Head, Detail Fracture, Other Misc.	1 %
	100 %

Rail Grinding
Preventative or Corrective

Severely Corrugated Rail

Welds

Thermite Weld

Electric Flash Butt Weld

Fastenings and Other Track Material

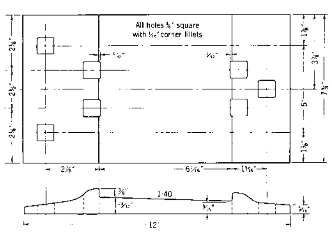
Transition Rail, tapered

Insulated Joint

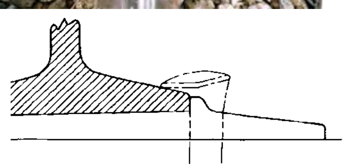
Transition Joint Bars (Compromise Joints)

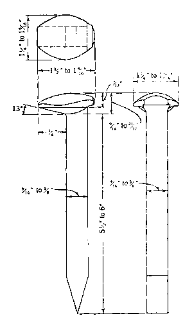
Fasteners & Tie Plates

- Tie plate supports the rail and distributes the load over a larger section of the tie surface.
- Fasteners (cut spikes are the most common type in NA) hold the track in gauge. Cut spikes do not provide much vertical restraint.
- Along with fasteners, ties provide gauge restraint and further distribute the load into the ballast.



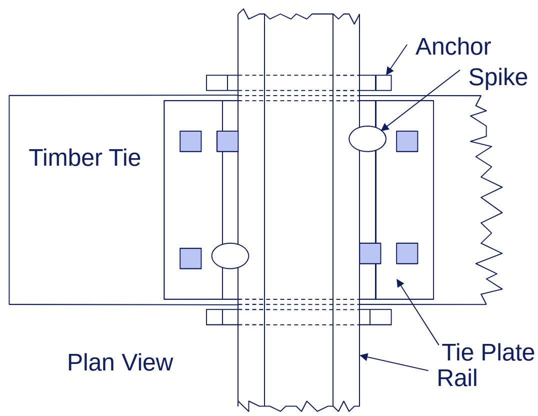
Tie plate

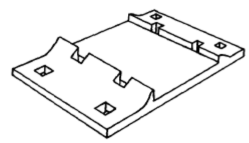




Standard "cut" spike

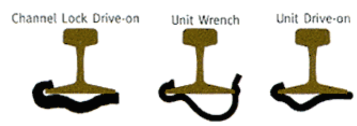
Timber Tie and Associated Components





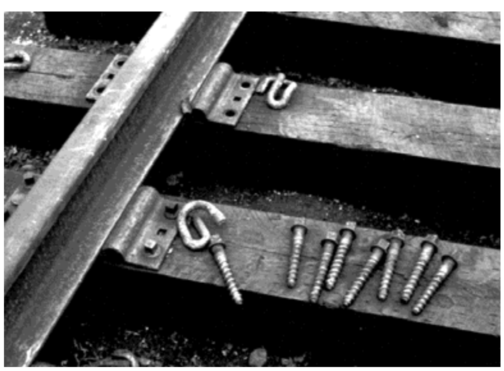
Double Shoulder Tie Plate

Cut Steel Track Spike



Rail Anchors

Screw Spikes and Spring Clips



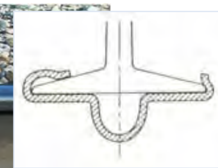
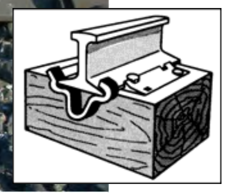
- Considered a “premium” system for fastening rail to ties
- more expensive than conventional cut spikes and tie plates

Premium Fastening Systems

- Concrete or steel ties
- Variety of spring fasteners
- Justification for their use is based on demands on the track system
  - High Tonnage and Wheel Loads
  - High Speed
  - Maintenance objectives
- Ultimately a matter of economics
- Is it cost effective given the particular circumstance of construction and operation to invest in more costly, but better-performing components and systems?
- That is, if I spend more to build it, will I spend less maintaining it?

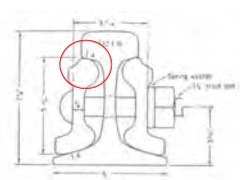
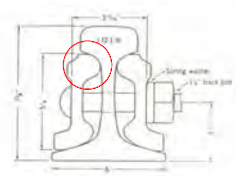
Representative Rail Fasteners

Rail Anchors

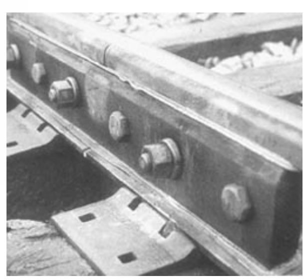
- Provide longitudinal restraint of rail
- Anchors are spring clamps that attach to the rail
- They are mounted adjacent to ties
- With enough in place, they prevent rail from “running” due to thermal, tractive or braking forces
- Objective is homogeneous distribution of contained stress in rail

Joint Bars

Head Contact vs. Head-Free Contact Joint Bars

Compromise Joint



Insulated Joint

A “Poor Man’s Railroad”

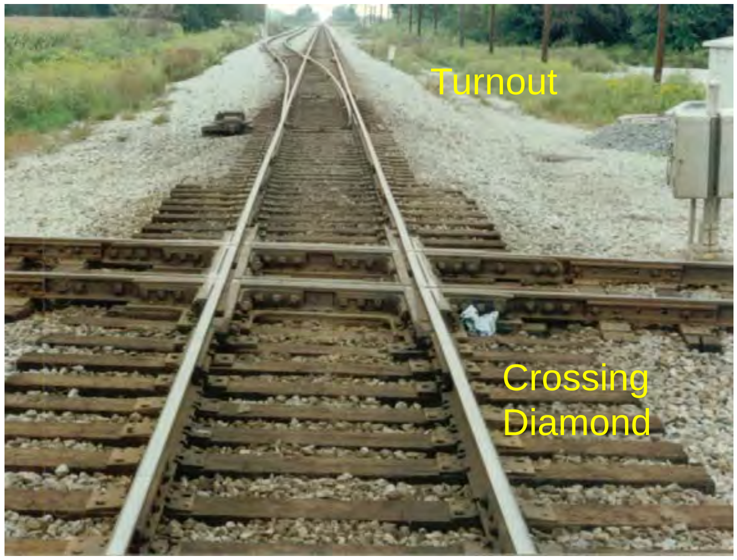
Gage Rods used to hold gage

Expansion Joints

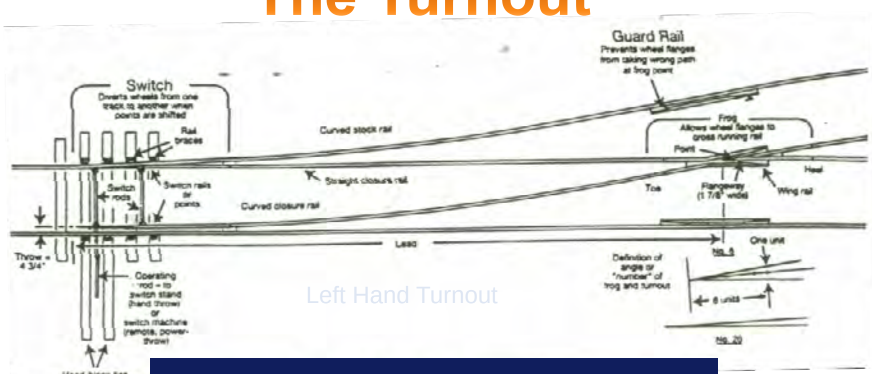
Near Movable Track such as at Moveable Bridges

Expansion joints are provided in running rails to allow for temperature changes. The additional rails in the centre of the track are bolted to the sleepers to prevent the sleepers being shifted by rail expansion.

Special Trackworks



The Turnout



Typical Turnout Proportions				
Frog No.	Turnout Lead Ft.	Sharpness of Curve	Max Speed on Diverging Route	Typical Locations
6	48	21°	10 mph	Industry tracks
8	67	12°	15	Yards
12	97	5°	25	Low speed crossovers
16	131	3°	30	Passing tracks
20	152	1.75°	45	Junctions, end of double track

No. 24 Turnouts being used for high

Switch Machines

Remote Electric Throw

Hand Throw

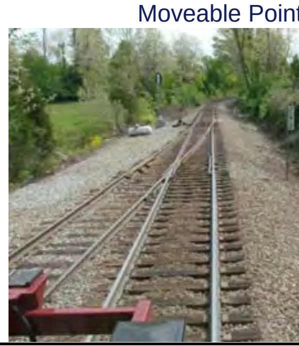
Switch Heater

Frogs

- Permit the wheel flange to cross over opposing rail in turnouts & crossings.

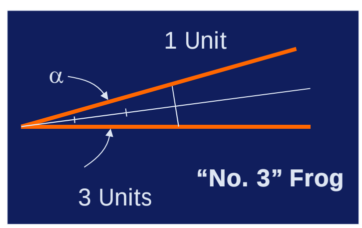
Moveable Point

Fixed



Frog Number

- Frog number: the number of units along the frog required to diverge one unit.
- As frog number grows, the diverging angle gets smaller.
- High speed turnouts need large frog nos. and therefore are longer



Frog No.	Max. Diverging Speed (mph)
6	10
8	15
12	25
16	30
20	45

Crossover-- 4 turnouts

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Rail Crossing Diamonds

90°

Skew

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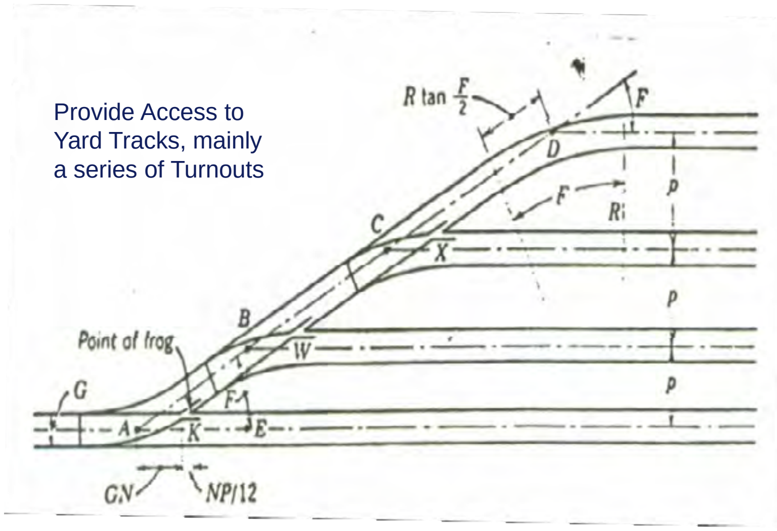
Ladder Tracks

Provide Access to
Yard Tracks, mainly
a series of Turnouts

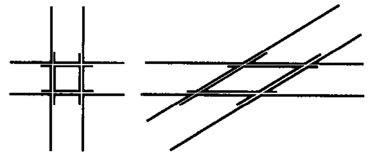


Ladder Tracks

Confusing Railroad "Crossing" Terminology

- **Crossing:**

  Two tracks crossing each other, Sometimes referred to as a "*railroad crossing at grade*". The combined hardware is also called a "*diamond*".

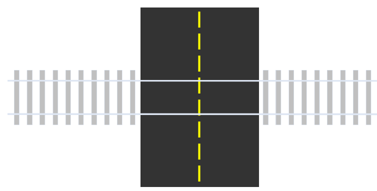


- **Crossover:**

  Two turnouts on parallel tracks that allow trains to cross over from one track to the other.

- **Grade Crossing:**

  Where a railroad and highway cross at grade Sometimes called a "*Highway/Rail Intersection*"



Frog Maintenance

Restore using welding

Renewing a 4-Diamond Crossing

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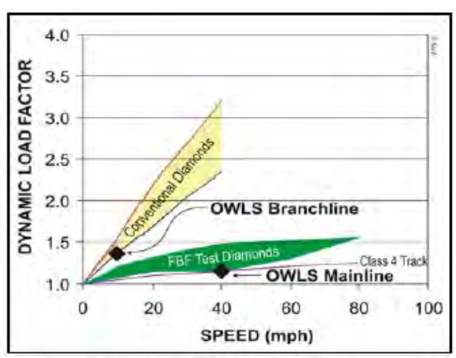
Design and Research



Dynamic Loads Measured at Crossing Diamonds

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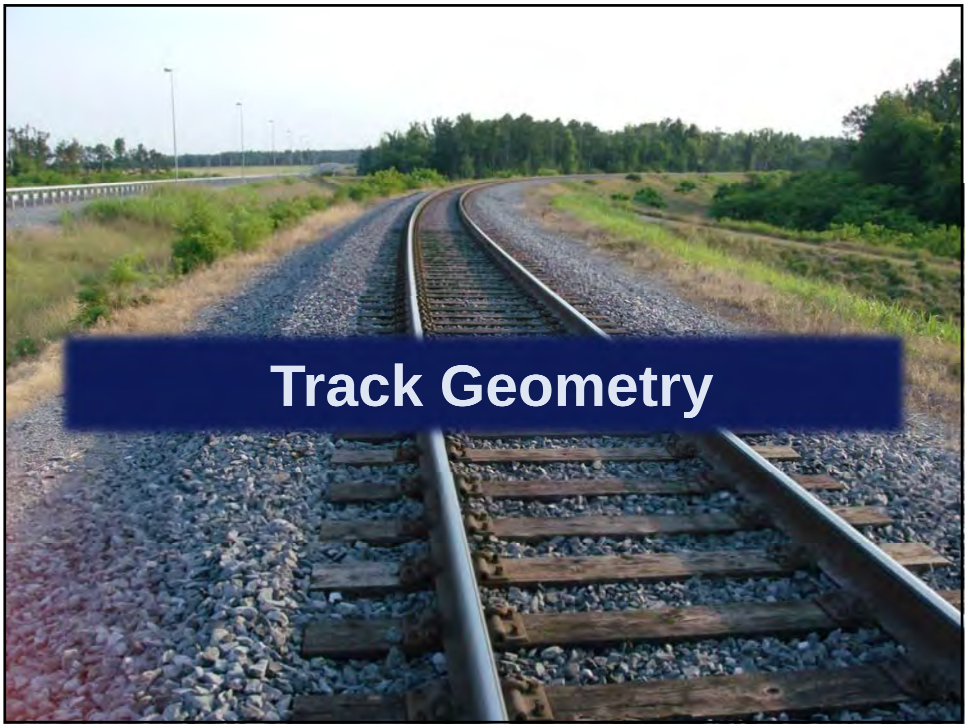
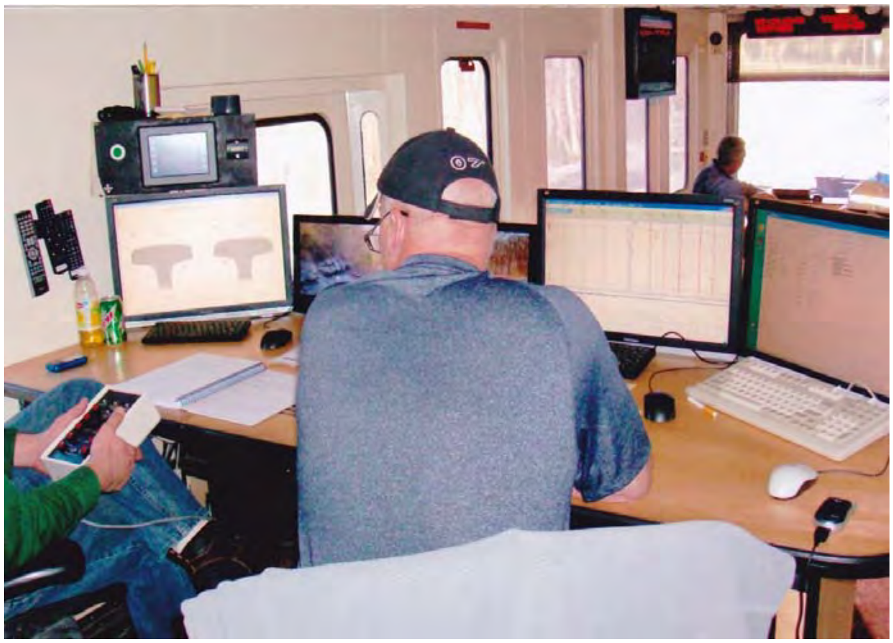


Measuring Track Geometry

- Need Some Measure of Track Conditions
  - Track Inspection
    - On the Ground
    - Detector Cars
      - TLV (Track Loading Vehicle)
      - TG (Track Geometry)
    - Rail (Sperry Cars)
  - Use TG/TLV Data
    - Adherence to FRA & RR standards (Safety)
    - Plan maintenance activities (Budget)
    - Evaluate the performance of the teams/roadmasters (Quality)



The Three Primary Track Geometry Terms

Gage

56 ½ inches (standard)

Line

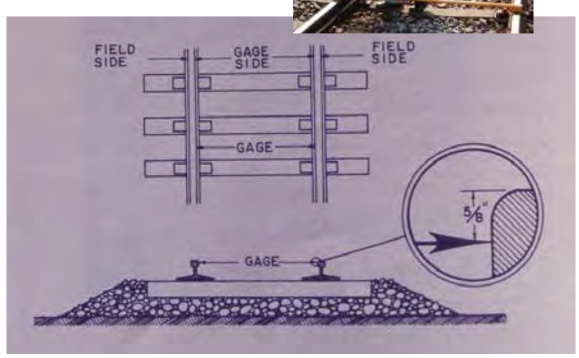
Horizontal

Alignment

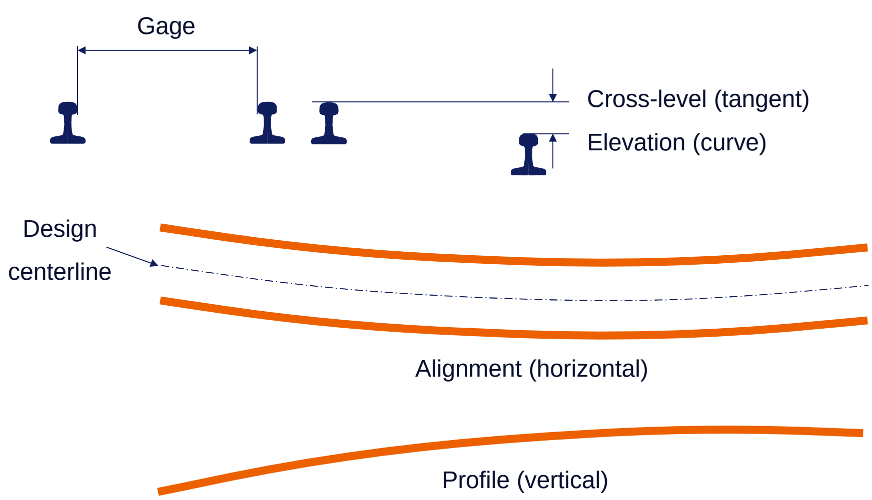
Surface

Vertical

Alignment



Track Geometry



Track Geometry

- Geometry measurement
  - Rail spacing (gage)
  - Rail vertical position (runoff, profile, cross-level)
  - Rail horizontal position (alignment)
- Measurements may be
  - At a point (deviation)
  - Along a section (difference)
- Values are critical to safe, reliable operation

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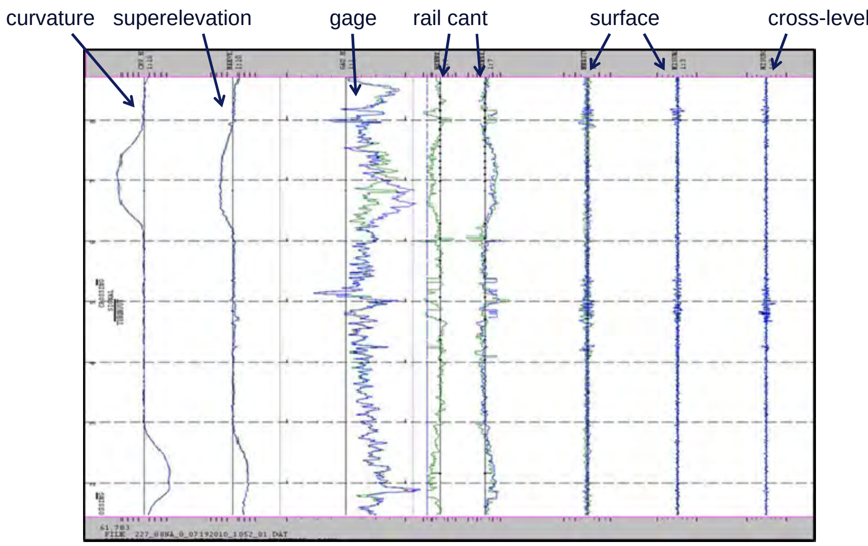
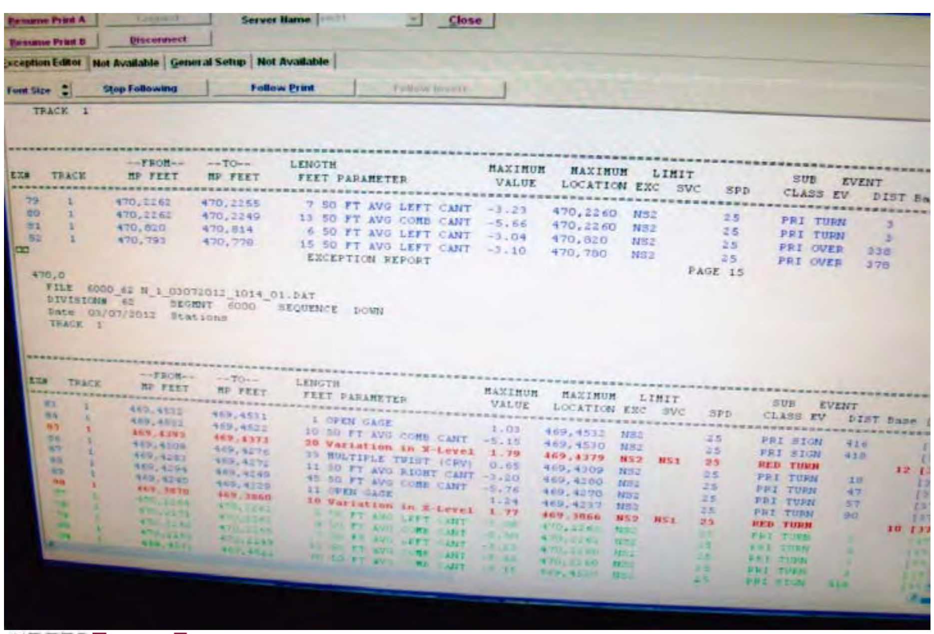
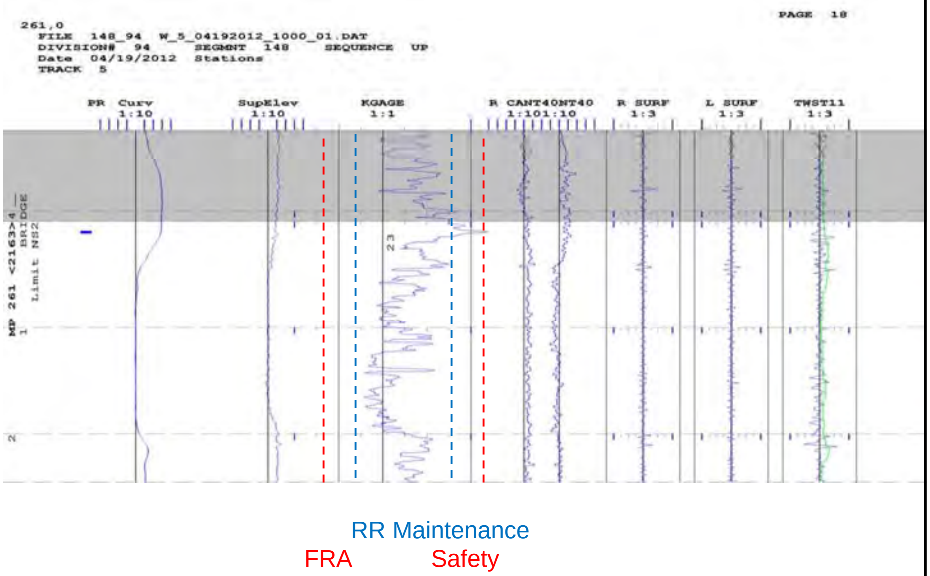
Track Geometry







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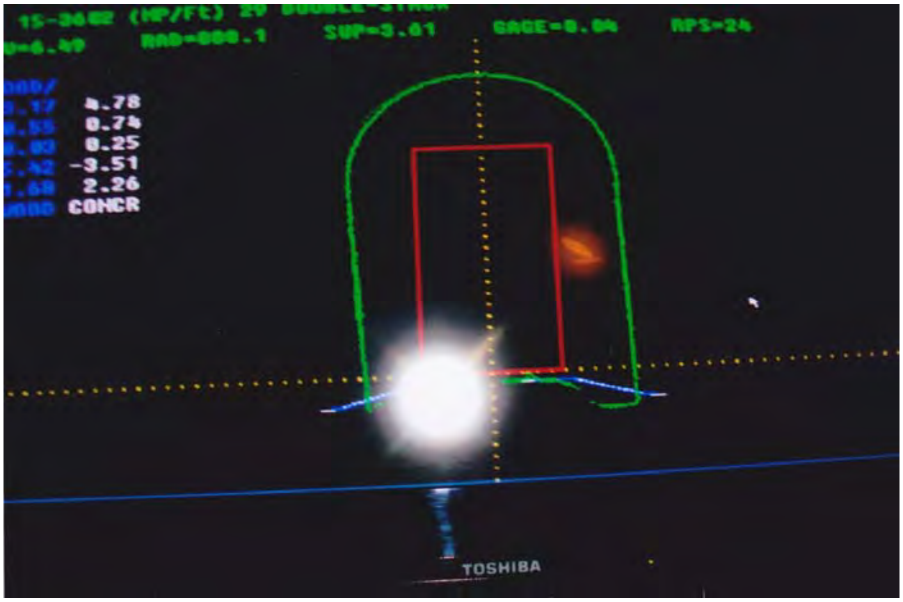

Hi-Rail Vehicle – Visual Track Inspection

FRA Track Safety Manual

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 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.

Track Geometry (Deviations from Ideal) Dictates Safe Speed

Track Quality Issues

FRA Safety Standards

Railroad Maintenance Standards

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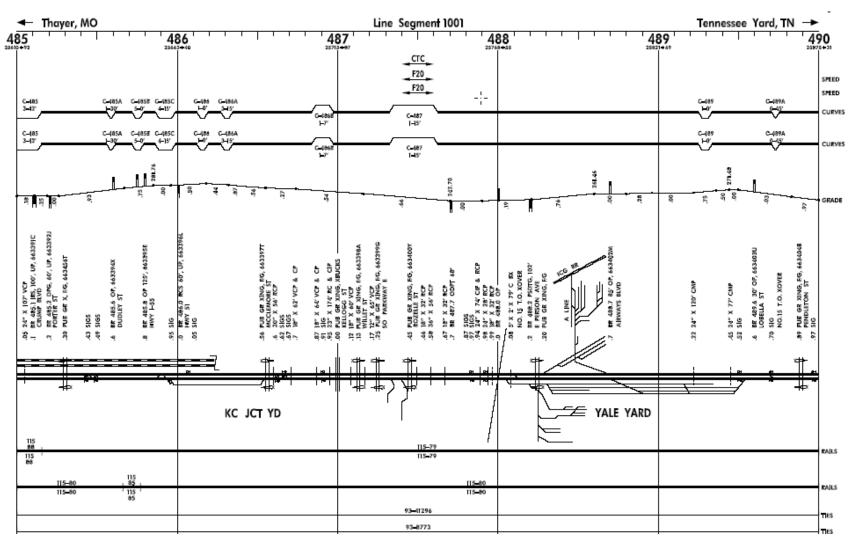
Track Chart



(All Features are Related to Milepost Locations)

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Options for Track NOT in Geometric Compliance

- Slow order track to complying class (lower class)
- Repair defect
- Operate under authority of qualified and experienced maintenance supervisor
- Take track out of service (least desirable)

Superelevation

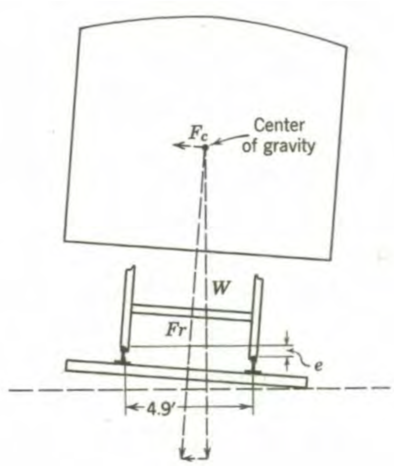
Balancing Superelevation:

$$e = 0.0007DV^2$$

Where:
e = equilibrium superelevation in inches
V = train speed in miles per hour
D = degree of curve

Design Superelevation:

$$e_c = 0.0007DV^2 - 3$$



(Superelevation for comfortable speed)

Establishing Superelevation

$$V_{\max} = \left(\frac{E_a + 3}{0.0007D} \right)^{1/2}$$

Where:

- V_{max} = maximum speed in miles per hour permitted with the value of E_a
- E_a = actual superelevation in inches
- D = Degree of curve

Note: Equation is based on 3 in. of unbalanced superelevation.

Appendix A - Maximum Allowable Curving Speeds

Table 1—Three Inches Unbalance

Table consists of pages 62 and 63

Elevation of outer rail (inches) →	0	½	1	1½	2	2½
Degree of curvature ↓	↓ Maximum allowable operating speed (mph) ↓					
0°30'	93	100	107	113	120	125
0°40'	80	87	93	98	103	109
0°50'	72	78	83	88	93	97
1°00'	66	71	76	80	85	89
1°15'	59	63	68	72	76	79
1°30'	54	58	62	66	69	72
1°45'	50	54	57	61	64	67
2°00'	46	50	54	57	60	63
2°15'	44	47	50	54	56	59
2°30'	41	45	48	51	54	56
2°45'	40	43	46	48	51	54
3°00'	38	41	44	46	49	51
3°15'	36	39	42	45	47	49
3°30'	35	38	40	43	45	47
3°45'	34	37	39	41	44	46
4°00'	33	35	38	40	42	44
4°30'	31	33	36	38	40	42
5°00'	29	32	34	36	38	40
5°30'	28	30	32	34	36	38
6°00'	27	29	31	33	35	36
6°30'	26	28	30	31	33	35
7°00'	25	27	29	30	32	34
8°00'	23	25	27	28	30	31
9°00'	22	24	25	27	28	30
10°00'	21	22	24	25	27	28
11°00'	20	21	23	24	26	27
12°00'	19	20	22	23	24	26

Appendix A - Maximum Allowable Curving Speeds

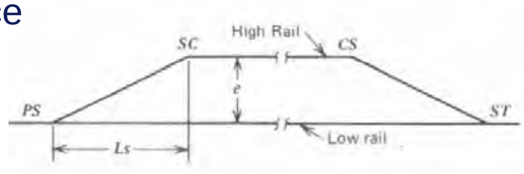
Table 1—Three Inches Unbalance

Table consists of pages 62 and 63

Elevation of outer rail (inches) →	3	3½	4	4½	5	5½	6
Degree of curvature ↓	↓ Maximum allowable operating speed (mph) ↓						
0°30'	131	136	141	146	151	156	160
0°40'	113	118	122	127	131	135	139
0°50'	101	106	110	113	117	121	124
1°00'	93	96	100	104	107	110	113
1°15'	83	86	89	93	96	99	101
1°30'	76	79	82	85	87	90	93
1°45'	70	73	76	78	81	83	86
2°00'	66	68	71	73	76	78	80
2°15'	62	64	67	69	71	74	76
2°30'	59	61	63	66	68	70	72
2°45'	56	58	60	62	65	66	68
3°00'	54	56	58	60	62	64	66
3°15'	51	54	56	57	59	61	63
3°30'	50	52	54	55	57	59	61
3°45'	48	50	52	54	55	57	59
4°00'	46	48	50	52	54	55	57
4°30'	44	45	47	49	50	52	54
5°00'	41	43	45	46	48	49	51
5°30'	40	41	43	44	46	47	48
6°00'	38	39	41	42	44	45	46
6°30'	36	38	39	41	42	43	45
7°00'	35	36	38	39	40	42	43
8°00'	33	34	35	37	38	39	40
9°00'	31	32	33	35	36	37	38
10°00'	29	31	32	33	34	35	36
11°00'	28	29	30	31	32	33	34
12°00'	27	28	29	30	31	32	33

Length of Spiral, L_s

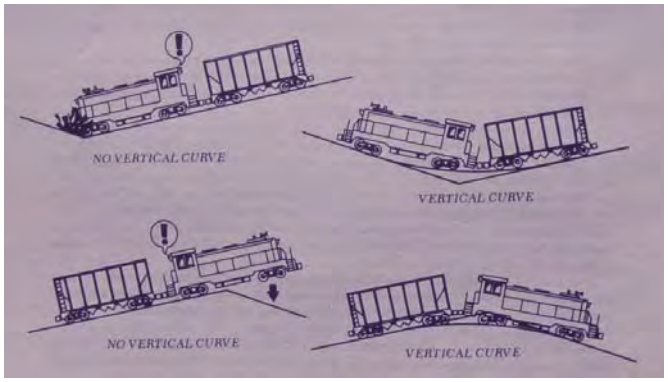
- Run in e
- Transition in D_c
- Consider
  - o lateral acceleration
  - o centrifugal force
  - o warp



Use the longest L_s value which is the minimum L_s for design

Vertical Curves

- Parabolic form is customary:
  - $y=kx^2$ where x is taken in the direction of the grade or tangent and y is in a radial direction.



- Rate of change is the algebraic difference in percent per 100 ft.

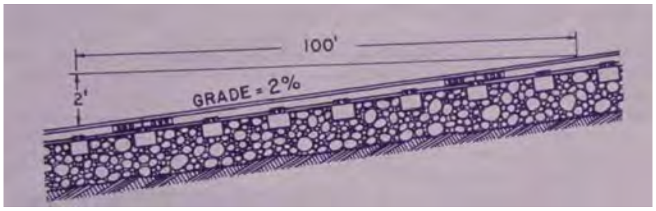
$$r = \frac{G_1 - G_2}{L}$$

Where:

r = rate of change in grade in percent per 100 ft

G_1 , G_2 = the two intersecting grades, taken as positive when ascending, negative when descending

L = curve length in 100-ft stations



Track Maintenance

Capitalized/Production and Line/Day-To-Day

Early Days

- Section gangs (cheap labor)
- Maintained small sections of track
- The RR's provided housing

Now Days

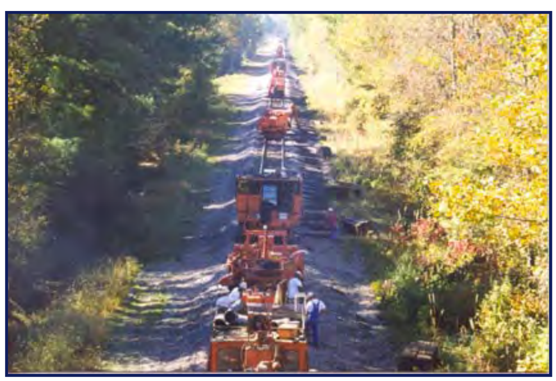
Maintain Long Sections of Track

Fewer People

Stress Safety

Mechanized

Production Oriented



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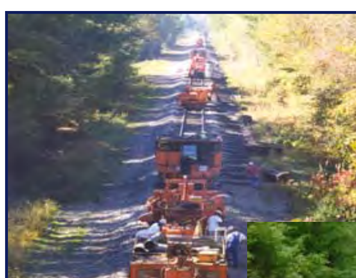
Small Production Teams

Large Production Teams

- Rail Change Out*
- Tie Change Out*
- Surface Track*
- Ditching
- Brush Cutting
- Curve Rail Change Out
- Track Undercutting
- Rail Grinding

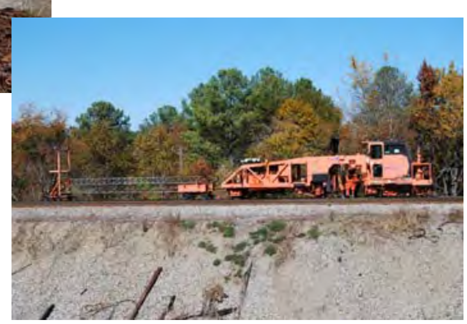
* Primary activities



Ballast Maintenance

- Fill in voids
- Restore Cross-Section
- Raise Track
- Adjust Geometry

Track Surfacing

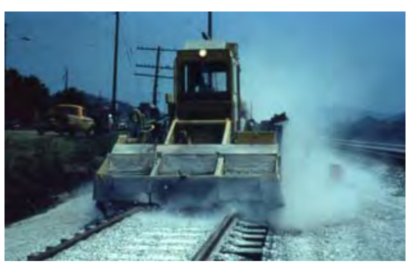


Purpose: Adjust Geometry --- horizontally (line) and vertically(surface and crosslevel)

Tamper

- The tamper adjusts the track alignment and surface
- Tamper heads compact ballast beneath the ties

Ballast Regulator



Regulator

- The regulator distributes and shapes ballast
- The operate has a number of movable blades to accomplish this
- Most regulators have a broom for cleaning track

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Compaction (Tamping)

- Can be
  - Hand (spot) or
  - Mechanized
- Performed under bearing areas (outer 2/3 of tie)
- Used to adjust geometry
  - Smooth
  - Smooth and Surface

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Continuous Action Tamper

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Ballast Compactor/Stabilizer

Restores Track Stiffness quickly after ballast has been disturbed

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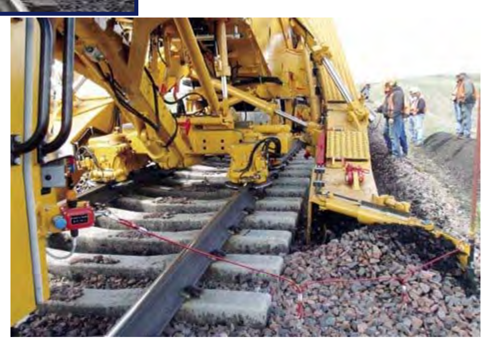
Undercutting

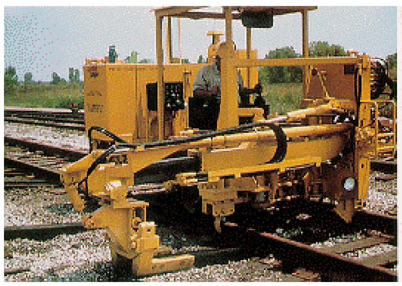
Removes Fouled Ballast

Undercutting

Process includes removal of fouled ballast and replacement with clean ballast



Tie Removal/Installation



Ditching, Drainage Improvement and Drift Removal

Rail Grinding

- Restores rail profile for improved life cycle

At-Grade Road Crossings

Rail Lubrication Systems (Friction Management)

Gage Side and Top-of-Rail

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Brush Cutting and Spraying to Clear Right-of-Way

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Slide Repair and Earth Retention

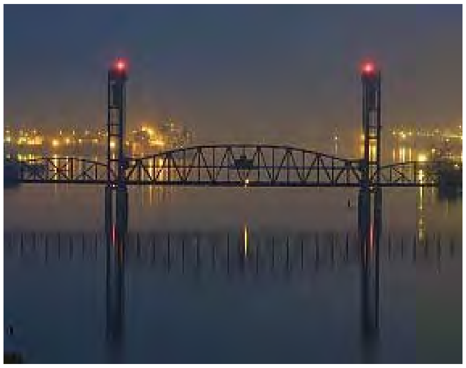
Geotechnical Engineering

Stabilizing Slopes

Emergencies & Disasters

- Warrant special activity
  - Floods
  - Snow & Ice
  - Derailment

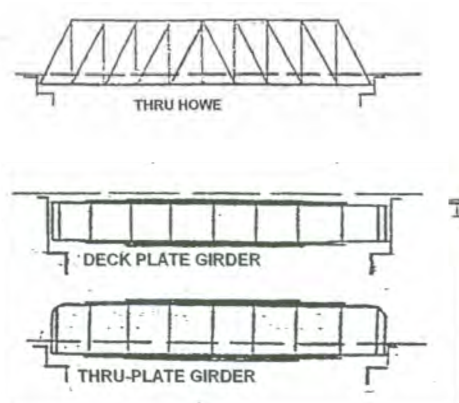
II. Drainage Structures



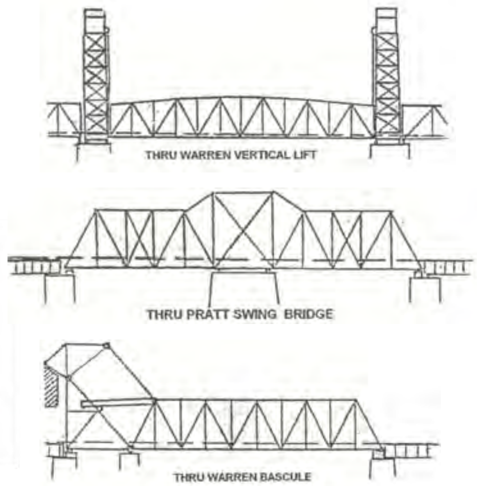
Bridges

Culverts and Pipes

Bridge Types



Fixed



Movable

Bridge Component Descriptions

- Type of Substructure Foundation and Support
- Type of Superstructure --- Truss or Girder or Beam
- Type of Deck --- Open or Ballasted
- Location of Track --- Deck(top) or Through
- Material --- Steel or Concrete or Timber or Stone

(Loadings and Span Length and Clearance Requirements)

Open Deck Girder

Open Deck Thru Truss

Open Deck

Ballasted Deck Timber Trestle

Ballasted Deck Concrete Girder

Ballasted Deck

Deck Plate Girder

Deck Truss

Deck Support

Through Girder

Through Truss

Through Support




Concrete Beams or Steel Girders with Ballasted Concrete Decks


Open Deck Timber Trestles and Viaducts

Combination Bridge

Open Deck Timber Trestle

Open Deck Through Steel Girder


Stone and Brick Masonry
and
Concrete

Arches


Modern Design – Concrete Ballasted Deck with Steel Girders or Truss or Concrete Girders/Beams

Combination – Open Deck Steel Girders for shorter spans and Open Deck Thru Trusses for longer spans across river

Conversion of Wooden Trestle to Concrete Ballast Deck Under Traffic

East Approach Mt Carmel, IL - Before

Common Practice Today for Modernizing U.S. Railroad Lines

After with Concrete Caps and Steel Support

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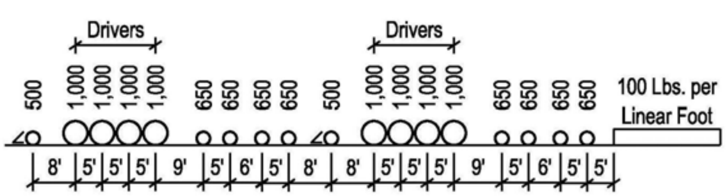
Track Realignment for New Bridge

Convert open deck thru truss to ballast deck concrete

Cooper Loading

- Developed by Theodore Cooper around 1900.
- Cooper Ratings are expressed as an E-”value”. The value is the weight on the drivers in 1,000 lbs.
- All of the axles are proportional to the drivers



Design vs. Rating

Design Process

- Live Load
- Trial Section Properties
- Other Loads
  - Dead Load
  - Impact
- Total Loads
- Allowable Stress
- Final Section Properties

Rating Process

- Section Properties
- Allowable Stresses
- Total Allowable Load
- Constant Loads
  - Dead Load
  - Wind
- Loads that vary with speed
  - Impact
  - Centrifugal Force
- Live Load

Bridge Inspection

Bridge Maintenance

Very Expensive

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Drainage Pipe

Ongoing Maintenance

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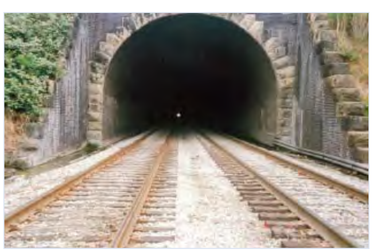
Culverts

III. Tunnels

Concrete

Rock -- Unlined



Masonry

Cut & Fill

Tunnels

Drainage

Drainage

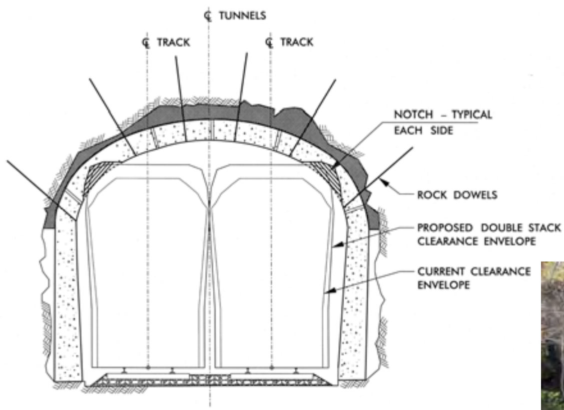
Cleaning

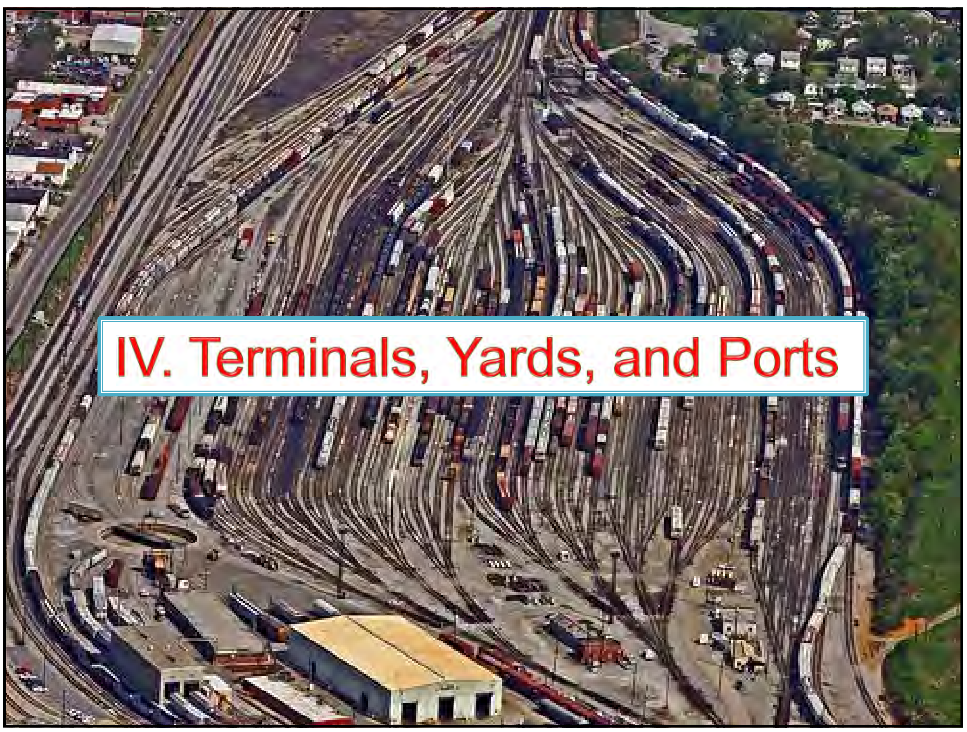
Bypass

Track Lowering for Double Stacks

Notching

Notching or Raising/Replacing the Crown for Double Stack Clearance

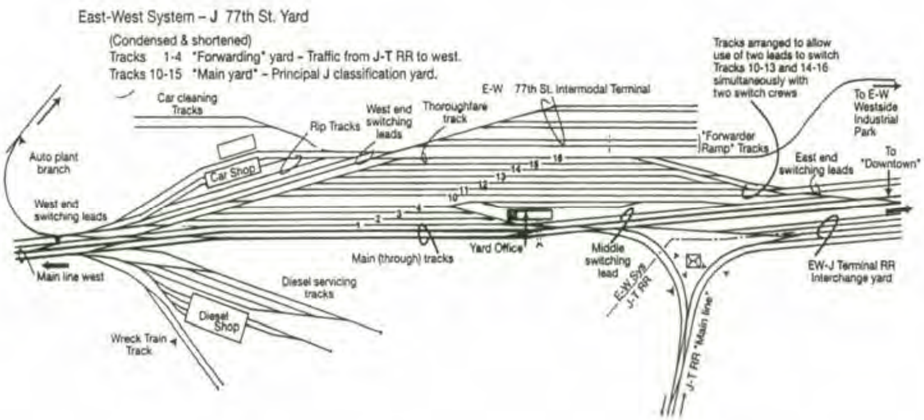




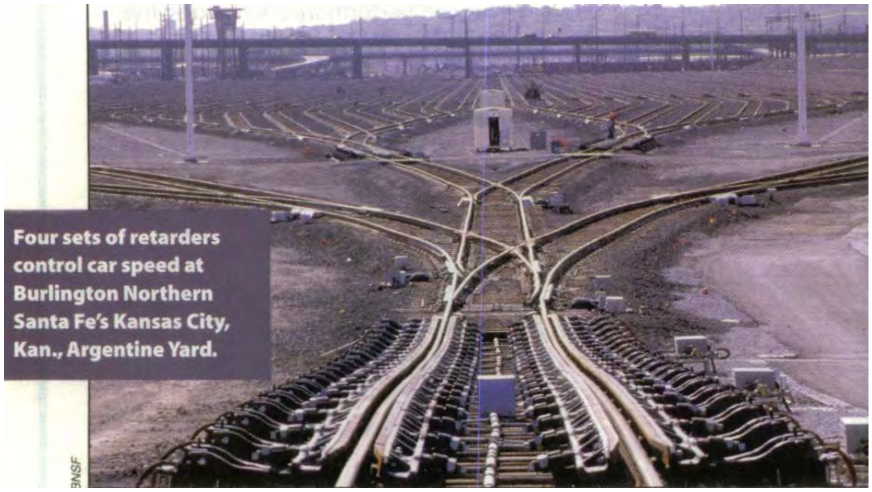
Terminals or Yards

- Types -- Flat & Gravity (hump)
- Flat
  - World's Largest: Bailey Rail Yard in North Platte, NE

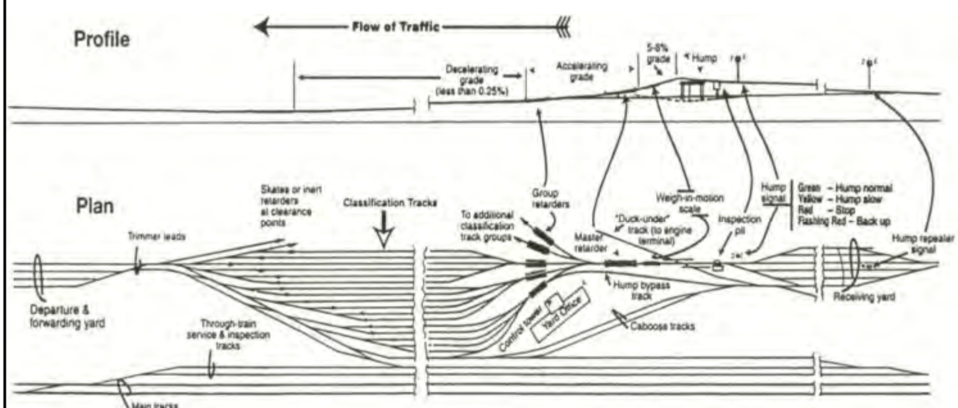
Flat Yard



Gravity (Hump) Yard



Hump Yard

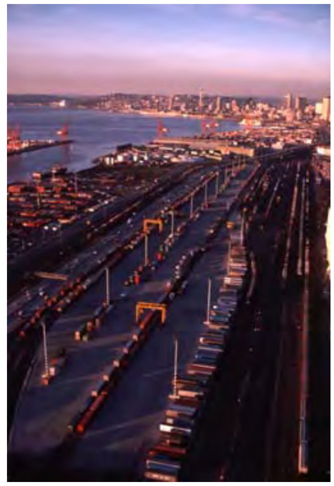


Large Hump Yard

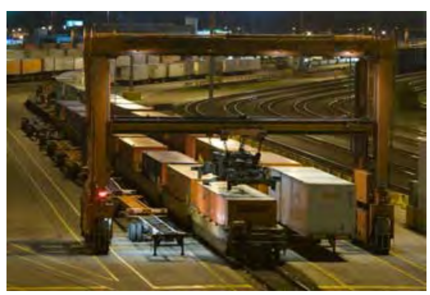
BNSF Argentine Yard - Kansas City, Kansas

Small Flat Yard

Ports



Intermodal Terminals



V. Buildings

VI. Environmental Facilities

- Storage
- Transfer
- Treatment

Tank Secondary Containment

- Above ground petroleum storage tanks are required to have an impervious secondary containment structure that is capable of holding the entire contents of the largest tank inside the area plus storm water from a significant rain event.

An unlined earthen secondary containment dike in a rail yard prior to upgrades

The secondary containment dike upgraded with a new geosynthetic clay liner (GCL)

Loading / Unloading Pads

- Concrete loading / unloading pads are designed to capture leaks and drips that may occur during petroleum transfer operations. Material collected by the loading / unloading pads can be routed to an on-site WWTP or removed and disposed of off site at a permitted facility.

Here is railcar loading / unloading pad that will route collected material to an on-site WWTP

Here a locomotive fueling tanker truck using a loading / unloading pad to collect material that must be inspected prior to discharge or disposal

Spill Containment Pans

- Spill containment pans are designed to capture leaks and drips from locomotives and railcars. Material collected in spill containment pans can be routed to an on-site WWTP or removed and disposed of off site at a permitted facility.

A locomotive fueling area equipped with metal containment pans

An in-track spill containment pan that is strategically positioned in a rail yard to collect material from a leaking railcar

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Equipment Wash Pads

- Equipment wash pads collect runoff from washing operations and route it to an on-site WWTP and/or POTW. The wash pads are designed to prevent wash water from co-mingling with storm water runoff.

A wash pad for large railcar loading equipment being constructed at a Railroad Intermodal facility

This operational wash pad at an Intermodal Facility collects wash water in a trench drain and routes it to an adjacent OWS prior to discharge

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Wastewater Treatment Facilities

- A wastewater treatment plant (WWTP) protects the environment by removing pollutants from potentially impacted water. A WWTP utilizes various physical and chemical treatment processes to ensure that discharged effluent meets the permitted requirements.

This WWTP was the first “green” building constructed on the NS system. It incorporated sustainable design elements and materials

The WWTP consists of an equalization basin, OWS, chemical feed building, DAF unit, settling pond, and sludge drying beds

VII. Signal Structures and Detectors

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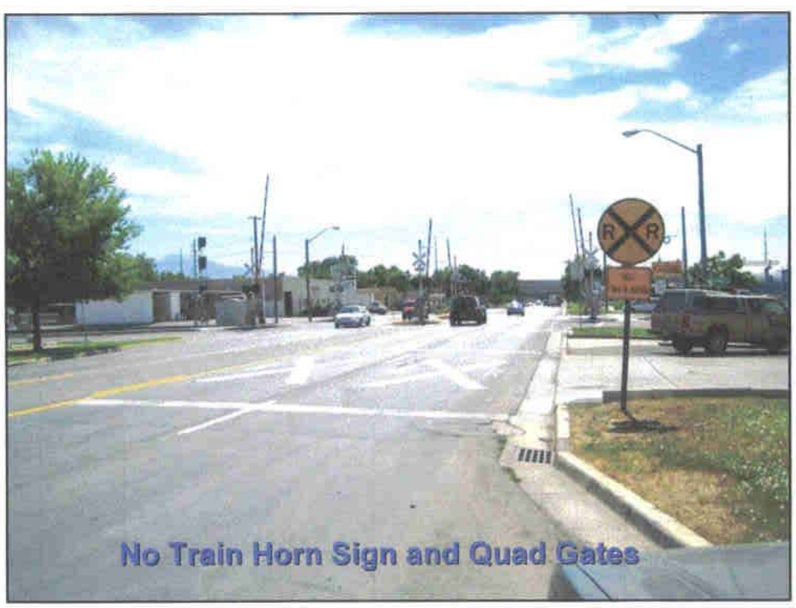
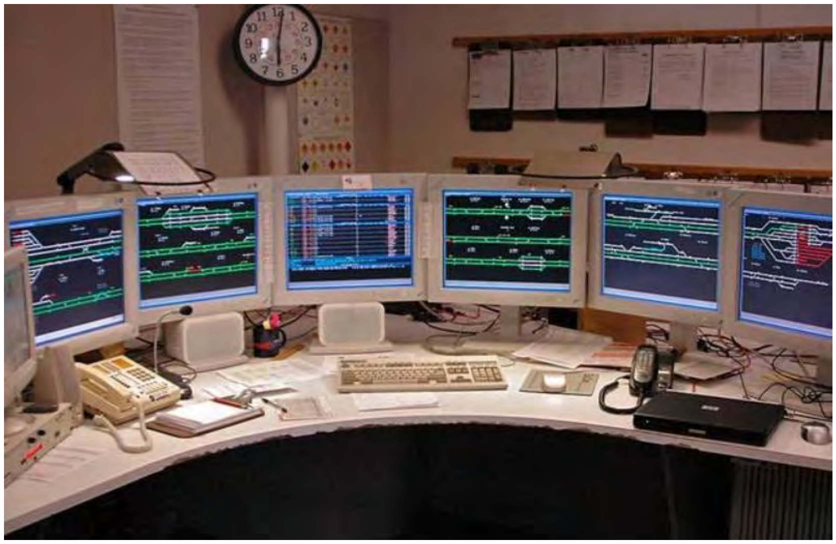
Signals
Intermediate Signal
Intermediate Signal: A block signal equipped with either a number plate, a "G" marker, or "P" marker. It conveys Proceed at Restricted Speed as its most restrictive indication.


No Train Horn Sign and Quad Gates

Train Dispatching



Centralized Traffic Control

Wheel Impact Load Detector

Train Dispatcher “Routes” Trains through Turnouts and Crossovers

VIII. Communications Structures

Thank You for Your Attention Any Questions ???

For More Information:
Access
www.engr.uky.edu/~jrose
Click on CE 533 Power Points

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Appendix B: REES 2014 Module on KENTRACK 4.0 Railway Trackbed Structural Design and Analysis Program and Tutorial

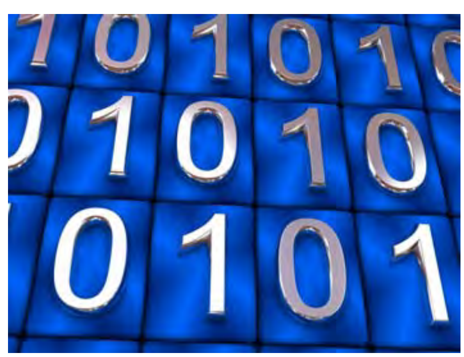
KENTRACK 4.0
Railway Trackbed Structural Design and Analysis Program and Tutorial

Jerry G. Rose, PE
University of Kentucky
Department of Civil Engineering

REES 3: Module 3-D
REES 2014

Kentrack

- 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



Introduction

- 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) Granular Trackbeds and Bound (elastic and viscous) Granular Trackbeds

Background

- Originally Kentrack was written in FORTRAN for DOS operation
- Since been upgraded to a Windows Platform
- Witczak E* Predictive Model was incorporated
- Unit system in 4.0 was expanded to
    - English Unit System
    - SI Unit System

Background

- The previous version included properties of asphalt cements.
- 4.0 has incorporated properties of performance graded asphalt binders,
- and has the option for
  - AC System (viscosity)
  - PG System (dynamic shear rheometer)

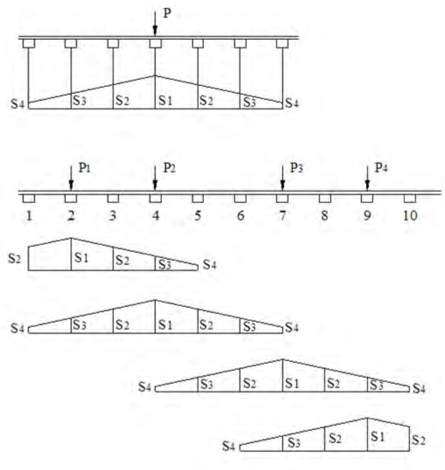
Asphalt Binders

AC Grading System **VS.** PG Grading System

Previous Kentrack	**Revised Kentrack**
Penetration, Viscosity graded	Superpave
Empirical specifications	Tests such as dynamic shear modulus, creep stiffness related to field performance.
No long-term aging consideration	Long-term aging is better simulated

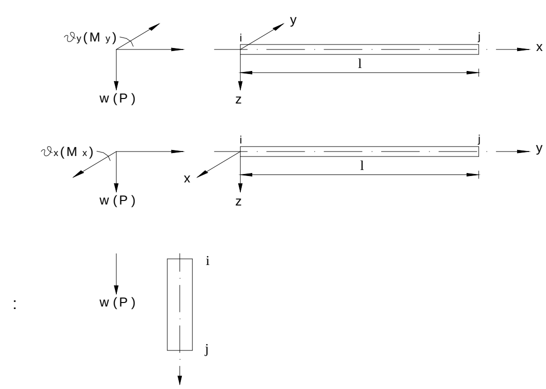
Superposition of Loads

$$S_1^{'} = S_2 \frac{P_1}{P} + S_4 \frac{P_2}{P}$$



= RAIL + TIE + SPRING

Finite Element Method



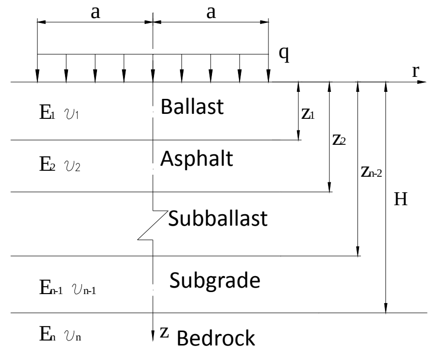
- **Trackbed Multilayered System**
  - ✓ Used to calculate the stress and strain in each layer

- **Trackbed Types**
  - ✓ **All-Granular**

    Ballast, Subballast, and Subgrade
  - ✓ **Asphalt Underlayment**

    Ballast, Asphalt and Subgrade
  - ✓ **Combination**

    Ballast, Asphalt, Subballast, and Subgrade

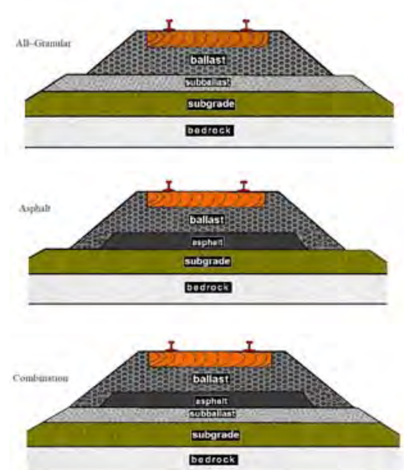


Combination Trackbed

INTRODUCTION

Trackbed Types

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



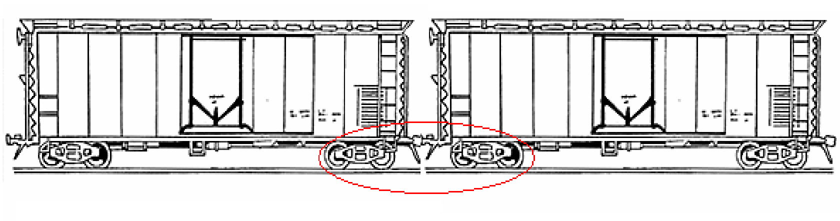
Kentrack Theory

- Damage Analysis
  - Based on minor linear damage analysis criteria
  - Performance is based on periods
    - For Kentrack this is four seasons

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

Loading Criteria

- Predicted number of repetitions



•Each car equals one repetition

Loading Criteria

- Predicted number of repetitions (N_p)

Wheel Load	= 36000 lb/wheel
For one car the total weight	= 36000 lb/wheel x 8
	= 286,000 lb/rep / 2000
	= 143 ton/rep
The number of repetitions assumed per year	= 200,000 rep/yr
The traffic per year	= 200,000 rep/yr x 143 ton/rep
	= 28,600,000 GT/yr / 1 x 10^6
	= 28.6 MGT/yr

Subgrade Damage Analysis

- Excessive permanent deformation controls failure
- Deformation is governed by the vertical compressive stress on the top of the subgrade
- Based on Highway experience
- The number of allowable repetitions before failure

$$N_d = 4.837 \times 10^{-5} \sigma_c^{-3.734} E_s^{+3.583}$$

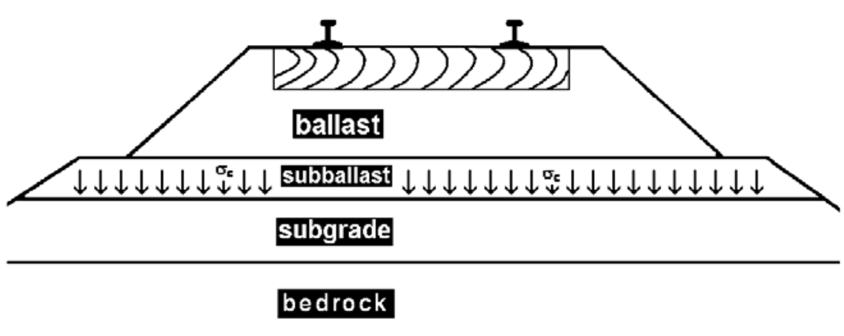
Asphalt Damage Analysis

- Fatigue cracking controls failure
- Fatigue cracking is governed by the tensile strain in the bottom of the asphalt
- Based on highway experience
- The number of allowable repetitions before failure

$$N_a = 0.0795\,\varepsilon_t^{-3.291}\,E_a^{-0.853}$$

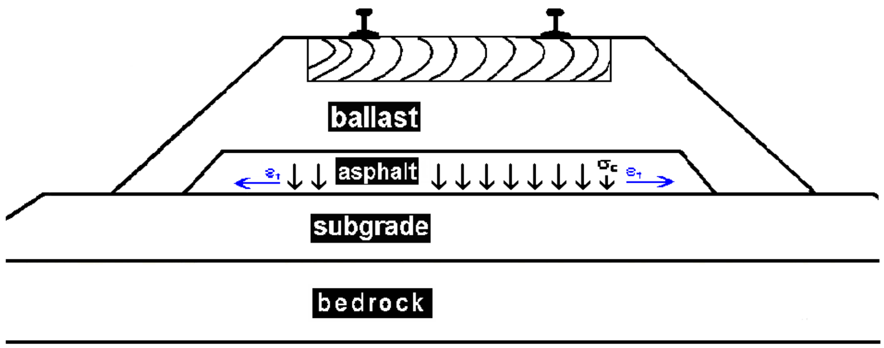
All-Granular Trackbed

- Failure Criteria
- Vertical Compressive Stress on Subgrade



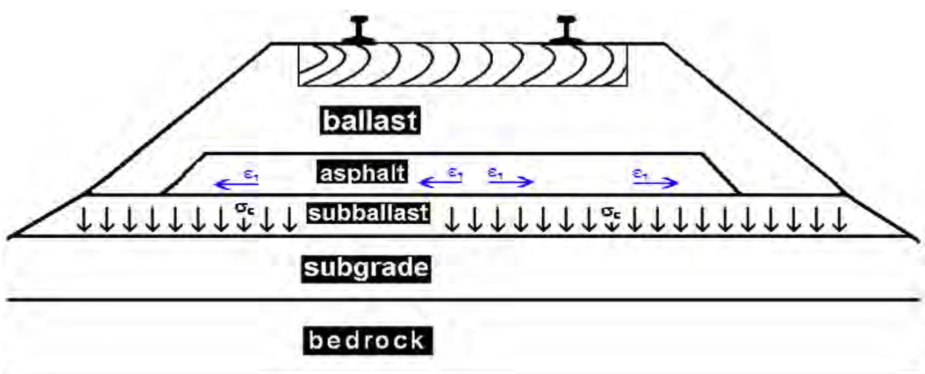
Asphalt Underlayment Trackbed

- Failure Criteria
- Vertical Compressive Stress on Subgrade, Tensile Strain at Bottom of Asphalt



Combination Trackbed

- Failure Criteria
- Vertical Compressive Stress on Subgrade, Tensile Strain at Bottom of Asphalt



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

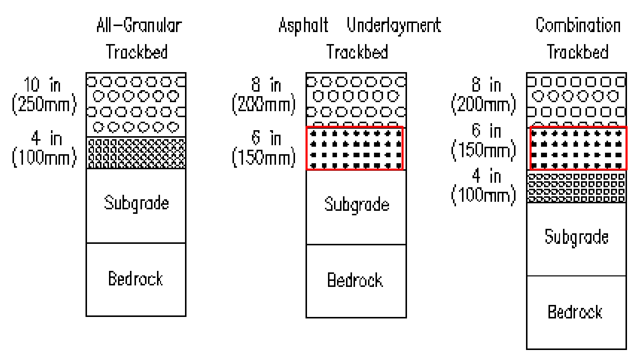
- Fatigue cracking controls failure
- Fatigue cracking is governed by the tensile strain in the bottom of the asphalt
- $N_a = 0.0795 \times \varepsilon_a{}^{-3.291} E_a{}^{-0.853}$

Service Life Prediction

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

- Subgrade Service Life
- Asphalt Service Life

DEFAULT SECTIONS



Standard Trackbed Sections

Wood ties

Rail = 132-lb

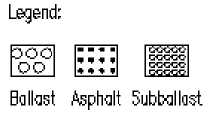
Wheel load = 36,000 lbs

Axle load = 36 ton

Ballast modulus = 18,000 psi

Subgrade modulus = 12,000 psi

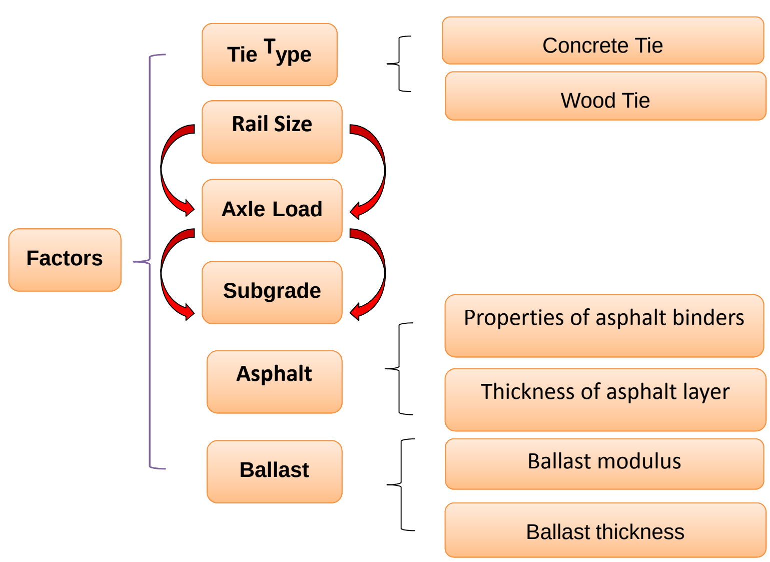
Legend:



Critical Outputs for Typical Default Sections

Trackbed Type	Subgrade Compressive Stress (psi)	Subgrade Service Life (yrs)	Asphalt Tensile Strain	Asphalt Service Life (yrs)
All-Granular Trackbed	13.5	6.0	n/a	n/a
Asphalt Underlayment Trackbed	10.8	21.4	1.48E-04	25.0
Combination Trackbed	9.8	28.5	1.29E04	34.0

SENSITIVITY ANALYSIS

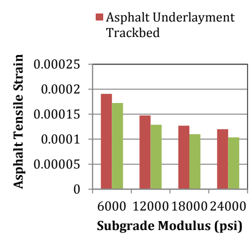


Details of Variable Parameters used in Sensitivity Analysis

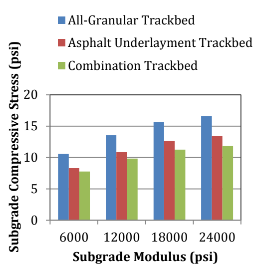
	Parameter	Values
	Tie Type	Wood Tie (20 in. spacing) Concrete Tie (25 in. spacing)
	Rail Size	RE 100, RE 115, RE 132, RE 140
	Axle Load (tons)	33, 36, 39
	Subgrade Modulus (psi)	6000, 12000, 18000, 24000
Ballast	Ballast Modulus (psi)	12000, 18000, 24000, 30000
Ballast	Ballast Thickness (in)	6, 8, 10, 12
Asphalt	Asphalt Thickness (in)	2, 4, 6, 8
Asphalt	Aggregate Passing #200 Sieve (%)	0, 2, 4, 6, 8, 10, 12
Asphalt	Aggregate Retained on #4 Sieve (%)	30, 40, 50, 60, 70
Asphalt	Aggregate Retained on #3/4 Sieve (%)	0, 10, 20, 30
Asphalt	Aggregate Retained on #3/8 Sieve (%)	20, 30, 40, 50, 60
Asphalt	Air Voids (%)	0, 2, 4, 6, 9
Asphalt	Effective Binder Content (%) by Volume	5, 10, 15, 20, 25
Asphalt	Viscosity (10^6 Poise)	10, 100, 1000, 10000, 100000
Asphalt	Asphalt Binder Grade	PG 64-22, PG 64-28, PG 64-34, PG 70-28, PG 76-28

Effects of varying Subgrade Modulus

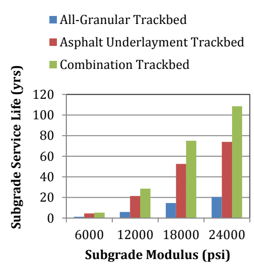
- A very critical parameter influencing the quality and load carrying capability of the track structure.
- A subgrade with high moduli provides a stiffer foundation that has greater bearing capacity and increases load carrying capability.



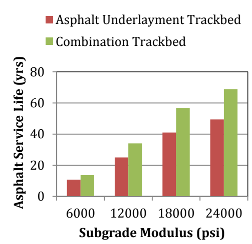
Asphalt Tensile Strain



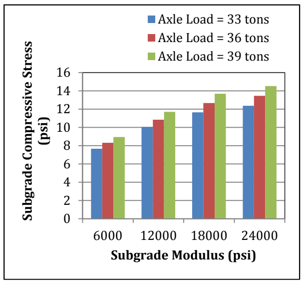
Subgrade Compressive Stress

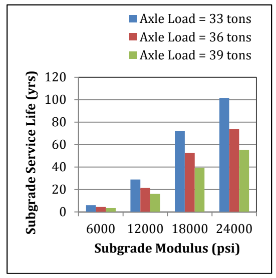


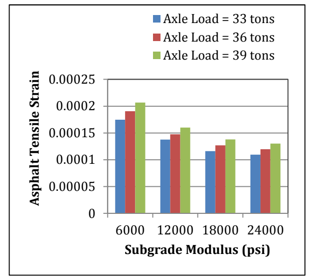
Subgrade Service Life

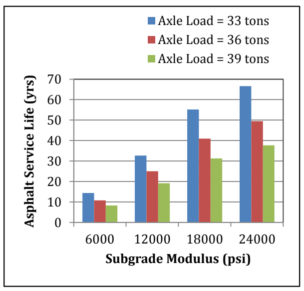


Asphalt Service Life



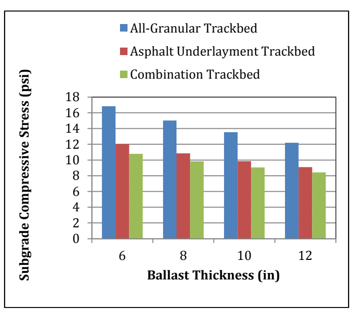


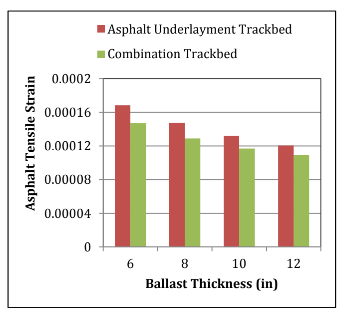


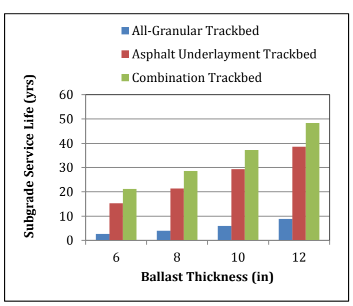


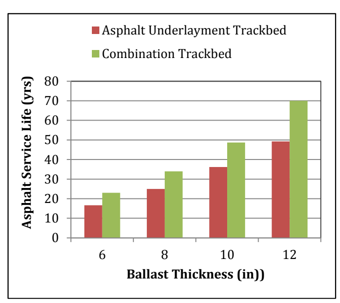
Effects of varying Axle Load and Subgrade Modulus for Asphalt Underlayment Trackbed

Subballast = 4 in. and Asphalt = 6 in.



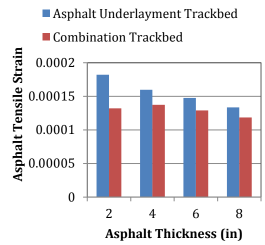






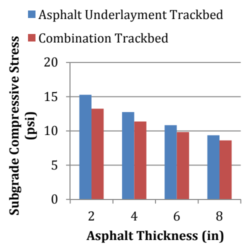
Effects of varying Ballast Thickness

Effects of varying Asphalt Thickness

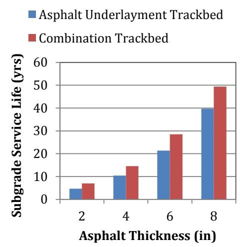


Asphalt Tensile Strain

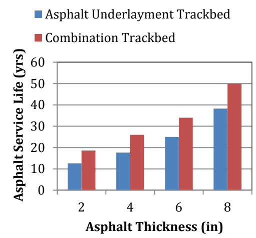
Ballast Thickness = 8 in



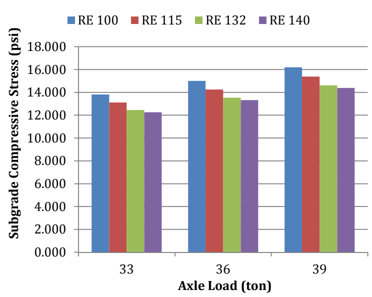
Subgrade Compressive Stress



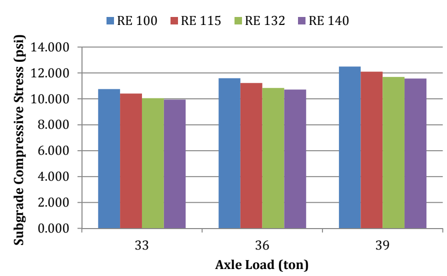
Subgrade Service Life



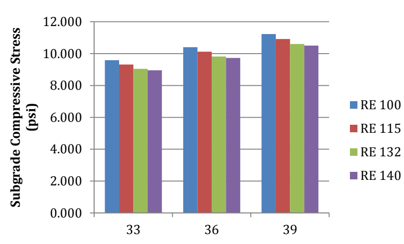
Asphalt Service Life



All-Granular Trackbed

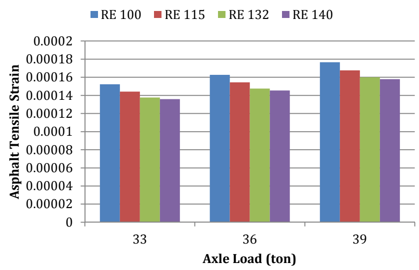


Asphalt Underlayment Trackbed

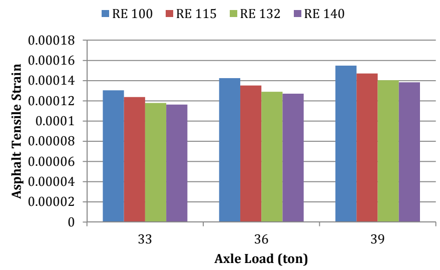


Combination Trackbed

Effects of varying Rail Size and Axle Load on Subgrade Compressive Stress



Effects of varying Rail Size and Axle Load on Asphalt Tensile Strain for the Asphalt Underlayment Trackbed



Effects of varying Rail Size and Axle Load on Asphalt Tensile Strain for the Combination Trackbed

Summary

- KENTACK is a versatile Layer Elastic, Finite Element Computer Program for the design and analysis of Trackbeds containing Unbound and Bound Granular Layers
- KENTRACK Outputs are Performance Based
- Calculates Stresses and Strains within the Track Structure
- Predicts Design Lives of Various Layers
- Evaluates Effects of Varying Loadings and Track Parameters (Sensitivity Analyses)

Summary (cont'd)

- Highway Structural Design Program Adapted to Railroad Loading Configurations and Magnitudes
- Uses the Highway Derived DAMA Program
- Considers the Fatigue Lives of Various Layers for Repeated Loadings
- Damage Analysis Predictions Based on Highway Failure Criteria
- Highway Loadings are Believed to be More Severe than Railroad Loadings and Environments – Thus Conservative Analysis

Sensitivity Analyses Findings Based on Kentrack Calculations and Predictions

- Subgrade Stiffness (Modulus) is a very significant factor influencing trackbed design and predicted performance
- Stiffer Subgrades produce slightly higher subgrade stresses, but predicted subgrade service lives are significantly increased
- Stiffer Subgrades produce lower asphalt tensile strains, and predicted asphalt service lives are increased
- A layer of Asphalt within the track structure results in lower subgrade stresses than a similar thickness of Granular subballast

Sensitivity Analyses (cond't)

- Increasing Axle Loadings result in increased subgrade stresses, and predicted subgrade service lives are reduced
- Increasing Axle Loadings result in marginally increased asphalt strains, and predicted asphalt service lives are marginally reduced
- Predicted subgrade design lives are higher for both the Asphalt and Combination Trackbeds as compared to All-Granular design
- Increasing Ballast thickness or Asphalt thickness reduces subgrade compressive stresses and asphalt tensile strains

TUTORIAL

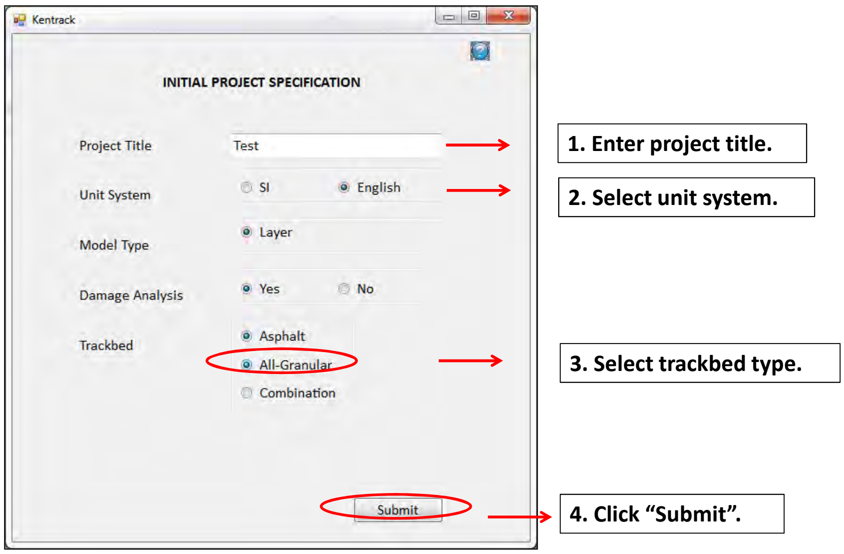
KENTRACK 4.0

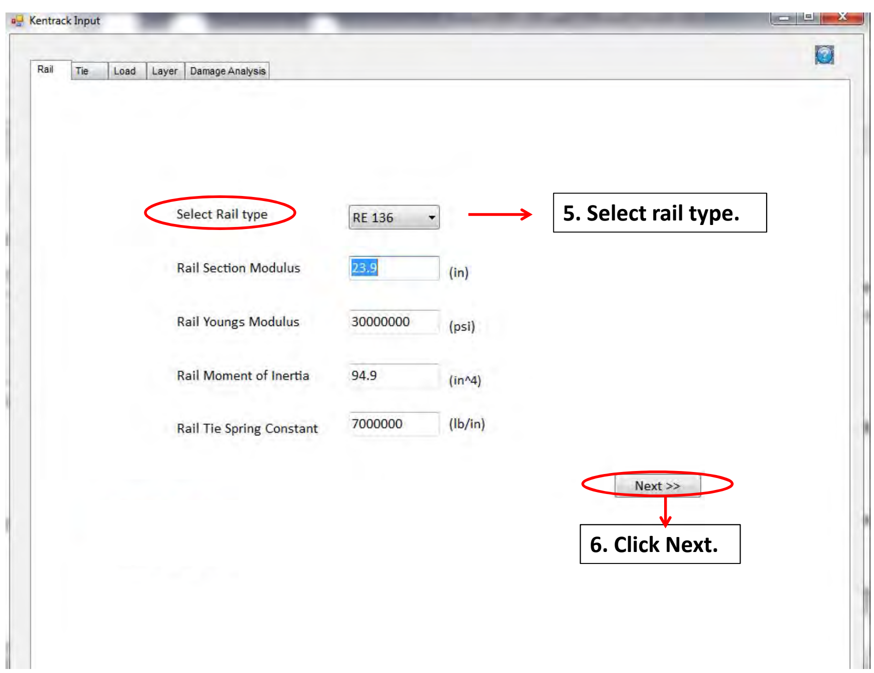
Railway Trackbed Structural Design and Analysis Program

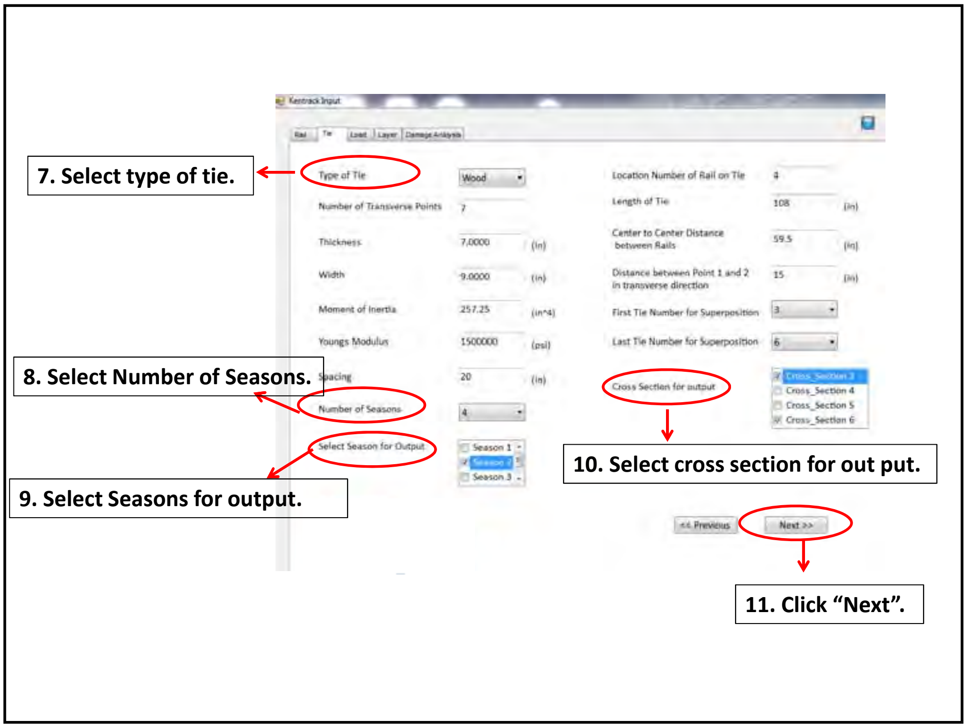
Program Default Conditions

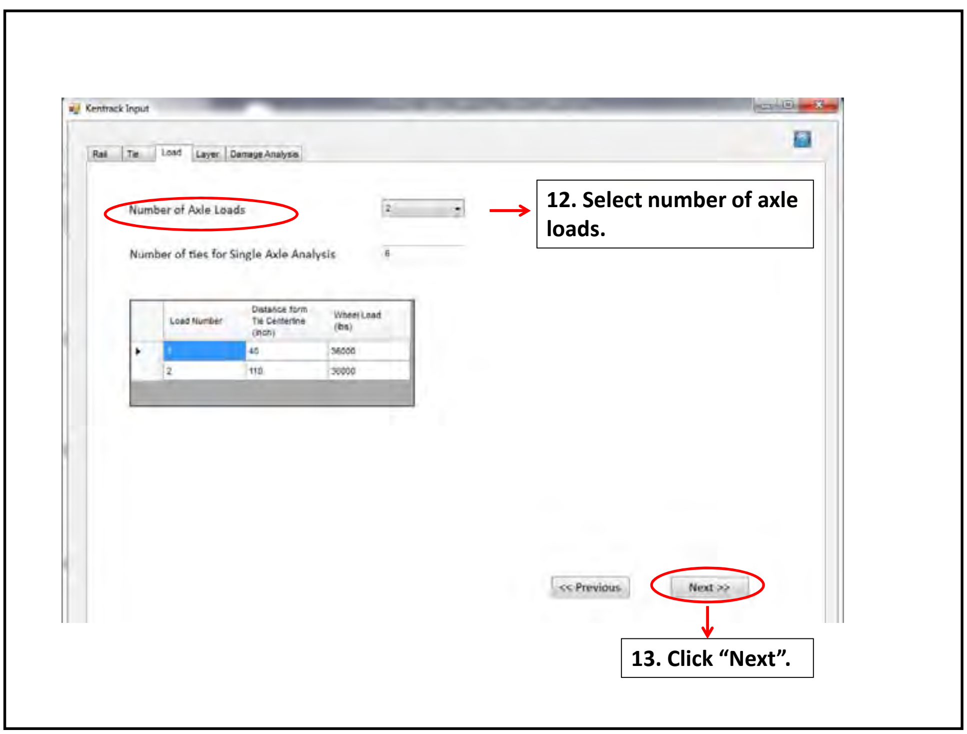
Procedures for Three Types of Trackbeds

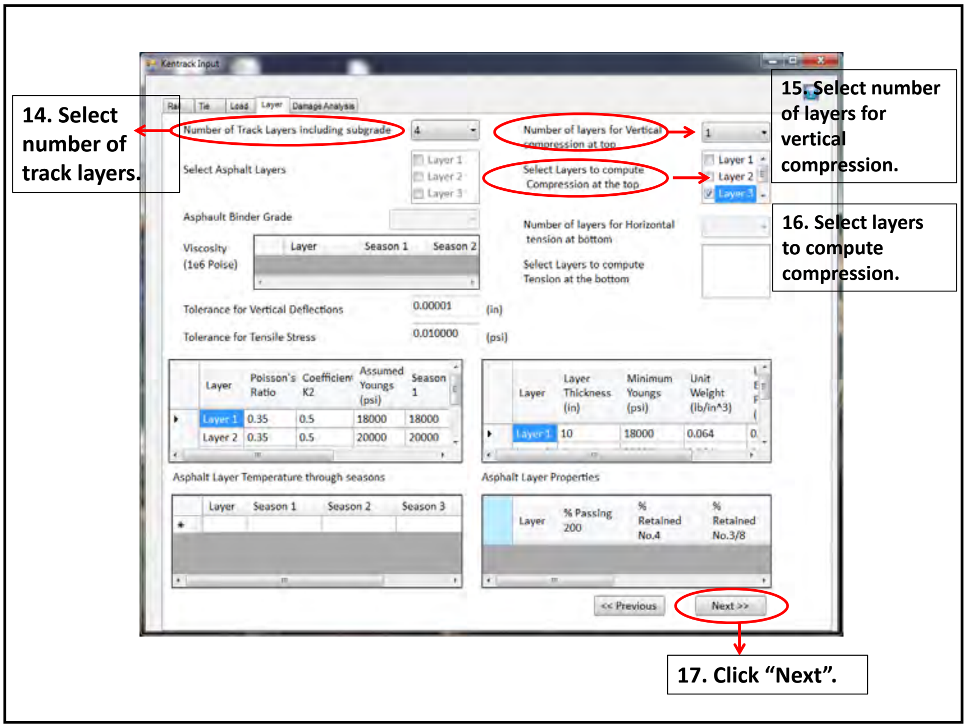
Kentrack 4.1
Step-by-Step Procedure for All-Granular Trackbed

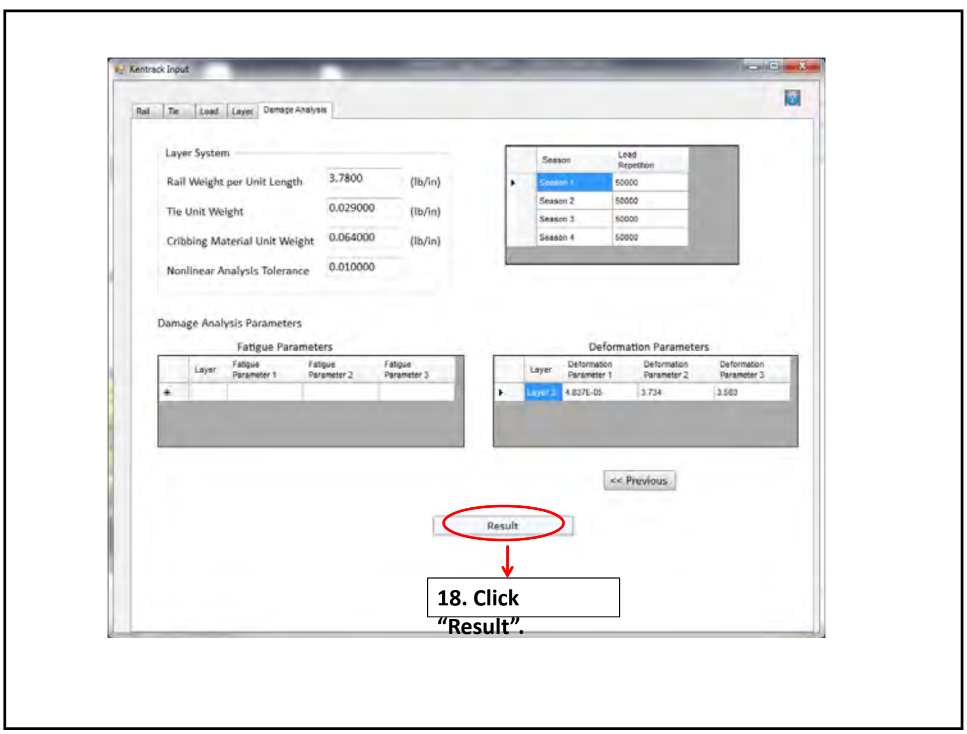


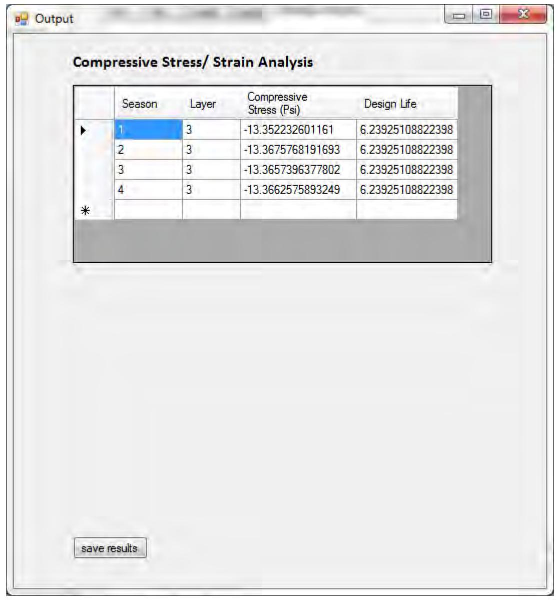



7. Select type of tie.
8. Select Number of Seasons.
9. Select Seasons for output.
10. Select cross section for out put.
11. Click "Next".
Kentrack Input
Rail
Tie
Load
Layer
Damage Analysis
Type of Tie
Wood
Number of Transverse Points
7
Thickness
7.0000
(in)
Width
9.0000
(in)
Moment of Inertia
257.25
(in^4)
Youngs Modulus
1500000
(psi)
Spacing
20
(in)
Number of Seasons
4
Select Season for Output
Season 1
Season 2
Season 3
Location Number of Rail on Tie
4
Length of Tie
108
(in)
Center to Center Distance between Rails
59.5
(in)
Distance between Point 1 and 2 in transverse direction
15
(in)
First Tie Number for Superposition
3
Last Tie Number for Superposition
6
Cross Section for output
Cross_Section 3
Cross_Section 4
Cross_Section 5
Cross_Section 6
<< Previous
Next >>

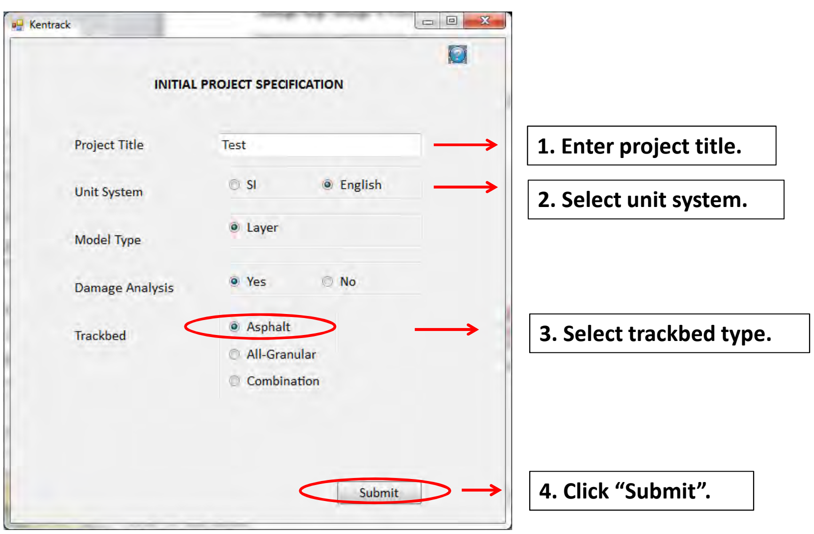

12. Select number of axle loads.
13. Click "Next".
Kentrack Input
Rail
Tie
Load
Layer
Damage Analysis
Number of Axle Loads
2
Number of ties for Single Axle Analysis
6
Load Number
Distance form Tie Centerline (inch)
Wheel Load (lbs)
1
40
36000
2
110
36000
<< Previous
Next >>

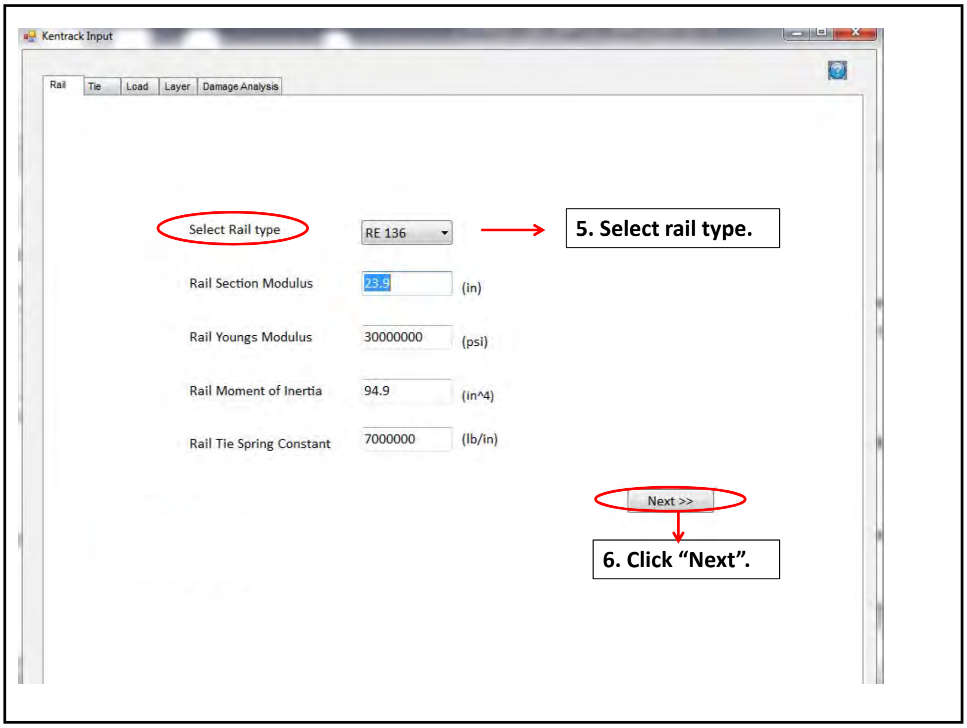

14. Select number of track layers.
15. Select number of layers for vertical compression.
16. Select layers to compute compression.
17. Click "Next".

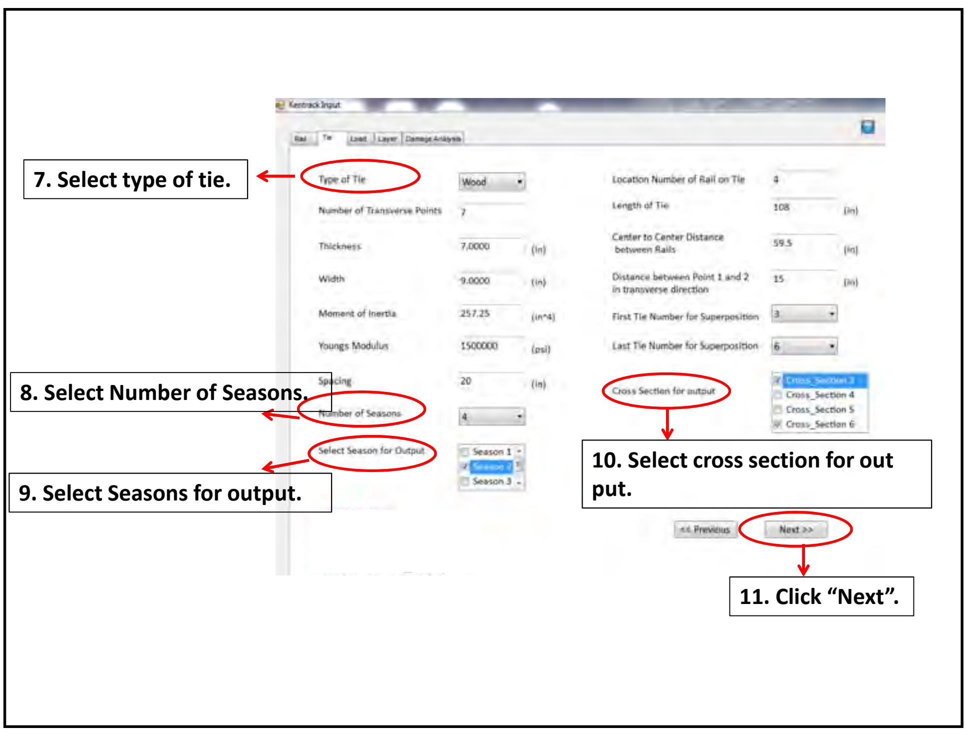

18. Click "Result".

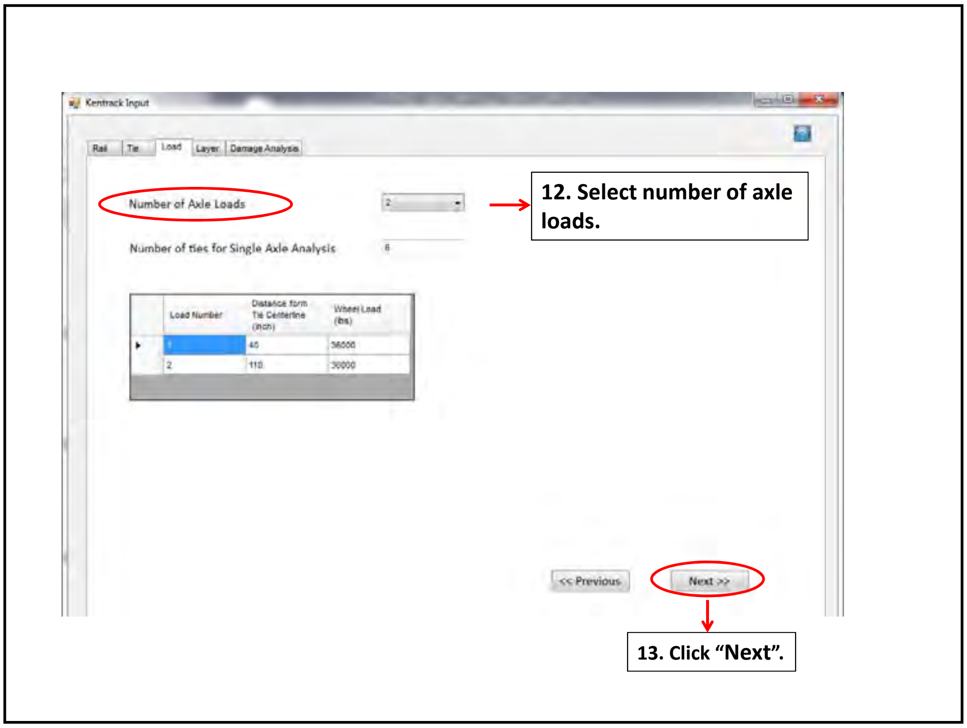


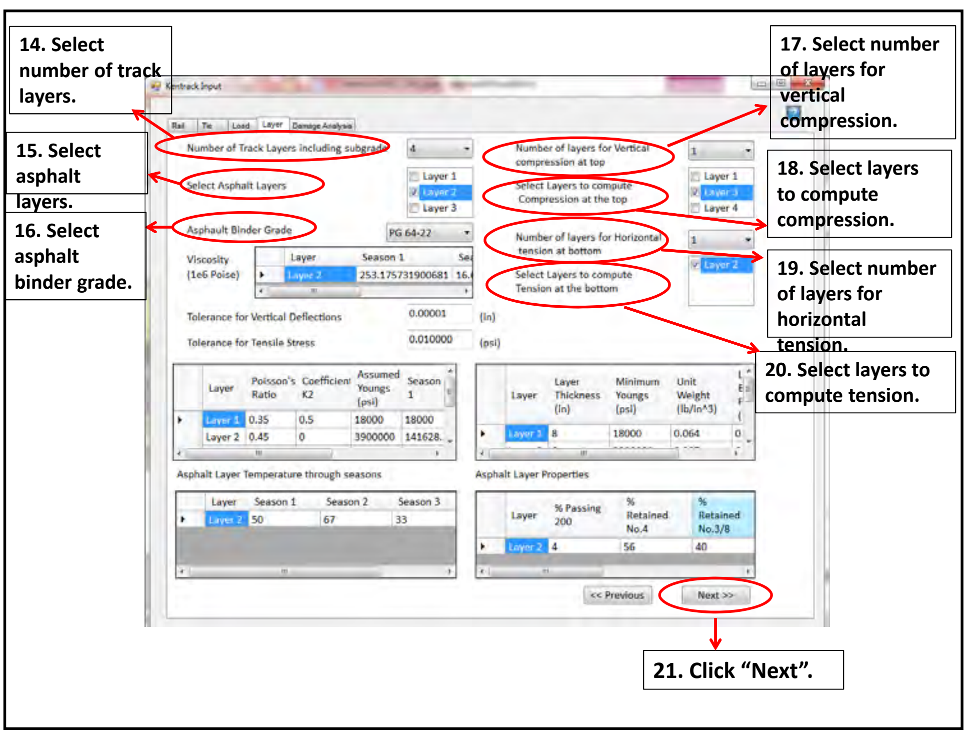
Kentrack 4.0
Step-by-Step Procedure for Asphalt Underlayment Trackbed

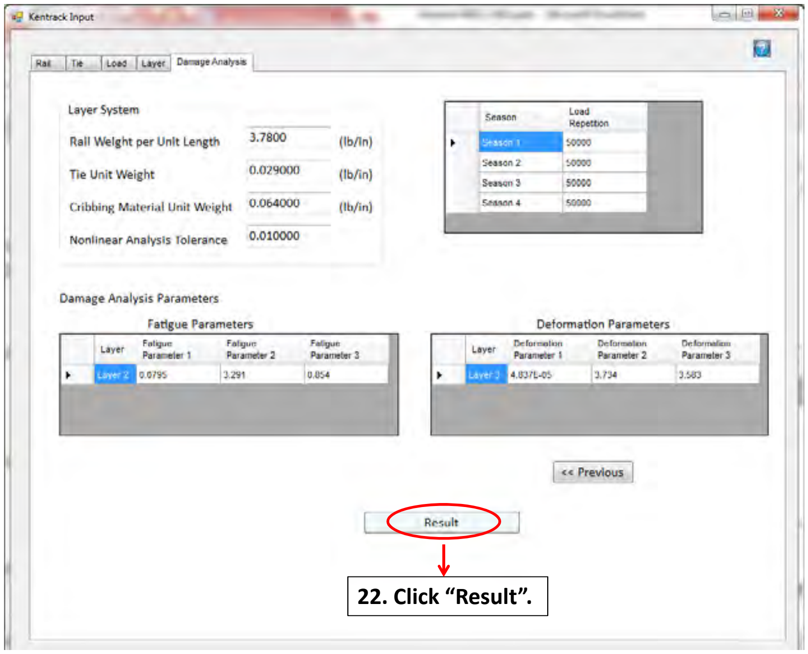


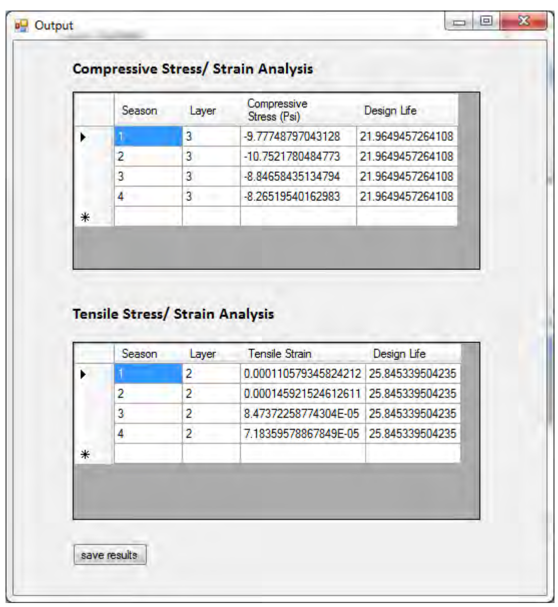

Kentrack Input
Rail
Tie
Load
Layer
Damage Analysis
Select Rail type
RE 136
5. Select rail type.
Rail Section Modulus
23.9
(in)
Rail Youngs Modulus
30000000
(psi)
Rail Moment of Inertia
94.9
(in^4)
Rail Tie Spring Constant
7000000
(lb/in)
Next >>
6. Click "Next".


Kentrack Input
7. Select type of tie.
Type of Tie
Wood
Number of Transverse Points
Thickness
Width
Moment of Inertia
Youngs Modulus
Spacing
Number of Seasons
Select Season for Output
Location Number of Rail on Tie
Length of Tie
Center to Center Distance between Rails
Distance between Point 1 and 2 in transverse direction
First Tie Number for Superposition
Last Tie Number for Superposition
Cross Section for output
8. Select Number of Seasons.
9. Select Seasons for output.
10. Select cross section for out put.
Next >>
11. Click "Next".

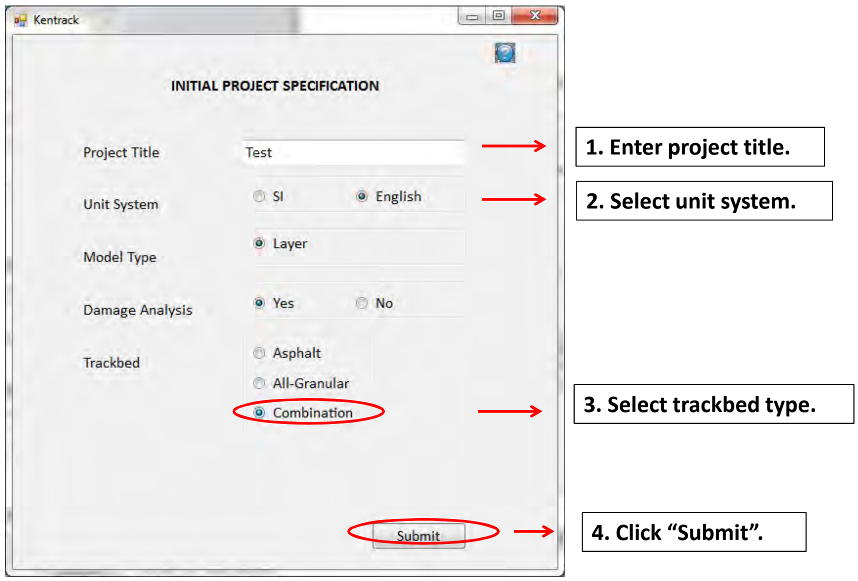

Kentrack Input
Rail
Tie
Load
Layer
Damage Analysis
Number of Axle Loads
Number of ties for Single Axle Analysis
12. Select number of axle loads.
<< Previous
Next >>
13. Click "Next".

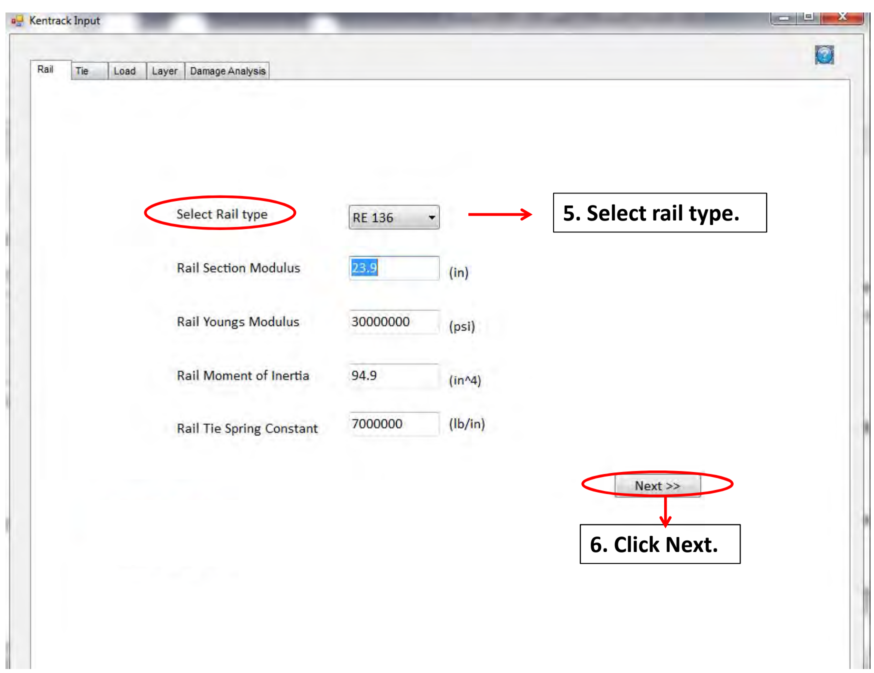

14. Select number of track layers.
15. Select asphalt layers.
16. Select asphalt binder grade.
Number of Track Layers including subgrade
Select Asphalt Layers
Asphault Binder Grade
PG 64-22
Tolerance for Vertical Deflections
Tolerance for Tensile Stress
Asphalt Layer Temperature through seasons
Asphalt Layer Properties
17. Select number of layers for vertical compression.
18. Select layers to compute compression.
19. Select number of layers for horizontal tension.
20. Select layers to compute tension.
<< Previous
Next >>
21. Click "Next".

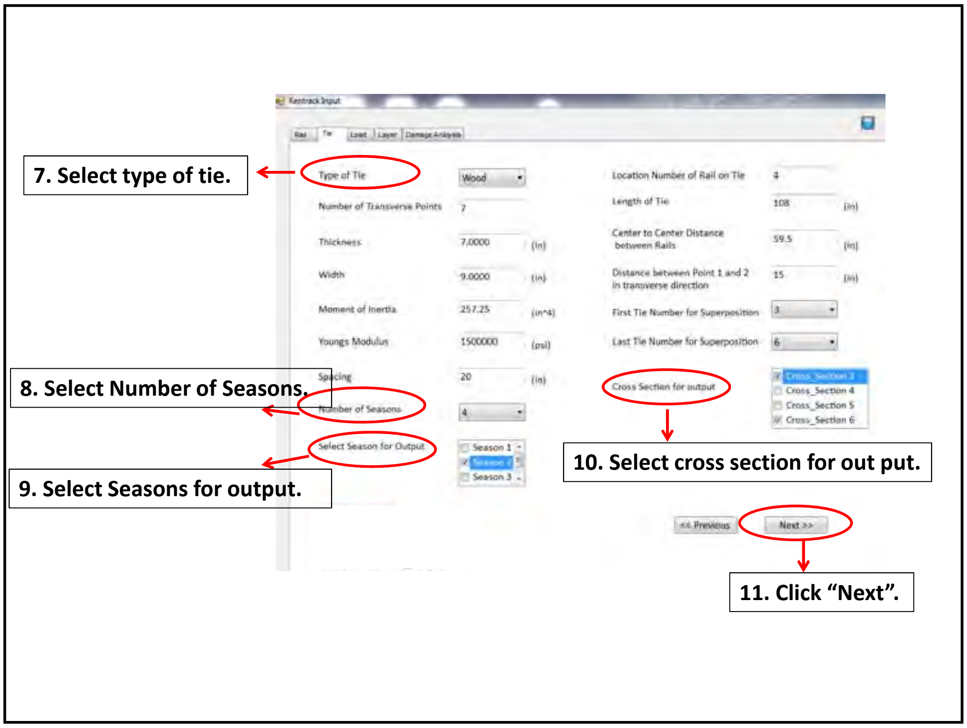

Kentrack Input
Rail
Tie
Load
Layer
Damage Analysis
Layer System
Rail Weight per Unit Length 3.7800 (lb/in)
Tie Unit Weight 0.029000 (lb/in)
Cribbing Material Unit Weight 0.064000 (lb/in)
Nonlinear Analysis Tolerance 0.010000
Season | Load Repetition
Season 1 | 50000
Season 2 | 50000
Season 3 | 50000
Season 4 | 50000
Damage Analysis Parameters
Fatigue Parameters
Layer | Fatigue Parameter 1 | Fatigue Parameter 2 | Fatigue Parameter 3
Layer 2 | 0.0795 | 3.291 | 0.854
Deformation Parameters
Layer | Deformation Parameter 1 | Deformation Parameter 2 | Deformation Parameter 3
Layer 2 | 4.837E-05 | 3.734 | 3.583
<< Previous
Result
22. Click "Result".

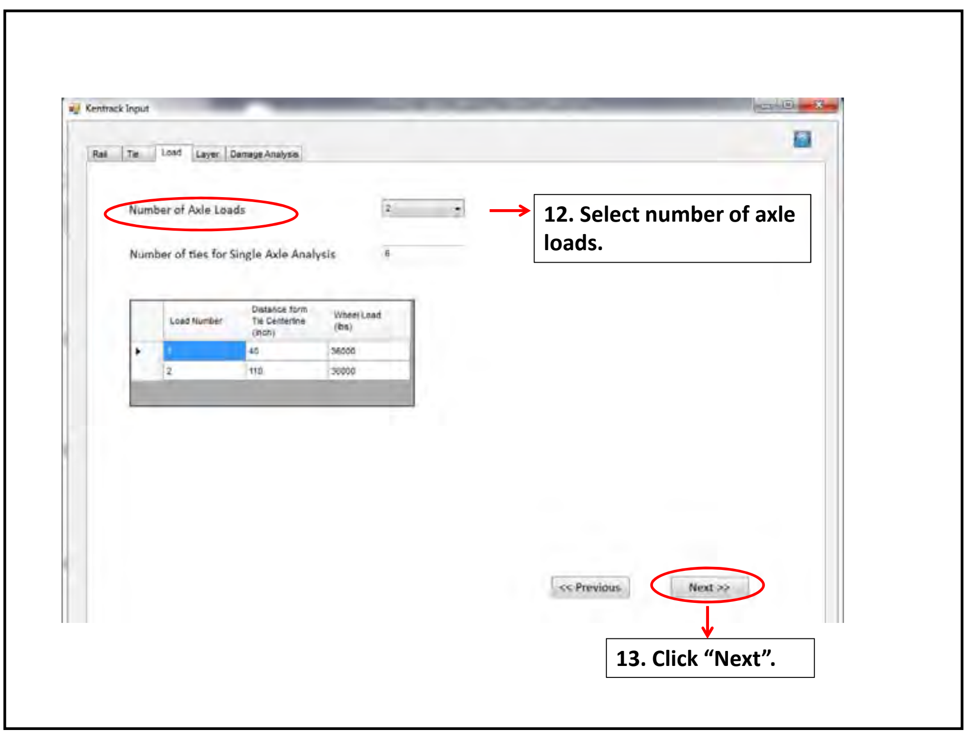

Output
Compressive Stress/ Strain Analysis
Season | Layer | Compressive Stress (Psi) | Design Life
1 | 3 | -9.77748797043128 | 21.9649457264108
2 | 3 | -10.7521780484773 | 21.9649457264108
3 | 3 | -8.84658435134794 | 21.9649457264108
4 | 3 | -8.26519540162983 | 21.9649457264108
Tensile Stress/ Strain Analysis
Season | Layer | Tensile Strain | Design Life
1 | 2 | 0.000110579345824212 | 25.845339504235
2 | 2 | 0.000145921524612611 | 25.845339504235
3 | 2 | 8.47372258774304E-05 | 25.845339504235
4 | 2 | 7.18359578867849E-05 | 25.845339504235
save results

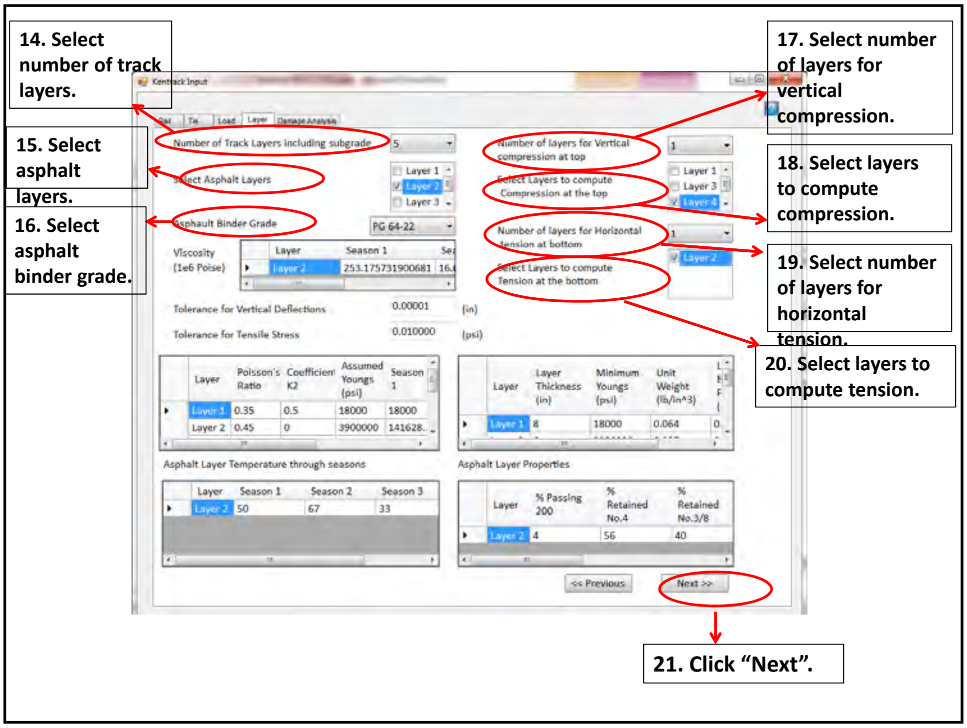
Kentrack 4.0
Step-by-Step Procedure for Combination Trackbed

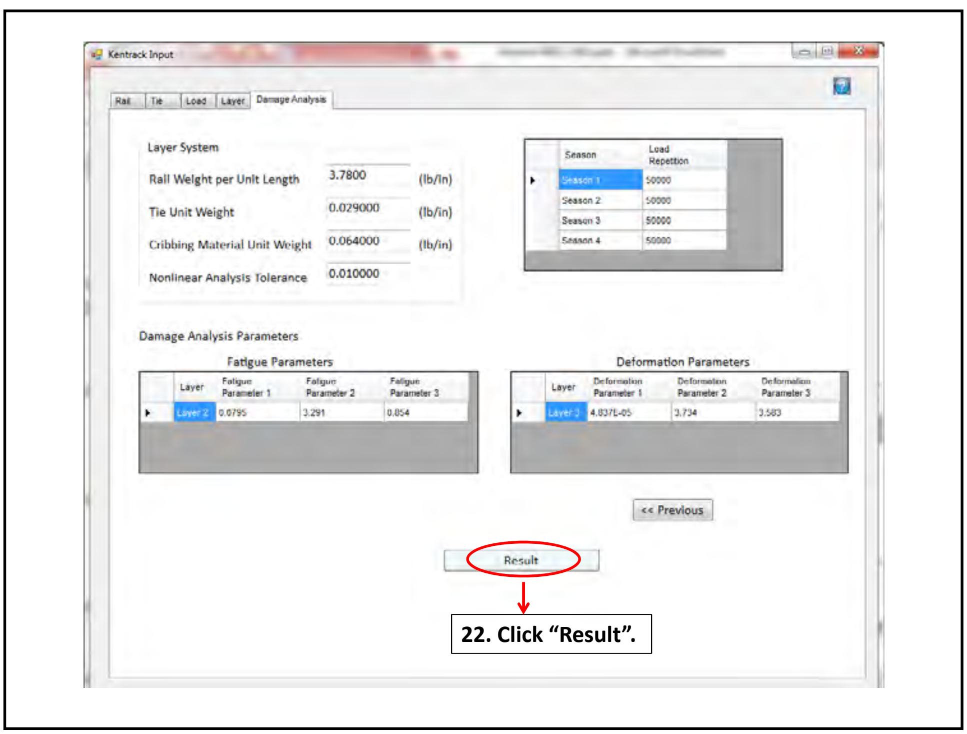


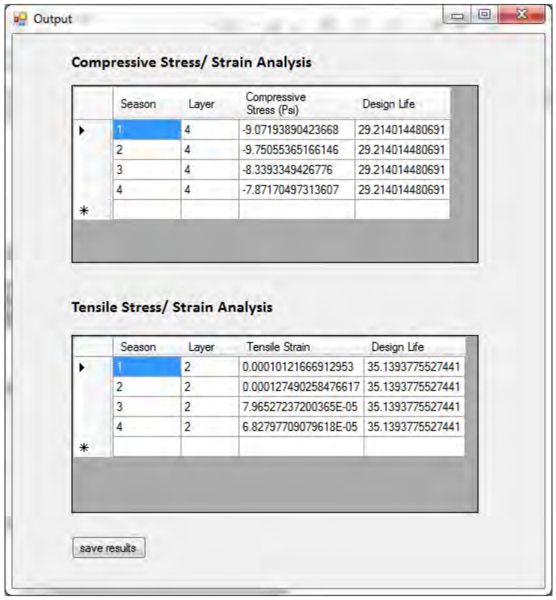



7. Select type of tie.
8. Select Number of Seasons.
9. Select Seasons for output.
10. Select cross section for out put.
11. Click “Next”.
Kentrack Input
Rail
Tie
Load
Layer
Damage Analysis
Type of Tie
Wood
Number of Transverse Points
7
Thickness
7.0000
(in)
Width
9.0000
(in)
Moment of Inertia
257.25
(in^4)
Youngs Modulus
1500000
(psi)
Spacing
20
(in)
Number of Seasons
4
Select Season for Output
Season 1
Season 3
Location Number of Rail on Tie
4
Length of Tie
108
(in)
Center to Center Distance between Rails
59.5
(in)
Distance between Point 1 and 2 in transverse direction
15
(in)
First Tie Number for Superposition
3
Last Tie Number for Superposition
6
Cross Section for output
Cross_Section 4
Cross_Section 5
Cross_Section 6
<< Previous
Next >>


12. Select number of axle loads.
13. Click “Next”.
Kentrack Input
Rail
Tie
Load
Layer
Damage Analysis
Number of Axle Loads
2
Number of ties for Single Axle Analysis
6
Load Number
Distance form Tie Centerline (inch)
Wheel Load (lbs)
1
45
36000
2
115
36000
<< Previous
Next >>


14. Select number of track layers.
15. Select asphalt layers.
16. Select asphalt binder grade.
17. Select number of layers for vertical compression.
18. Select layers to compute compression.
19. Select number of layers for horizontal tension.
20. Select layers to compute tension.
21. Click "Next".
Kentrack Input
Number of Track Layers including subgrade
Select Asphalt Layers
Asphalt Binder Grade
PG 64-22
Viscosity (1e6 Poise)
Tolerance for Vertical Deflections
Tolerance for Tensile Stress
Number of layers for Vertical compression at top
Select Layers to compute Compression at the top
Number of layers for Horizontal tension at bottom
Select Layers to compute Tension at the bottom
Asphalt Layer Temperature through seasons
Asphalt Layer Properties
<< Previous
Next >>


Kentrack Input
Rail
Tie
Load
Layer
Damage Analysis
Layer System
Rail Weight per Unit Length
3.7800
(lb/in)
Tie Unit Weight
0.029000
(lb/in)
Cribbing Material Unit Weight
0.064000
(lb/in)
Nonlinear Analysis Tolerance
0.010000
Damage Analysis Parameters
Fatigue Parameters
Deformation Parameters
<< Previous
Result
22. Click "Result".


Output

Compressive Stress/ Strain Analysis

Season	Layer	Compressive Stress (Psi)	Design Life
1	4	-9.07193890423668	29.214014480691
2	4	-9.75055365166146	29.214014480691
3	4	-8.3393349426776	29.214014480691
4	4	-7.87170497313607	29.214014480691

Tensile Stress/ Strain Analysis

Season	Layer	Tensile Strain	Design Life
1	2	0.00010121666912953	35.1393775527441
2	2	0.000127490258476617	35.1393775527441
3	2	7.96527237200365E-05	35.1393775527441
4	2	6.82797709079618E-05	35.1393775527441

save results

Table 1 Critical Outputs for All-Granular, Asphalt Underlayment, and Combination Trackbeds with Wood Ties

Trackbed Type	Subgrade Compressive Stress (psi)	Subgrade Service Life (years)	Asphalt Tensile Strain	Asphalt Service Life (years)
All-Granular Trackbed	13.37	6.2	n/a	n/a
Asphalt Underlayment Trackbed	10.75	22.0	0.000146	25.8
Combination Trackbed	9.75	29.2	0.000127	35.1

Thank You for Your Attention
Any Questions ???

To Access the KENTRACK 4.0 Program, go to:

http://www.engr.uky.edu/~jrose/ce533_html/kentrack.html

OR

Go to my Webpage: www.engr.uky.edu/~jrose
Click on Recent Railroad Engineering Papers, Presentations, Reports, and Programs;
Scroll down to Programs;
Click on Kentrack 4.0.

Appendix C: List of other education related papers and presentations produced

List of other education-related papers and presentations produced (not counted as part of UKY NURail research products)

2012 presentations

Jerry G. Rose, "Optimizing Sub-Structure Designs and Installation Practices to Improve Long-Term Performances of Highway-Railway At-Grade Crossings", USACE Transportation Systems Workshop, Austin, TX (March)

Jerry G. Rose, "Introduction to Railway Infrastructure", Railway Engineering and Education Symposium, Overland Park, KS (June)

Jerry G. Rose, "KENTRACK 4.0: A Railway Trackbed Structural Design Program", Railway Engineering and Education Symposium, Overland Park, KS (June)

Jerry G. Rose, "Rehabilitation Techniques to Improve Long-Term Performances of Highway-Railway At-Grade Crossings", Southeastern Rail-Highway Safety Conference, Charlotte, NC (November)

2013 presentations

Jerry G. Rose, "Domestic and International Design Practices, Applications, and Performances of Asphalt/Bituminous Railway Trackbeds," Annual Meeting of the Transportation Research Board, Session 755, Track Structure – Substructure Interaction Session Railroad Track Structure System Design Committee (AR050) Washington, DC (January)

Jerry G. Rose, "Improving the Performance of Rail/Highway Crossings" 99th Annual Purdue Road School Purdue University West Lafayette, Indiana (March)

Jerry G. Rose, "International Design Practices, Applications, and Performances of Asphalt/Bituminous Railway Trackbeds" Track Substructure Workshop 7, Transportation Test Center Pueblo, Colorado (March)

Jerry G. Rose, "Domestic and International Design Practices, Applications, and Performances of Asphalt/Bituminous Railway Trackbeds," Union Pacific Railroad, Omaha, Nebraska (April)

Jerry G. Rose, "Selected In-Track Applications and Performances of Hot-Mix Asphalt Trackbeds", 2013 Joint Rail Conference, Knoxville, TN (April)

Souleyrette, Reginald R., "NHI Highway Rail Grade Crossing Improvement Program," Short Course, St. Louis, MO, (September)

Jerry G. Rose, "Highway-Railway At-Grade Crossing Rehabilitation Practices to Enhance Long-Term Performances: Criteria and Evaluations", National Highway-Rail Grade Crossing Safety Conference, Fort Worth (November 3-6)

2014 presentations

Souleyrette, Reginald R., "Hot-Mix Asphalt (Bituminous) Railway Trackbeds: In-Track Tests, Evaluations, and Performances -- A Global Perspective: Part I -- Introduction to Asphalt Trackbeds and International Applications and Practices," Part II -- United States Asphalt Trackbed Applications and Practices," Part III -- U.S. Asphalt Trackbed Materials Evaluations and Tests," 3rd International Conference on Transportation Infrastructures - ICTI, Pisa, Italy (April)

Rose, Jerry G., "Rehabilitation, Assessment, and Management Practices to Ensure Long-Life, High Performance Highway-Railway At-Grade Crossings," Oregon Department of Transportation, Salem, Oregon (April)

Rose, Jerry G., "KENTRACK 4.0: A Railway Trackbed Structural Design Program", Joint Rail Conference, Colorado Springs, CO (April)

Rose, Jerry G., "Rehabilitation, Assessment, and Management Practices to Ensure Long-Life, High Performance Highway-Railway At-Grade Crossings," Joint Rail Conference, Colorado Springs, CO (April)

Rose, Jerry G. and Reginald R. Souleyrette, "Hot-Mix Asphalt (Bituminous) Railway Trackbeds: In-Track Tests, Evaluations, and Performances -- A Global Perspective: Part I -- Introduction to Asphalt Trackbeds and International Applications and Practices," Part II -- United States Asphalt Trackbed Applications and Practices," Part III -- U.S. Asphalt Trackbed Materials Evaluations and Tests," *When Rail Meets Soil* Technical Workshop Caltrain Headquarters, San Carlos, CA (May)

Rose, Jerry G., "Rehabilitation, Assessment, and Management Practices to Ensure Long-Life, High Performance Highway-Railway At-Grade Crossings," *When Rail Meets Soil* Technical Workshop Caltrain Headquarters, San Carlos, CA (May)

Rose, Jerry G., "KENTRACK 4.0: A Railway Trackbed Structural Design Program", Railway Engineering and Education Symposium Overland Park, KS (June)

Rose, Jerry G., "Introduction to Railway Infrastructure", Railway Engineering and Education Symposium Overland Park, KS (June)

Rose, Jerry G., "Maintaining Adequate Trackbed Structural Support – An Important Railway Infrastructure Issue" William W. Hay Railroad Engineering Seminar, University of Illinois/RAILTEC (December)

2013 publications

Jerry G. Rose, "Selected In-Track Applications and Performances of Hot-Mix Asphalt Trackbeds", 2013 Joint Rail Conference, Knoxville, TN, 2013;():V001T01A017. doi:10.1115/JRC2013-2525. (April)

Xu, P., R. Liu., Q. Sun, R. Souleyrette and J. Rose, "A Novel and Reliable Track Condition Prediction Model for Condition Based Track Maintenance, ASME, IEEE and ASCE Joint Rail Conference, Knoxville, April 2013.

Jerry G. Rose, “Highway-Railway At-Grade Crossing Rehabilitation Practices to Enhance Long-Term Performances: Criteria and Evaluations”, Proceedings, National Highway-Rail Grade Crossing Safety Conference, Fort Worth, 23pp. (November)

2014 publications

Liu, S., R. Souleyrette and J. Rose, “Kentrack 4.0: A Revised Railway Structural Design Program,” Proceedings of the 91st Annual Meeting of TRB, Washington, DC, Jan. 2014.

Rose, J. and R. Souleyrette, “Hot-Mix Asphalt (Bituminous) Railway Trackbeds: In-Track Tests, Evaluations, and Performances -- A Global Perspective: Part I -- Introduction to Asphalt Trackbeds and International Applications and Practices,” Proceedings of the 3rd International Conference on Transportation Infrastructures - ICTI 2014, Pisa, Italy, April 22-25, 2014.

Rose, J. and R. Souleyrette, “Hot-Mix Asphalt (Bituminous) Railway Trackbeds: In-Track Tests, Evaluations, and Performances -- A Global Perspective: Part II -- United States Asphalt Trackbed Applications and Practices,” Proceedings of the 3rd International Conference on Transportation Infrastructures - ICTI 2014, Pisa, Italy, April 22-25, 2014.

Rose, J. and R. Souleyrette, “Hot-Mix Asphalt (Bituminous) Railway Trackbeds: In-Track Tests, Evaluations, and Performances -- A Global Perspective: Part III -- U.S. Asphalt Trackbed Materials Evaluations and Tests,” Proceedings of the 3rd International Conference on Transportation Infrastructures - ICTI 2014, Pisa, Italy, April 22-25, 2014.

Rose, J. S. Liu, and R. Souleyrette, “Kentrack 4.0: A Railway Trackbed Structural Design Program,” Proceedings, Joint Rail Conference, Paper 2014-3752, 2014;():V001T01A010. doi:10.1115/JRC2014-3752.Colorado Springs, CO, April 2-4, 2014.

Rose, J. B. Malloy, B. and R. Souleyrette, “Rehabilitation, Assessment and Management Practices to Ensure Long-Life, High Performance Highway-Railway At-Grade Crossings,” Proceedings, Joint Rail Conference, Paper 2014-3761, 2014;():V001T01A013. doi:10.1115/JRC2014-3761.Colorado Springs, CO, April 2-4, 2014.

Rose, Jerry G. and Brett R. Malloy, “Effect of Enhanced Trackbed Support on Railway/Highway At-Grade Crossing Performance,” Kentucky Transportation Center Report No. KTC-14-19/SPR452-13-1F. December 2014 180pp.

Malloy, Brett R., and Jerry G. Rose, “Railway/Highway At-Grade Crossing Surface Management: An Overview,” Kentucky Transportation Center Report No. KTC-14-19/SPR452-13-2F. December 2014. 62pp.

Malloy, Brett R., Jerry G. Rose, and Macy L. Purcell, “Recommendations for KYTC’s Railway/Highway At-Grade Crossing Management Practices,” Kentucky Transportation Center Report No. KTC-14-19/SPR452-13-3F. December 2014. 30pp.

Malloy, Brett R., Macy L. Purcell and Jerry G. Rose, “Railway/Highway At-Grade Crossing Surface Rehabilitation Manual: Recommendations and Guides,” Kentucky Transportation Center Report No. KTC-14-19/SPR452-13-4F. December 2014. 60pp.