KENTRACK — A Railway Trackbed Structural Design Program

by

Jerry G. Rose, Ph.D., PE
Professor of Civil Engineering
161 OH Raymond Building
University of Kentucky
Lexington, Kentucky 40506-0281 USA
phone (859) 257-4278, fax (859) 257-4404
e-mail jrose@engr.uky.edu

and

Karthik Charan Konduri, EIT
(formerly Graduate Research Assistant)
Transportation Engineer
Strand Associates, Inc.
Joliet, Illinois 60431USA
phone (815) 744-4200, fax (815) 744-4215
e-mail: karthik_charan@yahoo.com

Offered for Publication and Presentation at the American Railway Engineering and Maintenance-of-Way Association, 2006 Annual Conference and Exposition, September 17-20, 2006, Louisville, Kentucky (Copy of KENTRACK Program, including tutorial, help file, software instructions, and example data files, provided to attendees upon request.)

June 2006

ABSTRACT

KENTRACK is a layer elastic finite element computer program that can be utilized for the structural design of railway trackbeds. It is applicable for the analysis and design of component thicknesses for various types of track structures and for conventional all-granular track structures. The primary governing factor is limiting the vertical compressive stresses on the subgrade. A damage analysis is conducted and is used to predict the service life of the trackbed components for various combinations of traffic, tonnages, subgrade support, and component layer thicknesses. The program has been recently converted to a more user-friendly Window's based platform. This modification is highlighted. The program is applicable for the routine design of conventional trackbeds and for evaluating the relative effects of incorporating innovative materials and products within the structure. The following topics are included herein: 1) KENTRACK computer program theory, 2) Damage analysis predictions, 3) Methodology utilized, 4) Tutorial example calculations, 5) Effects of varying significant variables, and 6) Comparisons of verification measurements with predicted values.

KEYWORDS

Railway, Kentrack, Trackbed, Structural Design, Layer Elastic, Finite Element, Multilayer

INTRODUCTION

Railroads have been in existence in this country for over 170 years. During this period the railroads have changed, keeping pace with the technological advancements and the demands of the industry. The railroads have witnessed significant increases in annual gross ton miles, train speeds, and axle loads.

To accommodate these changes, larger rail sections are being used, namely RE 136 and RE 140. Also different types of ties including wood, concrete, and composite ties along with premium quality fasteners have been improved for optimum performance. Though the upper section of the track has seen many changes, an all important track component -- the granular support layer -- has not significantly changed. During the past two decades research has centered on development of new trackbed designs. During this period in the United States, Hot Mix Asphalt (HMA) trackbeds have been developed and tested. Numerous test and revenue trackbeds have been constructed over different types of subgrade and with varied thicknesses.

KENTRACK is a layer elastic finite element computer program that can be utilized for the structural design of railway trackbeds. The Windows based upgraded version KENTRACK 2.0.1 presented in this paper contains a Graphic User Interface. The effects of subgrade modulus, ballast/HMA thickness and axle load on trackbed design, as determined and predicted by the computer program, are also presented.

The HMA trackbeds have been found to impart the following benefits to the track structure according to the studies conducted on the test installations (Asphalt Institute, 1998).

- A stronger support layer below the ballast layer which distribute reduced stresses onto the subgrade
- A waterproofing layer preventing any water from entering the subgrade and hence eliminating subgrade moisture variations
- A resilient layer between the ballast and subgrade, eliminating the likelihood of subgrade pumping
- A confining layer for the ballast so it can develop high shear strength and provides uniform pressure distribution

- An impermeable layer to diver water to the ditches, eliminating subgrade moisture fluctuations

Hot Mix Asphalt Trackbed

HMA trackbeds are not only applicable for freight lines but can also be used in light rail, commuter rail and high speed passenger rail lines which require tight adherence to maintaining consistent track geometry. Two HMA trackbed designs are currently being used:

- **Underlayment**

  In underlayment the HMA is used as a mat or subballast between the ballast and the subgrade as shown in Figure 1.

- **Overlayment**

  In overlayment the HMA layer is placed over the subgrade and the ties are placed directly over the HMA layer as shown in Figure 2. In this method the only use of ballast is to provide the cribbing.

The underlayment design is more widely used and is preferred over the overlayment design. For underlayment the asphalt layer is protected from the environment and also the track geometry can be easily adjusted (Rose, Brown and Osborne, 2000). Due to these reasons only underlayment is discussed in this paper.

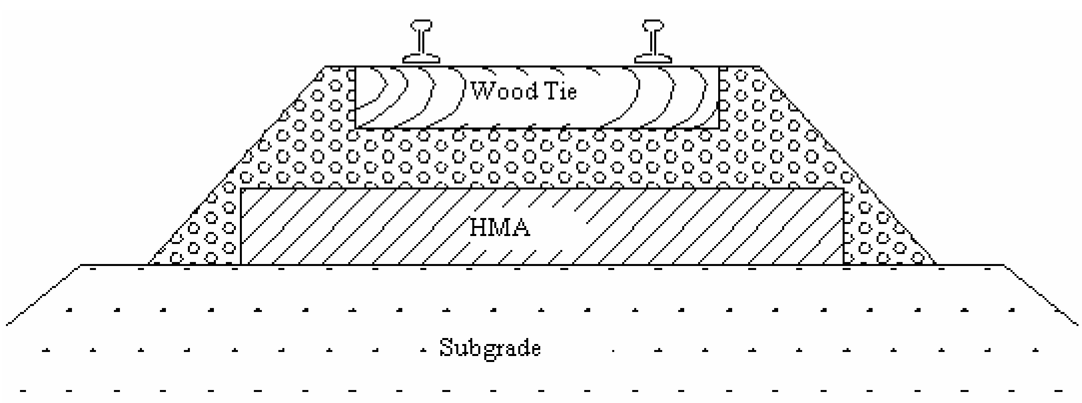


Figure 1: Underlayment Trackbed Design

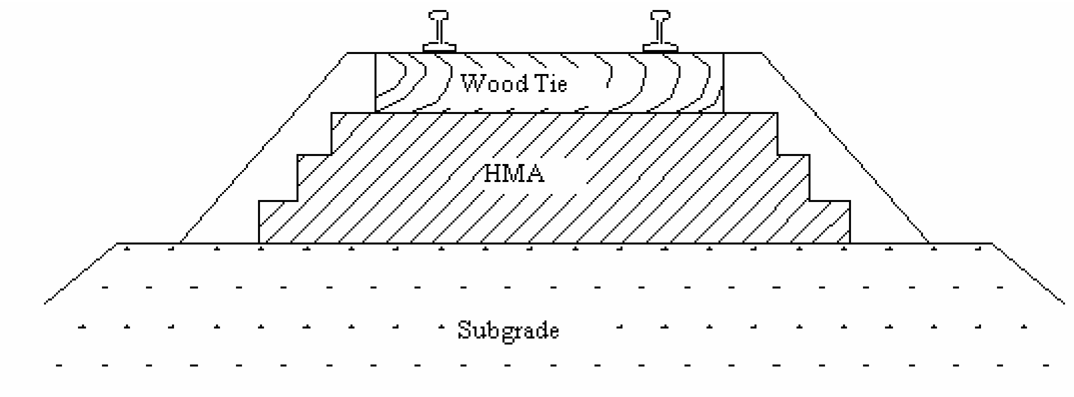


Figure 2: Overlayment Trackbed Design

BACKGROUND

Two methods are used for analyzing trackbeds. One of them is based on Boussinesq elastic theory, known as the single layered theory. This method assumes the support layer to be elastic and isotropic which is not usually the case because the support system is composed of the ballast layer and the subgrade. The other method uses empirical equations based on experience. Two empirical equations have been developed and used for railroad trackbed structural analysis and design. They are:

Japanese National Railways (JNR) equation:

$$P_c = \frac{50P_m}{10 + h^{1.35}}$$

Where,

P_c = subgrade pressure (kPa)

P_m = applied stress on ballast (kPa)

h = ballast depth (cm)

Talbot's equation:

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

Where,

P_c = subgrade pressure (psi)

P_m = applied stress on the ballast (psi)

h = ballast depth (in.)

These two methods were developed primarily for all-ballast trackbeds. For similar input parameters the results do not compare favorably. To address the deficiencies and limitations of the Boussinesq's method, JNR method and Talbot's method, computer programs have been developed to design and analyze trackbeds. These include ILLITRACK (Robnett, 1975), GEOTRACK (Chang, 1980) and KENTRACK (Huang 1984).

ILLITRACK, a computer program to analyze all-granular trackbeds, was developed at the University of Illinois. It is based on finite element method. The model analyzes only in the longitudinal or in the transverse direction, whereas the actual track is in three dimensions.

GEOTRACK, a computer program developed at University of Massachusetts. It uses multilayered theory and a three dimensional model for the trackbed. It was developed to analyze all-granular trackbeds.

KENTRACK was developed specifically to analyze the stresses and strains in HMA trackbeds. It is equally applicable for analyzing all-granular trackbeds.

KENTRACK: THEORY BEHIND THE PROGRAM

KENTRACK was developed at the University of Kentucky for analyzing railroad trackbeds in the early 1980's (Huang, Lin, Deng and Rose, 1984). The program has been upgraded from its Disk Operating System (DOS) version to a windows platform with a Graphic User Interface (GUI). This allows the user to change parameters much easier than the previous DOS version.

The KENTRACK program is based on two main theories, finite element method and multi layer system. Stresses and strains are calculated using the finite element method and multi layer system which facilitates the analysis of all types of trackbeds (Rose, Su and Long, 2003).

Superposition of Loads

The railroad structure consists of rail, ties, fasteners and a layered support system. The multilayered support system consists of ballast layer, subballast layer in granular trackbed which is replaced with a HMA layer in HMA trackbed, subgrade and bedrock. The stresses, strains and deflection of the rail and tie subjected to several loads can be obtained by superposing the effect of each load. This is illustrated in Figure 3. The variable S_i is the deflection in the i[th] tie due to load P. The deflections in the ties due to each of the loads P_1 to P_4 are shown in the figure. After superposing, the deflection at the first tie can be calculated as

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

It can be seen in Figure 3 that the load P is distributed over four ties, but it is reasonable to assume that the wheel load P is distributed over six ties and it gives reliable results for rails and ties.

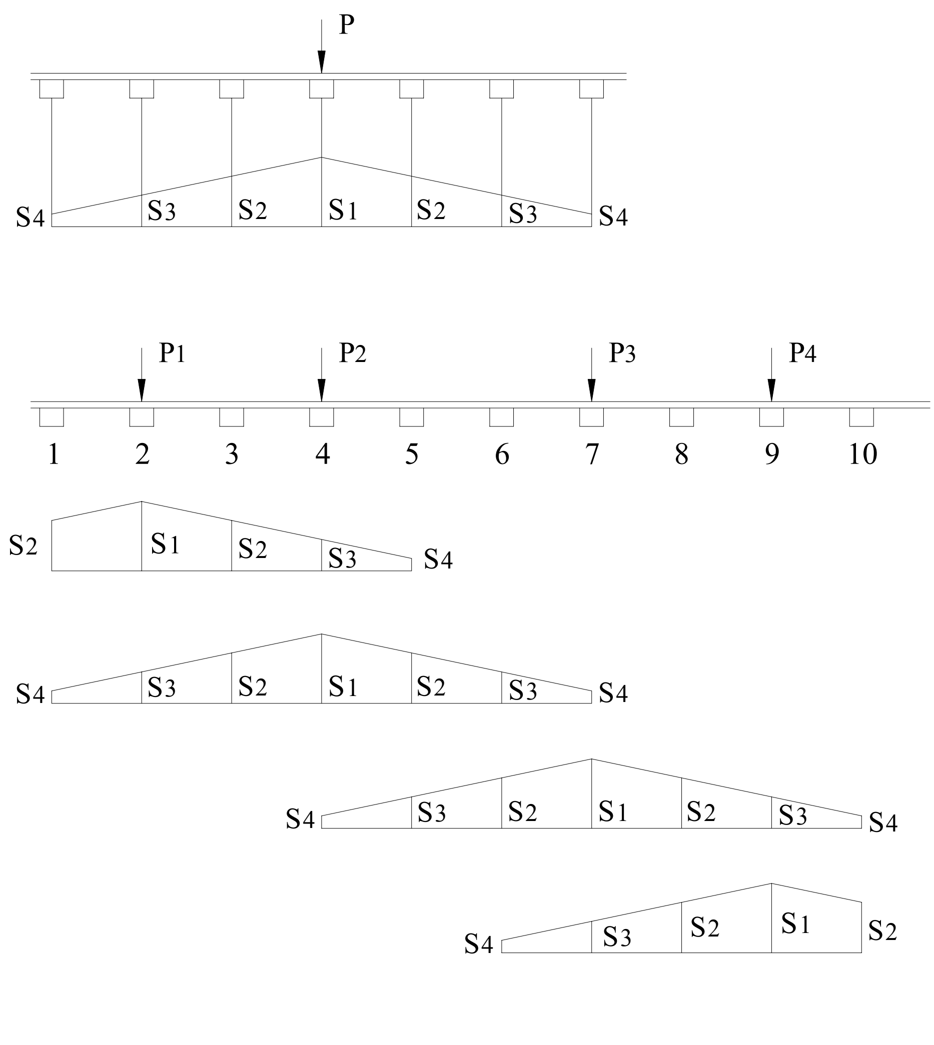


Figure 3: Superposition of multiple loads

Due to the symmetry of the track in longitudinal and transverse directions only a quarter of the track is considered during analysis. The railroad track model used in the analysis is shown in Figure 4.

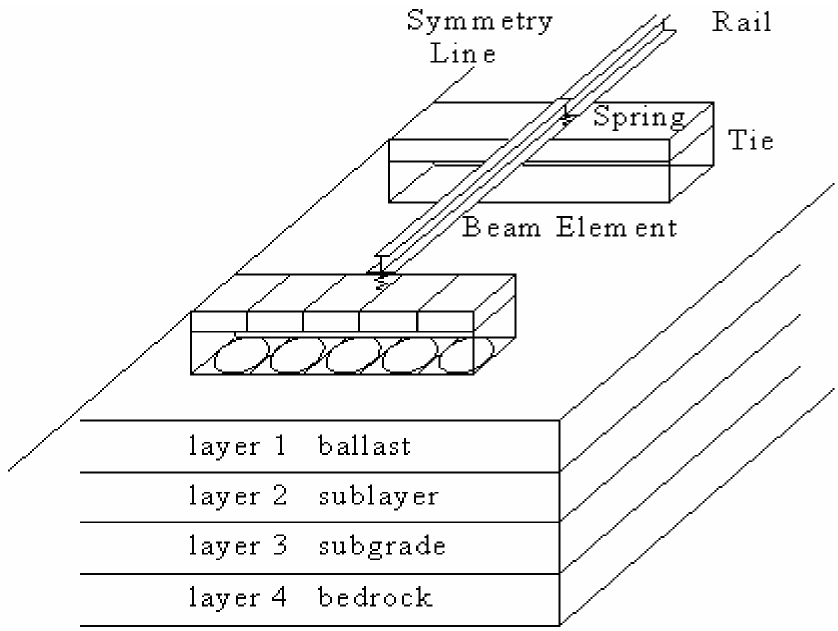


Figure 4: Railroad Track Model

Finite Element Method

Finite element method is used to calculate the stresses and strains in the rail and the tie. Rail and ties are modeled as beam elements and the spring element is used to model the fasteners between the rail and ties as shown in Figure 5.

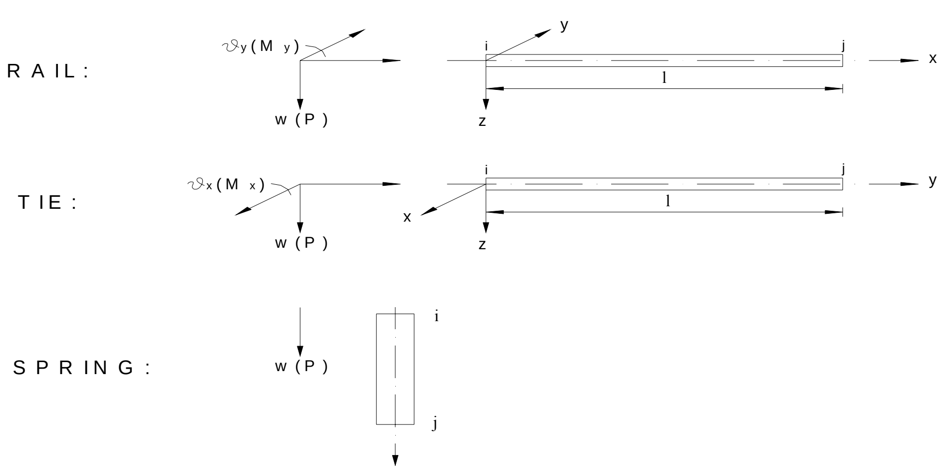


Figure 5: Beam and spring element used in KENTRACK

The stresses obtained below the ties are applied as circular loads on the top layer. The radius of each circular load is obtained by dividing the area of the tie by the number of elements as shown in Figure 4.

Multilayered System

The multilayered system used by KENTRACK to calculate the stresses and strains in the different layers is shown in Figure 6. The circular loads previously calculated are applied on the top layer.

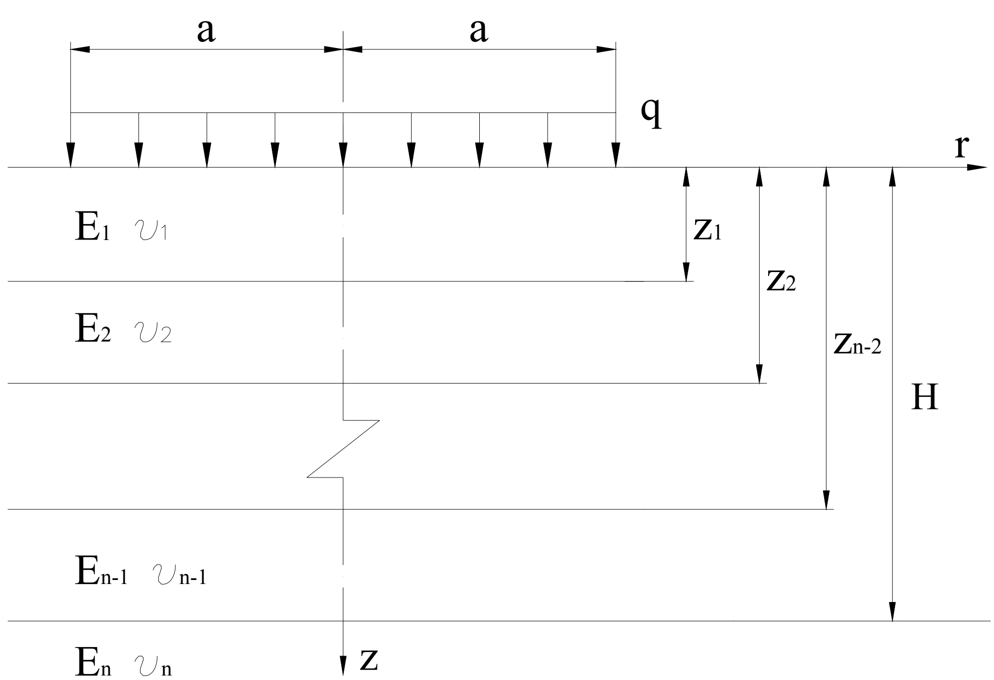


Figure 6: Multilayered system

The stresses and strains in the different layers system are calculated using the general equation of the multi-layered system.

$$\nabla^4\sigma = \left(\frac{\partial^2\sigma}{\partial r^2} + \frac{1}{r}\frac{\partial\sigma}{\partial r} + \frac{\partial^2\sigma}{\partial r^2}\right)\left(\frac{\partial^2\sigma}{\partial r^2} + \frac{1}{r}\frac{\partial\sigma}{\partial r} + \frac{\partial^2\sigma}{\partial z^2}\right)$$

The stresses and strains obtained from the above equation are not the actual stresses and strains due to a uniform load q over a circular area. To find the actual stresses and strains, the Hankel transform method is used.

$$R = \frac{qa}{H}\int_0^\infty \frac{R^*}{m} J_1\left(\frac{ma}{H}\right)dm$$

Where,

R^* = stress or displacement due to loading which can be expressed as $-mJ_0(m\alpha)$

R = stress or displacement due to load q

J = Bessel function

M = parameter

Material Properties

HMA railroad trackbed is comprised of the ballast, HMA and subgrade soil. These materials are considered elastic and different equations are used to describe their properties.

Ballast in a newly constructed trackbed behaves non-linearly and behaves linearly when considered in an aged trackbed that has become compacted. The resilient modulus of ballast is calculated using the following equation:

$$E = K_1\theta^{K_2}$$

Where, $\theta = \sigma_1 + \sigma_2 + \sigma_3 + \gamma z(1 + 2K_0)$

K_1 and K_2 = coefficients

σ_1, σ_2, σ_3 = the three principal stresses

γ = unit weight of the material

K_0 = lateral stress ratio

The dynamic modulus of HMA is calculated using the method developed by the Asphalt Institute (Hwang and Witczak, 1979). To accurately model the asphalt, different temperatures should be used for the different periods since the dynamix modulus is dependent on the temperature.

Subgrade is always considered to be a linearly elastic material. The bottommost layer is generally the bedrock which is considered to be incompressible with a Poisson's ratio of 0.5.

Damage Analysis

The service life of the layers is predicted by using the minor linear damage analysis criteria. The design life is calculated using:

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

Where,

L = is the design life in years

N_p = predicted number of repetitions during each period

N_a or N_d = allowed number of repetitions during each period

N = number of periods

The passage of one car in a train is equivalent to one load repetition. The predicted number of repetitions varies with the traffic that the trackbed is subjected. For an assumed N_p = 200,000 and 36,000 lb wheel load, the traffic would be 28.6 MGT. An illustration and calculations for the same are shown in Figure 7.

In the asphalt layer, the tensile strain at the bottom of the asphalt layer controls its service life. In subgrade soil, the permanent deformation controls its service life.

The number of allowable repetitions for HMA before the failure occurs is calculated using the following equation recommended by the Asphalt Institute (Asphalt Institute, 1982).

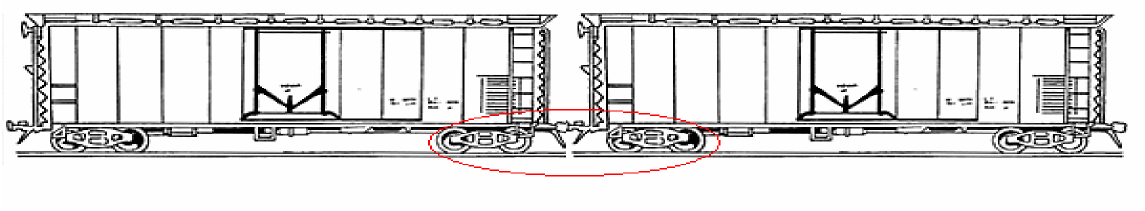
$$N_a = 0.0795\varepsilon_t^{-3.291} E_a^{-0.853}$$

Where,

ε_t = horizontal tensile strain at the bottom of asphalt

E_a = elastic modulus of asphalt in psi

The equation was developed for HMA layers in highway environment, and the results are conservative.



Wheel load	= 36000 lb/wheel
For one car the total weight	= 36000 lb/wheel x 8 = 286,000 lb/rep
	= 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
	= 28.6 MGT/yr

Figure 7: Million Gross Tons per year calculation

The number of allowable repetitions for subgrade layer before failure occurs due to excessive vertical compressive stress is computed by the following equation (Huang, Lin, Deng, Rose, 1984)

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

Where,

σ_c = vertical compressive stress on the top of subgrade in psi

E_a = subgrade modulus in psi

METHODOLOGY

KENTRACK can be used to analyze both HMA and all-granular trackbeds. Typical HMA track section and all-granular track section used in the analysis are shown in Figure 8 a and 8 b respectively.

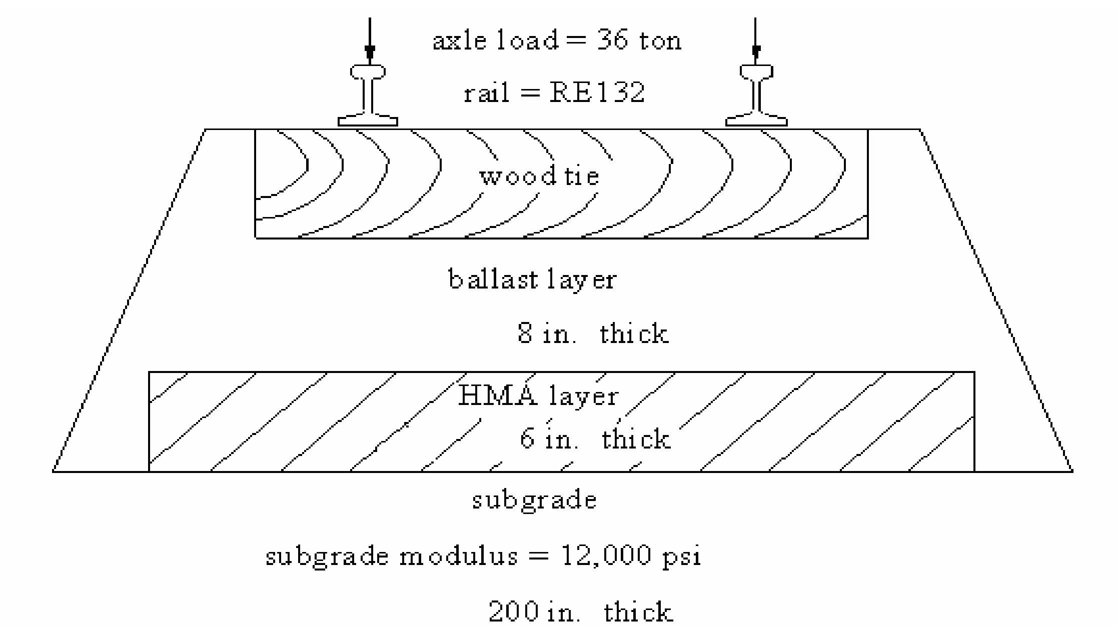


Figure 8 a: HMA track section

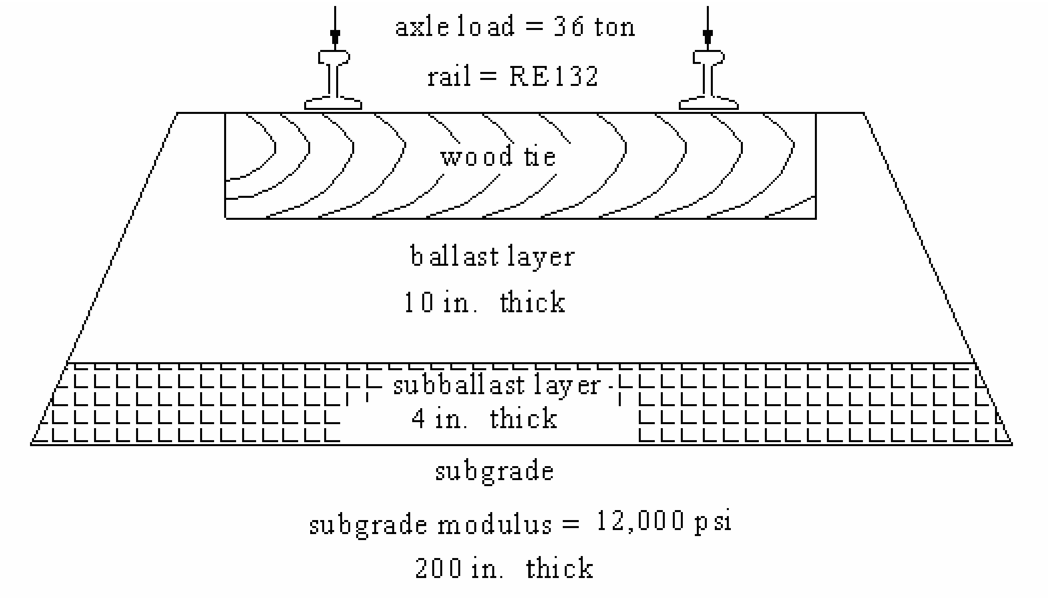


Figure 8 b: All - Granular Track section

In the analysis the effects of varying the various factors on both HMA and all-granular trackbeds is performed to understand the HMA trackbed behavior in comparison to all-granular trackbed.

The critical outputs for the track sections in Figures 8 a and 8 b are summarized in Table 1.

Critical Outputs		
Variable	Standard HMA trackbed	Standard Ballast Trackbed
Subgrade Vertical Compressive Stress (psi)	11.9	13.8
HMA Tensile Strain (in/in)	0.000183	N/A
Service life of Subgrade (yrs)	15.5	5.6
Service life of HMA (yrs)	20.4	N/A

Table 1: Critical Outputs for typical HMA and Ballast Sections with a wooden tie

It can be seen from Table 1 that the HMA layer reduces the compressive stress acting on top of the subgrade from 13.8 to 11.9 psi and also increases the service life of the subgrade by almost 3 times. When a subgrade in a rail trackbed fails, settlement of the subgrade occurs, which causes a depression in the track profile. This can be easily rectified by adding ballast and surfacing the track to its desired position.

The failure criteria used for the railway trackbeds was developed based on highway loading conditions and environments. The service life predicted by KENTRACK is conservative because the stress levels experienced by railway subgrades are lower than that of highways (Rose, Su and Twehues, 2004). Also, settlement in railroad trackbeds is not as significant as in highways and can be rectified easily. It has also been found that unlike highways, where the settlement generally occurs due to water infiltrating into the subgrade, the HMA acts as a waterproofing layer in the trackbed preventing the infiltration of water into the subgrade (Rose, Li and Walker, 2002).

Wood ties are more prevalent in US railroads than concrete ties. Wood ties are used in the subsequent evaluations. The combined thickness of the ballast and subballast for all-granular track sections and combined thickness of ballast and HMA for HMA track sections has been maintained at 14 in.

Tables 2 and 3 list the constant and the variable trackbed parameters. The temperatures are the average values for a particular season considering moderate climate. Those values need to be changed depending on the geographical location.

Parameter Name	Parameter Values
Rail Size	RE100, RE115, RE132, RE140
Tie Type (Fastener Type)	Wood Tie (Spike), Concrete Tie (Elastic Clip)
Ballast Modulus (psi)	18000, 24000, 31000, 40000, 47000
Poisson’s Ratio for Ballast	0.35 (after compact), 0.25 (before compact)
Ballast Thickness (inch)	6, 8, 10, 12
HMA Thickness (inch)	4, 6, 8
Subgrade Modulus (psi)	3000, 6000, 9000, 12000, 15000, 18000, 21000, 24000, 27000, 30000

Table 2: Parameters that vary

Parameter Name	Parameter Values
Wheel Load (pound force)	Two@36000
Distance between Loads (inch)	70
Tie Spacing (inch)	20 (wood tie)
	24 (concrete tie)
Tie Dimension (inch)	Wood: 102, 7, 9
	(length, thickness, width)
	Concrete: 102, 7, 11 (length, thickness, width)
Subballast Thickness (inch)	4
Subballast Modulus (psi)	20000
Poisson's Ratio for Subballast	0.35
Poisson's Ratio for HMA	0.45
Volume of Voids for HMA(%)	5.7
Temperature for HMA (°F)	50 (spring)
	63 (summer)
	37 (autumn)
	20 (winter)
HMA Modulus (psi)	698000 (spring)
	372000 (summer)
	1250000 (autumn)
	2260000 (winter)
Volume of Bitumen for HMA (%)	13.5
HMA Viscosity at 70 °F (poise)	2500000
Subgrade Thickness (inch)	200
Poisson's Ratio for Subgrade	0.4
Poisson's Ratio for Bedrock	0.5
Traffic Volume (MGT)	32

Table3: Parameters that are constant

Effect of Subgrade Modulus

The wheel loads on any trackbed are ultimately transmitted to the subgrade. The subgrade is characterized by its resistance to deformation -- stiffness and its bearing capacity -- strength. The effect of subgrade on the stresses, strains and predicted life of HMA trackbeds was determined using the track section shown in Figure 8 a. The Poisson's ratio was set to 0.4 and the subgrade modulus was varied from 3000 psi to 21000 psi at increments of 3000 psi, corresponding to a series of soils from weak to strong. An all-granular trackbed, shown in Figure 8 b, was evaluated for comparisons. The HMA layer was replaced with a subballast layer, keeping the combined thickness the same.

The effect of the subgrade modulus on the vertical compressive stress on the subgrade is shown in Figure 9. Note that as the subgrade modulus increases the vertical compressive stress acting on the subgrade also increases. Also, the vertical compressive stress acting on the subgrade for HMA trackbed, is less than the vertical compressive stress on the subgrade for the ballast trackbed.

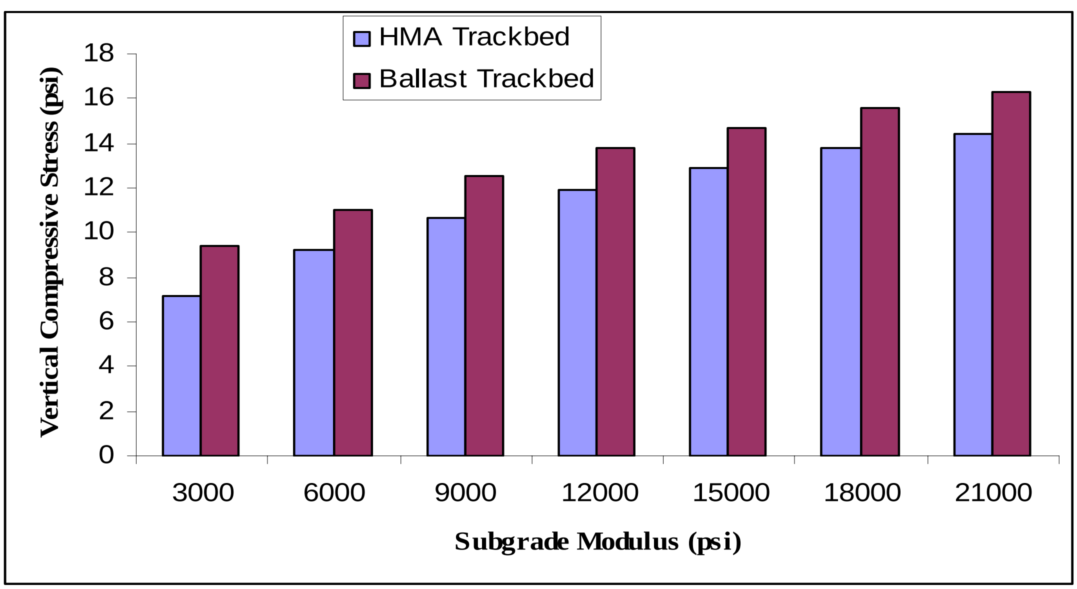


Figure 9: Effect of subgrade modulus on vertical compressive stress

The variation in the predicted service life with the change in subgrade modulus is shown in Figure 10. It can be seen that with the increase in subgrade modulus, the predicted service life of the subgrade also increases. It is also interesting to note that with the increase in subgrade modulus both the vertical compressive stresses and the predicted service life of the subgrade increase. The rate at which the vertical compressive stress increases is lesser than the rate at which the bearing capacity of the subgrade is increasing, hence the extended service life.

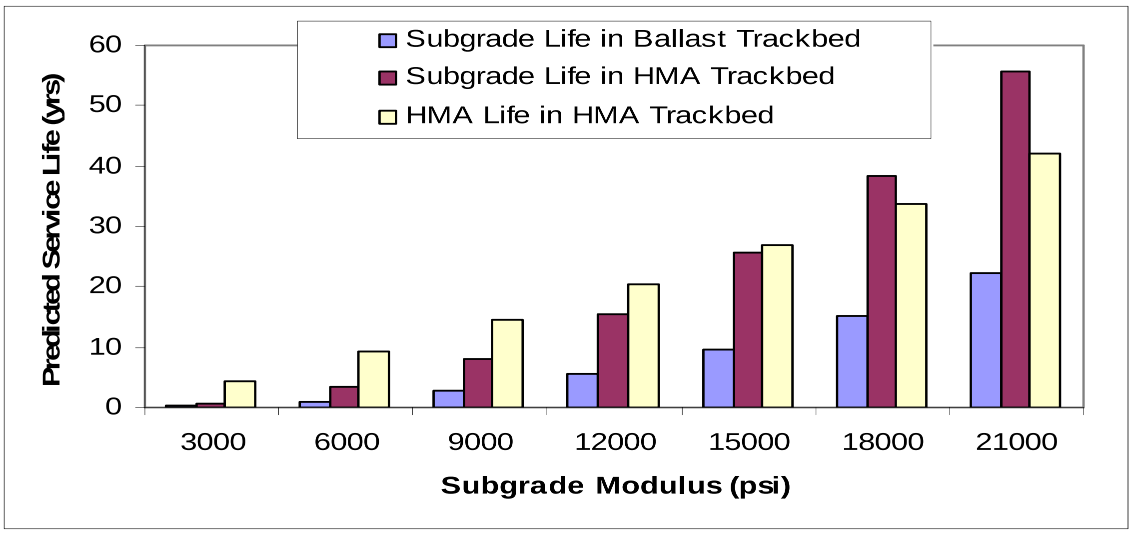


Figure 10: Effect of subgrade modulus on predicted service lives

Figure 11 shows the effect of subgrade modulus on the tensile strain at the bottom of the HMA layer. When the subgrade modulus is low the subgrade provides little or no resistance to the HMA deformation and hence the high tensile strain. As the subgrade modulus increases the subgrade resists the deformation and hence the decrease in tensile strain.

The predicted lives of the subgrade and HMA (Figure 10) both increase with increase in the subgrade modulus. It is interesting to note that at a subgrade modulus of 18000 psi the predicted service life of the subgrade is greater than the predicted service life of the asphalt. This can be explained by the increased stiffness of the subgrade. The predicted service life of the subgrade in a HMA trackbed is almost always more than twice the predicted service life of the subgrade in a ballast trackbed.

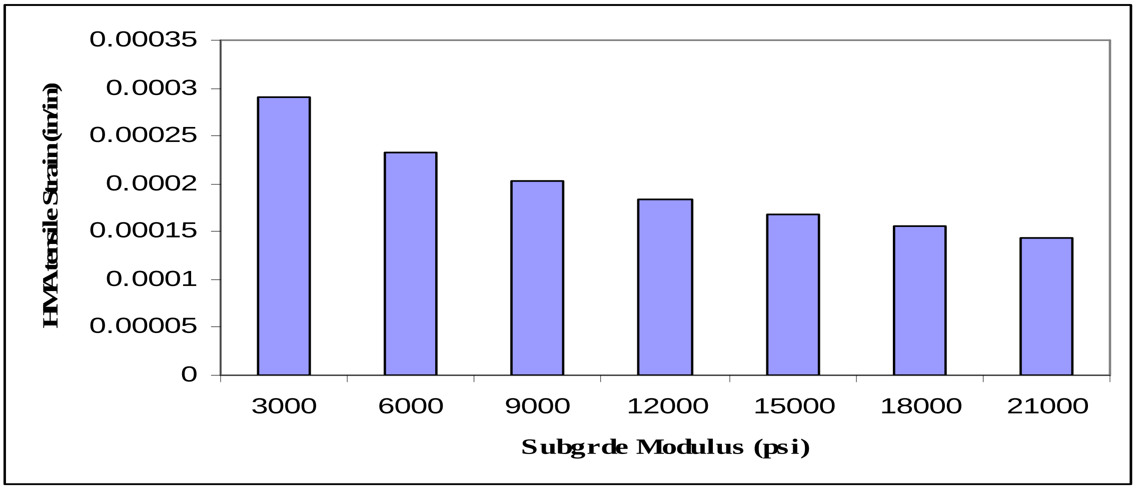


Figure 11: Effect of subgrade modulus on HMA tensile strain

Effect of Axle Load

The imposed axle load is a very significant factor in the design and analysis of railroad trackbeds. In the previous analysis, the 36 ton axle load was used as the standard design value. Axle loads of 33 tons are used commonly on freight lines. Extensive research is being conducted on 39 ton axle loads. This is the reason for evaluating the performance of trackbeds with varying axle loads. The trackbeds shown in Figure 8 a and 8 b have been evaluated for 33, 36 and 39 ton axle loads. Also, three subgrade modulus values - 6000, 12000 and 18000 psi - corresponding to weak, normal and good subgrade have been used to study the effect of different axle loads.

Figures 12 and 13 show the effect of axle loads on the vertical compressive stress acting on the subgrade in HMA trackbed and all-granular trackbed respectively. With the increase in axle loads the compressive stresses increase in both the cases. For a subgrade modulus of 6000 psi, the stress increases by about 17.5 % for an increase in axle loads from 33 to 39 tons for both HMA trackbed and an all-granular trackbed.

It can also be seen from Figures 12 and 13, that for a same axle load and same subgrade modulus the vertical compressive stress on the subgrade is greater in the ballast trackbed compared to an asphalt trackbed. For example when the axle load is 33 ton and a subgrade modulus of 6000 psi, the subgrade compressive stress is 10.1 psi in a ballast trackbed and 8.4 psi in a HMA trackbed.

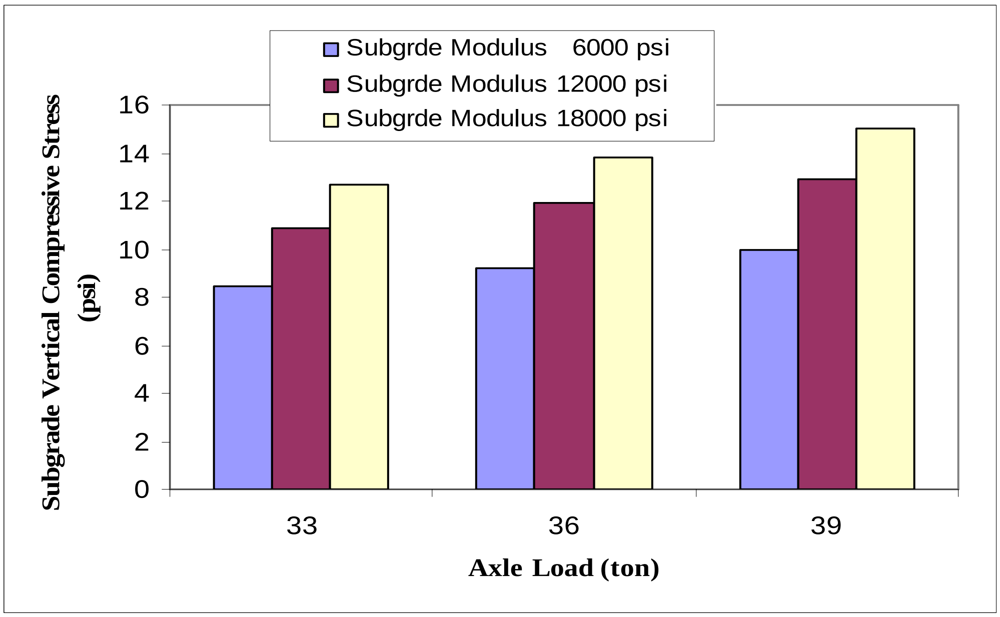


Figure 12: Effect of axle loads on vertical compressive stress on subgrade in HMA trackbed

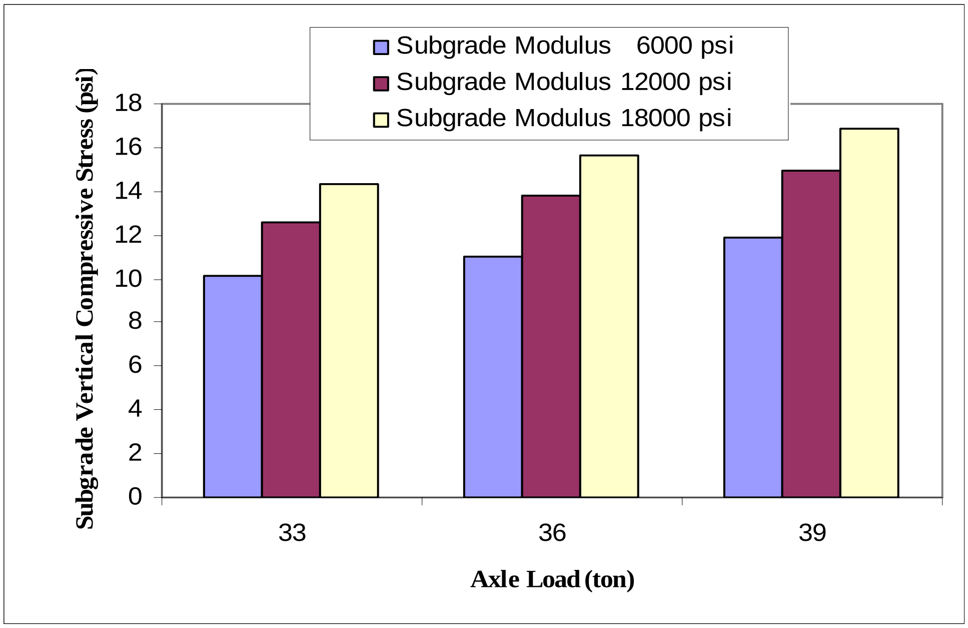


Figure 13: Effect of axle loads on vertical compressive stress on subgrade in ballast trackbed

Figure 14 shows the effect of axle load and subgrade modulus on the HMA tensile strain. The heavier axle load produces higher tensile strain in the HMA layer.

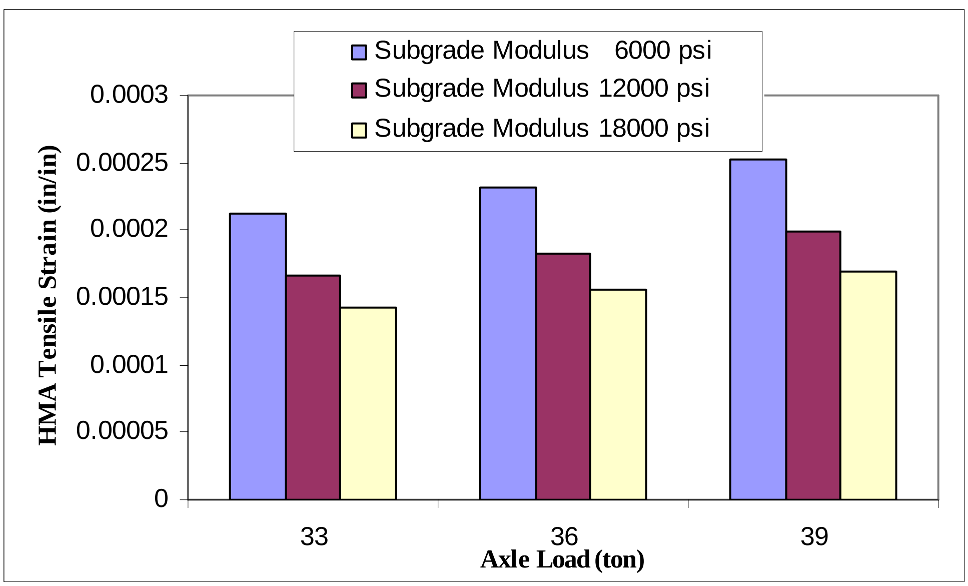


Figure 14: Effect of axle load on the HMA tensile strain in a HMA trackbed

Figures 15, 16 and 17 show the effect of axle loads on the predicted service lives of HMA, subgrade in HMA trackbed and subgrade in ballast trackbed respectively. The predicted service lives of the HMA layer and subgrade layer decrease with increase in axle loads. This can be explained by the increased tensile strain in the HMA layer and increased vertical compressive stresses in the subgrade layer. For a subgrade modulus of 6000 psi, as the axle load increases from 33 to 39 tons, the predicted service life of the subgrade is reduced by 45.8 % in HMA trackbed and 45.6 % in ballast trackbed.

Another interesting observation is that the predicted service life of subgrade in HMA trackbed under 39 tons axle load is greater than the predicted service life for subgrade in a ballast trackbed for any subgrade modulus. This implies that the HMA trackbed is superior to ballast trackbed relative to load carrying capabilities.

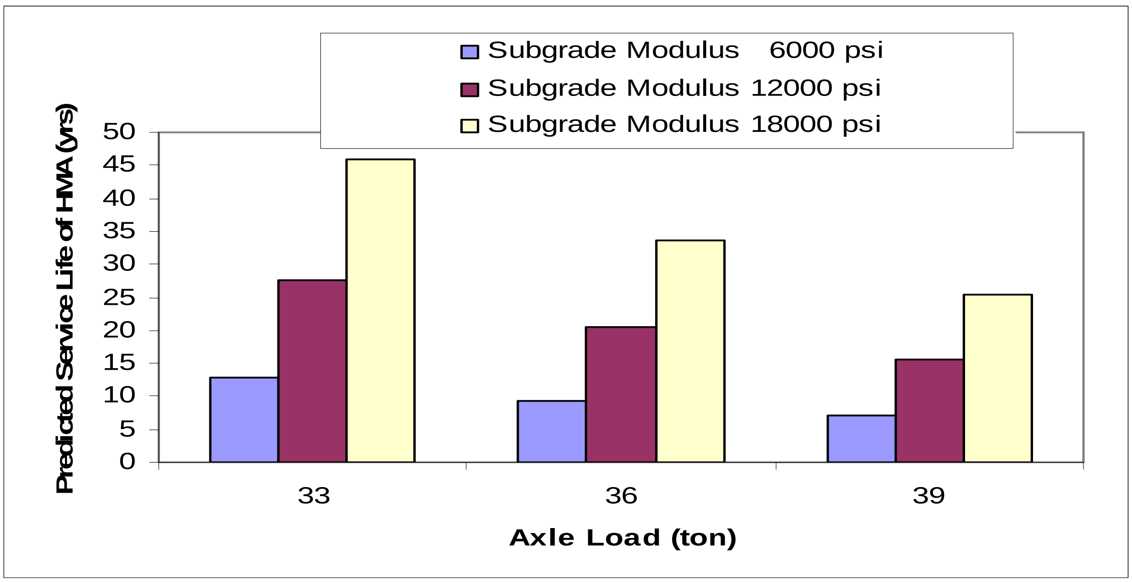


Figure 15: Effect of axle load on the predicted service life of HMA in HMA trackbed

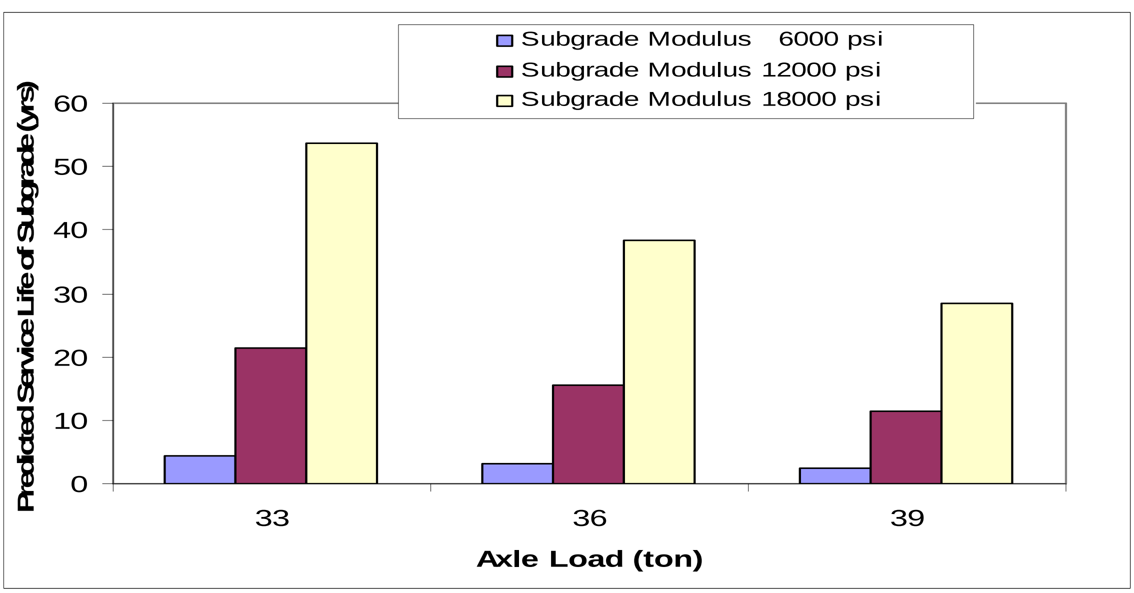


Figure 16: Effect of axle load on the predicted service life of subgrade in HMA trackbed

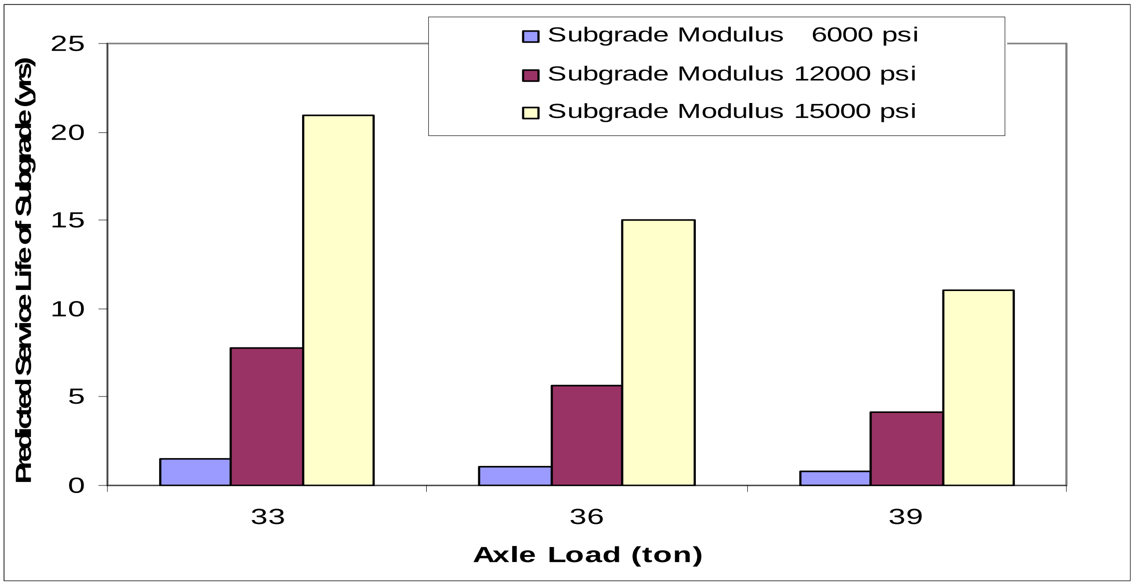


Figure 17: Effect of axle load on the predicted service life of subgrade in ballast trackbed

Effect of Varying the Thickness of Ballast

Ballast is one of the main components of trackbed design. It distributes the wheel loads onto the underlying layers at reduced intensities, provides resilience to the track structure, assists in the drainage of water from the track structure, and assists in the adjustment of track geometry. Ballast also has some disadvantages. Due to its open graded nature it has very high porosity. Also, newly laid ballast is subject to high deformations and is subsequently prone to fouling.

In this section the effect of varying the thickness of the ballast on the service life, stresses and strains are discussed. The sections shown in Figure 8 a and 8 b have been used for evaluating the effects of changing the ballast thickness. In the HMA trackbed the combined thickness of the ballast and asphalt layer has been maintained at 14 in. In the ballast trackbed the combined thickness of ballast and subballast also has been maintained at 14 in. The subgrade modulus of 12000 psi has been used in the evaluation.

It can be seen from Table 4 that in the case of HMA trackbed, as the ballast thickness decreases from 10 to 6 in. the service life of the subgrade increases from 10.4 to 23.3 yrs and the vertical compressive stress on the subgrade decreases from 12.6 to 11.0 psi. This can be explained by the increase in the asphalt thickness.

Asphalt Track Bed Subgrade Modulus 12000 psi, Axle Load 36 ton		
Asphalt Thickness - 4 in. Ballast Thickness – 10 in.	Tensile Strain in the asphalt	0.000167
	Compressive Stress on Subgrade	12.6
	Service life of Asphalt Layer	23.8
	Service life of subgrade layer	10.4
Asphalt Thickness - 6 in. Ballast Thickness – 8 in.	Tensile Strain in the asphalt	0.000183
	Compressive Stress on Subgrade	11.9
	Service life of Asphalt Layer	20.4
	Service life of subgrade layer	15.5
Asphalt Thickness – 8 in. Ballast Thickness – 6 in.	Tensile Strain in the asphalt	0.000180
	Compressive Stress on Subgrade	11.0
	Service life of Asphalt Layer	22.4
	Service life of Subgrade layer	23.3

Table 4: Effect of varying the thickness of the asphalt and ballast layer

It is interesting to note that the service life of the asphalt decreases from 23.8 to 20.4 yrs and then increases to 22.4 yrs. As the ballast thickness decreases from 10 in. to 8 in., the tensile strain increases from 0.000167 to 0.000183. This can be explained by the increased stresses in the asphalt layer due to the reduced ballast thickness. As the thickness is further reduced to 6 in. the strain decreases to 0.000180. This can be explained by the increase in thickness of the asphalt. But as can be seen from the table, the decrease in tensile strain is minimal when the asphalt thickness is increased from 6 to 8 in.

In case of ballast trackbed as shown in Table 5 as the ballast thickness decreases the vertical compressive stress acting on the subgrade decreases, but the change is very insignificant, only from 13.8 to 13.5 psi. The change in service life is also minimal; it increases from 5.6 to 6.0 yrs. Also for a change in subballast thickness from 6 to 8 in. the compressive stress acting on the subgrade changes only from 13.7 to 13.5 psi, but the compressive stress acting on the subballast increases from 20.1 to 23.4 psi. Hence, it seems that the subballast does not have a pronounced affect on the subgrade vertical compressive stress.

Ballast Track Bed Subgrade Modulus 12000 psi, Axle Load 36 ton		
Subballast Thickness – 0 in. Ballast Thickness – 14 in.	Compressive Stress on Subballast	N/A
	Compressive Stress on Subgrade	13.8
	Service life of Subballast Layer	N/A
	Service life of subgrade layer	5.6
Subballast Thickness – 6 in. Ballast Thickness – 8 in.	Compressive Stress on Subballast	20.1
	Compressive Stress on Subgrade	13.7
	Service life of Subballast Layer	2.1
	Service life of subgrade layer	5.7
Subballast Thickness – 8 in. Ballast Thickness – 6 in.	Compressive Stress on Subballast	23.4
	Compressive Stress on Subgrade	13.5
	Service life of Subballast Layer	1.3
	Service life of Subgrade layer	6.0

Table 5: Effect of varying the thickness of the subballast and ballast layer

For similar values of ballast and subballast /asphalt thickness the service life of the subgrade in the case of HMA trackbed is 15.5 yrs and that for a ballast trackbed is 2.1 yrs., further proving that HMA trackbed is superior to ballast trackbed.

PREDICTIVE VALUES VERSUS IN-TRACK DATA

Compressive stress data has been obtained for two in-track test sites under heavy axle loads (Rose, Su and Twehues, 2004). Earth pressure cells were installed over the HMA layer and over the subgrade layer. The results were compared with predictive values from KENTRACK for comparable component trackbed materials and thicknesses. The in-track measurements confirm the predictive values from KENTRACK, thus providing the program a measure of credibility. Further discussion is available in the aforementioned reference. Table 6 contains a listing of the predictive values and measurements.

Comparison of the KENTRACK Predictive values (KPV) Versus In-Track Data (ITD) at TTCI in Pueblo, Colorado			
Thickness Ballast/ HMA inches	Vertical Compressive Stress on **Ballast** KPV/ITD psi	Vertical Compressive Stress on **HMA** KPV/ITD psi	Vertical Compressive Stress on **Subgrade** KPV/ITD psi
12 / 4	43.5 / -	11.7 / 14.9	8.3 / 8.0
8 / 8	47.0 / -	21.9 / 14.9	8.2 / 7.7

Comparison of the KENTRACK Predictive values (KPV) Versus In-Track Data (ITD) for the CSX Mainline at Conway, Kentucky			
Thickness Ballast/ HMA inches	Vertical Compressive Stress on **Ballast** KPV/ITD psi	Vertical Compressive Stress on **HMA** KPV/ITD psi	Vertical Compressive Stress on **Subgrade** KPV/ITD psi
10 / 5	47.9 / -	21.0 / 16.0	13.6 / -
10 / 8	48.7 / -	22.0 / 15.0	11.7 / -

Table 6: Comparisons of predictive values and in-track data (Rose, Su and Twehues, 2004)

KENTRACK VERSION 2.0.1

KENTRACK, initially developed for a Disk Operating System platform, has been modified into a windows based platform with a Graphic User Interface (GUI). The GUI allows the user to change various properties of the track structure much easier than with the previous version. The output generated comprises two parts -- the first part consists of values of the properties that are entered and the second part consists of the results for the various periods at the various cross-sections. Finally it has the damage analysis, with the maximum compressive stress, tensile strain and service life values for the layers chosen.

No major changes have been made to the FORTRAN code that is used to carry out the analysis. The program is very versatile and unlike its predecessor allows the user to change values easily.

Instructions to use the new version and the commonly used values for each of the variables are provided in the help section of the software (KENTRACK, 2006).

SUMMARY

The KENTRACK computer program used to analyze railway trackbeds has been described in this paper. The program which was in DOS version has been converted into a windows based application with a Graphic User Interface. The GUI version has been specifically evaluated herein. The effect of the various factors on the trackbed design has been evaluated using the software. It has been found that the use of asphalt instead of all-granular subballast has a positive impact on the predictive performance of the trackbed. There is a significant reduction in the stresses and strains. There is a significant increase in the service life, indicating the use of HMA trackbed will decrease maintenance and rehabilitation costs.

The variable that most affects the service life of a railway trackbed is subgrade modulus. Hence the proper preparation and protection of a subgrade is necessary during the construction and subsequent maintenance of the railway trackbed. HMA layers act as a waterproofing layer to the underlying subgrade layer and hence the subgrade modulus is not adversely affected (Rose, Li and Walker, 2002).

HMA damage analysis is based on equations developed for highway pavements. The tensile strain and the vertical compressive stress values obtained for railway trackbeds are conservative. The actual service lives of the subgrade and HMA layer will be longer than the predicted values due to less severe loading and environmental conditions when compared to highway pavements.

FINDINGS

Varying Subgrade Modulus

As the subgrade modulus increases there is an increase in the vertical compressive stress on the subgrade. The range of increase in vertical compressive stress is from 7 to 16 psi. The vertical compressive stresses in the HMA trackbeds are about 11 to 25% lower than the stresses in an all-granular trackbed.

The increase in subgrade modulus causes very little change in the magnitude of vertical compressive stress. This is due to the improved capacity of the high modulus subgrade to withstand the stresses. As the subgrade modulus increases the service lives of both the subgrade and asphalt increase significantly. This is due to the improved stiffness of the subgrade.

The HMA tensile strain decreases with increase in the subgrade modulus. This is because the HMA does not deform as much as it would for a subgrade with a lower modulus. The primary reason for trackbed failure is the permanent deformation in the subgrade. The exception is when the subgrade modulus is very high then the HMA layer will fail initially due to cracking.

Varying Axle Loads

As axle loads increases, the vertical compressive stress on the subgrade also increases. But the change is not very significant, since changing the axle loads from 33 to 39 tons for a subgrade modulus of 12000 psi causes an increase of 2.0 psi in the case of HMA trackbed and 2.3 psi in the case of all-granular trackbed. Also, the stresses on ballast trackbed are about 12 % to 19 % greater than the stresses on HMA trackbed. The HMA tensile strains increase with increase in the axle loads.

Increasing axle loads decreases the predicted service lives of both the HMA and all-granular trackbeds.

Varying the Thickness of Ballast

For a given total thickness of HMA plus ballast, as the thickness of HMA is increased, by reducing the ballast thickness, the stresses on the subgrade decreases. Increasing HMA thickness from 4 in. to 8 in. reduces the subgrade compressive stress by about 13 %.

Increasing HMA thickness increases the predicted service life of the subgrade significantly. For an increase in HMA thickness from 4 in. to 8 in. the subgrade service life increases by about 13 yrs.

For similar values of layer thicknesses, the vertical compressive stress in the subgrade is 13 % less in HMA trackbed compared to all-granular trackbed.

FUTURE RESEARCH SUGGESTIONS

- The damage analysis equations are adopted from highway pavements. Studies should be conducted on revenue HMA trackbeds to study the aging of HMA and develop damage analysis equations for HMA in railroad trackbeds.
- KENTRACK does not consider any of the dynamic factors in the analysis. Future studies should attempt to incorporate external dynamic variables into the analysis of trackbeds.

ACKNOWLEDGEMENTS

The research reported herein was largely supported by CSX Transportation. Previous civil engineering graduate students at the University of Kentucky involved with various phases of development of this program include Bradley Long, Bei Su, Frank Twehues and Peddu Kumar.

REFERENCES

Asphalt Institute, (1998) HMA Trackbeds – Hot Mix Asphalt for Quality Railroad and Transit Trackbeds, Information Series 137, 10 pages.

Asphalt Institute, (1982) Research and Development of The Asphalt Institute's Thickness Design Manual (MS-1) Ninth Edition, Research Report 82-2, 150 pages.

Chang, C. S., Adegoke, C. W. and Selig, E. T., (1980) The GEOTRACK Model for Railroad Track Performance, Journal of Geotechnical Engineering Division, ASCE, Vol. 106, No. GT11, November, pp. 1201-1218.

Huang, Y. H., Lin, C., Deng, X., and Rose, J., (1984) KENTRACK, A Computer Program for Hot-Mix Asphalt and Conventional Ballast Railway Trackbeds, Asphalt Institute (Publication RR-84-1) and National Asphalt Pavement Association (Publication QIP-105), 164 pages.

Hwang, D., Witczak, M.W., (1979) Program DAMA (Chevron), User's Manual, Department of Civil Engineering, University of Maryland.

KENTRACK Version 2.0.1, (2006) Program, Help File and Example Data Files, Department of Civil Engineering, University of Kentucky.

Robnett, Q. L., Thompson, M. R., Knutson, R. M., and Tayabji, S. D., (1975) Development of a Structural Model and Materials Valuation Procedures, Ballast and Foundation Materials Research Program, University of Illinois, report to FRA of US/DOT, Report No. DOT-FR-30038.

Rose, J.G., Su, Bei, and Twehues, F., (2004) Comparisons of Railroad Track and Substructure Computer Model Predictive Stress Values and In-situ Stress Measurements, Proceedings of the 2004 AREMA Annual Conference.

Rose, J.G., Li, Ding, and Walker, L., (2002) Tests and Evaluations of In-Service Asphalt Trackbeds, Proceedings of the 2002 AREMA Annual Conference.

Rose, J.G., Brown, E.R. and Osborne, M.L., (2000) Asphalt Trackbed Technology Development – The First 20 Years, Transportation Research Record 1713, Transportation Research Board, pp.1-9

Rose, J.G., Su, Bei, and Long, W.B., (2003) KENTRACK: A Railway Trackbed Structural Design and Analysis Program, Proceedings of the 2003 AREMA Annual Conference.

Su, Bei, (July, 2003) KENTRACK: A Finite Element Computer Program for the Structural Design and Analysis of Railroad Track Structures, MSCE Thesis, Department of Civil Engineering, University of Kentucky.