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Overloading analysis of bituminous pavements in India using M-E PDG

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Abstract

Bituminous pavements constructed across India undergo premature failure much before their design life. There could be many reasons attributed to such failure and these include inappropriate selection of materials, lack of dependable traffic and axle load data and limited information related to distresses for analysis. In this paper, using a comprehensive traffic and axle load data and using robust material properties, the distresses of a real-life pavement were quantified. A location along NH 13 which had the maximum overloading was chosen for the analysis. The stress-strain analysis was performed for a trial section using the performance conditions specified in IRC:37-2012. The real time traffic data and climatic conditions pertaining to this location were used for the design. Using such data and appropriate material parameters collected at the pavement engineering laboratory at IIT Madras, proof-checking of the design was carried out using AASHTOWare software. Optimized thicknesses were also obtained for sections suggested by IRC:37-2012.

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1. Introduction

The stress-strain response of a bituminous pavement depends on a number of factors including the properties of materials used in different layers, traffic on the pavement and the environmental conditions prevalent in the location. The stress-strain response is normally integrated with the distress transfer functions in bituminous pavement design. Any design process, especially the bituminous pavement design involves invoking considerable approximations related to the usage of design inputs as well as the solution methodology. A proper sensitivity analysis of the whole design process can yield details related to the robustness of these approximations in the final design process. In this work, attention is focused on the IRC method of pavement design using IRC:37-2012.

A major approximation in pavement design is related to the consideration of distresses in the pavement. In IRC:37-2012, rutting in subgrade and fatigue cracking initiated at the bottom of the bituminous layers are considered as the two predominant distresses. The fact that the pavements in India experience high pavement temperatures around 60°C and above for most duration in a year necessitates considering rutting in the bituminous layers also as a critical factor. Rutting of individual layers and total rutting should be taken as design criteria rather than the rutting in the subgrade. The other point of concern here is related to not considering the distress associated with top-down cracking. Top-down cracking can cause more damage to the pavement compared to bottom-up cracking. In India, this should be considered as an additional distress especially with the heavy axle loads, slow speeds and increased use of modified binders.

The material properties used in different layers is another area subjected to considerable approximation. It is well known that the material properties are dependent on a number of factors and these are related to the environmental conditions. For instance, the “modulus” parameter associated with bituminous mixtures depends on the pavement temperature prevalent in the field and the speed (rate of load application) of the vehicles. Though the variation of modulus with temperature has been addressed in IRC:37-2012, the variation of modulus with frequency has not been taken into consideration. Also for the granular layers, especially the subgrade, the modulus depends on the soil moisture content which eventually varies with rainfall in that location. Nevertheless, a constant value has been used in IRC:37-2012 for the entire design period to represent the subgrade modulus. Ignoring such factors in the material characterization can lead to under/over-estimation of the damage in the pavements.

Depending on the data available, one can use judiciously the traffic and axle load data in the pavement design process. There are at least two critical factors related to traffic one has to take into consideration before designing a pavement and they are vehicle class and axle load distribution. In India, information related to vehicle class distribution is available for most locations from the MoRTH website (MoRTH-2014). However, there is minimal information related to axle load distribution. The axle configuration and design of vehicles traversing the pavements in India are such that they tend to carry more than the approved axle loads.

Axle overloading has been observed to cause a drastic increase in the pavement damage. The damage caused by a 100% overloaded vehicle was observed to be equivalent to 18 passes of a standard axle. The heavy vehicles which account only for 15 to 20% of the traffic spectrum cause 60% of the damage to the pavement (CSIR, 1997). It was also shown that, for a pavement having a design life of 15 years when subjected to 5% overloading, the design life can reduce to 12.3 years. Similarly, the same pavement if it was subjected to 10% and 20 % overloading, the design life reduced to 10.27 and 7.25 years respectively (Pais *et al.*, 2013). The magnitude of damage was observed to be dependent on the vehicle class (Weissmann *et al.*, 2013) and axle type (Salama *et al.*, 2006). Many studies evaluated the impact of overloading by removing the overloaded vehicles from the traffic spectrum and recalculating the damage (Pais *et al.*, 2013). Studies have also shown that there is significant improvement in the service life of a pavement when the legal axle limits are strictly enforced (Sharma *et al.*, 1995). It is evident that the axle loads of the vehicles especially which are overloaded cause significant damage to the pavement. The pavement design should have a framework capable of handling the axle load distribution of vehicles so that one can quantify the influence of overloaded vehicles.

For the design of bituminous pavement, IRC:37-2012 has suggested IITPAVE software to perform stress-strain analysis for a given set of loading conditions and material properties. This software however, does not have provisions to perform a rigorous damage analysis incorporating such detailed information. In this method of design, the traffic spectrum is converted into equivalent number of repetitions of standard axles. The ratio of the load of any given axle to that of a standard axle raised to a power 'n' is used to calculate the equivalent number of repetitions of a standard axle. The value of 'n' commonly used is 4. The validity of this value has been analysed in many studies. The value of 'n' has been observed to vary with the type of damage, type of axle and condition of the pavement (Archilla and Madanat, 2000; Prozzi and Madanat, 2004). Also, the damage caused by an overloaded vehicle has been observed to be higher than the damage caused by equivalent number of passes of standard axle. An ideal design procedure should place the actual axle loads on the pavement to evaluate the damage rather than using equivalence factors.

To perform a detailed stress-strain analysis incorporating most of the above discussed factors, sophisticated software solutions are required. The AASHTOWare software developed based on the M-E PDG framework (AASHTO 2012) is one such software which aids in a comprehensive pavement design. The distresses considered here are top-down cracking, bottom-up cracking, total rutting and rutting in bituminous layers. The material properties are also evaluated for smaller units of time considering the influence of environmental conditions and traffic. The bituminous materials are evaluated based on the pavement temperature, frequency of travel of the vehicle and ageing in bitumen with time. The subgrade modulus is evaluated for the soil water content using a separate infiltration and drainage model. Traffic is separated into different axle load groups for each axle type and vehicle class. This axle load group is then placed on the pavement and the damage is evaluated. A similar procedure is repeated for each axle load group for each axle type in each vehicle class using the incremental damage concept. The M-E PDG framework has also provisions to incorporate monthly variations in axle load distribution. Such provisions can effectively take into account the realistic traffic conditions prevalent in the field.

Understanding the influence of axle overloading considering the realistic material properties on top-down and bottom up cracking, total rutting and bituminous layer rutting is the focus of this paper. The stress-strain analysis was performed for a trial section chosen from the IRC catalogue to evaluate its performance conditions specified in IRC:37-2012. A real time traffic data collected from a selected highway in India was used. Using such data and using appropriate material parameters collected at the pavement engineering laboratory at IIT Madras, proof-checking of the design was carried out. To bench-mark the results with traditional analysis, the KENLAYER program was used and it was seen that overloaded traffic section with realistic material properties and temperature can result in completely different set of distresses. Using modified binder material properties, thickness optimization was also performed.

2. Data collection and analysis

Data collection is the most important step for an efficient design of a bituminous pavement. The data collection here includes traffic data, material properties, and climate data. The analysis performed on the data to be used in various design procedures are also discussed in detail.

2.1. Traffic data

Traffic data was collected from M/s V.R TECHNICHE, Delhi and L&T IDPL, Chennai for three stretches in India NH 13 (1 location), NH 6 (7 locations) and NH 9 (2 locations). For each location, the vehicles were grouped into different vehicle classes based on their axle configuration. To calculate the percentage of overloading, the gross weight of each vehicle class was calculated knowing the axle configuration and the axle load specified for each axle type from IRC:3-1983. Two sections, one from NH 13 and another from NH 9 were identified which had the maximum and minimum percentages of overloading respectively (Table 1). To compare the influence of overloading, these two sections were considered for analysis.

Table 1. Percentage of overloading for each class.

Vehicle type	NH 13	NH 9
2 axle	39.8	3.5
3 axle	94.9	24.4
4 axle	67.9	5.9
5 axle	100	54.5

6 axle	NA	42.9

For pavement design as per IRC:37-2012, different multiplicative factors are used to convert different axle load and axle types into equivalent number of passes of standard axle (ESAL) of specified load. The design based on IRC:37-2012 guidelines, specifies the use of vehicle damage factors (VDF) while the AASHTO method of pavement design (NCHRP 1-37A, 2004) uses truck factors. One can obtain different VDF values depending on the method of calculation also. For instance, consideration of VDF separately for each vehicle class can provide different ESAL compared to one value for all vehicle classes. In this paper, the VDF and average truck factors (ATF) are calculated as specified in their respective standards and compared. There is negligible difference between the ATF used in AASHTO and the VDF specified in IRC as shown in Table 2. Since VDF and ATF can be used interchangeably, all further discussions are made using VDF.

Table 2. VDF and ATF for NH 13 and NH 9

Highway	Traffic	VDF	ATF
NH 13	With overloading	5.46	5.2
	Without overloading	2.43	2.45
NH 9	With overloading	1.84	1.82
	Without overloading	1.42	1.52

The effect of overloading is clearly reflected in Table 2. NH 13 having a higher percentage of overloading has higher VDF (~3 times) compared to NH 9. To consider the influence of overloading on VDF, the axles which exceeded the allowable load were limited to the load specified in IRC:3-1983 and the VDF was recalculated. The actual traffic will be referred to as *'with overloading'* and the one with overloaded axles limited to legal axle limits will be referred as *'without overloading'* henceforth. It was noticed that when the overloaded axles were limited to legal axle limits, the reduction in VDF value was higher (~ 50%) for NH 13 compared to NH 9. This indicates that NH 13 has higher magnitude of load for the overloaded vehicles in addition to the percentage of overloading. The percentage of overloaded vehicles and the magnitude of load for the overloaded axles are both critical factors influencing the VDF value. Henceforth the analysis will pertain only to NH13.

2.2. Material properties

The material parameters for different layers are not constant throughout the design period for any given location. They vary with the climatic conditions prevalent at the selected location. For the subgrade layer, the variation in the CBR with moisture content has to be taken into consideration. The moisture content in the subgrade varies with precipitation and water table depth. The variation of resilient modulus with moisture content is given in Equation 1 based on the AASHTO method of pavement design (NCHRP 1-37A, 2004).

$$\frac{M_R}{M_{Ropt}} = a + \frac{b-a}{1+EXP\left(ln\frac{-b}{a}+K_m(S-S_{opt})\right)}, \tag{1}$$

where M_R is the resilient modulus at given condition, M_{Ropt} is the resilient modulus at optimum moisture content, a and b are the minimum and maximum values of Log $\frac{M_R}{M_{Ropt}}$, K_m is the regression parameter and $(S-S_{opt})$ is the variation in degree of saturation expressed in decimal. The values of a, b, K_m are specified in AASHTO (NCHRP 1-37A, 2004) for coarse grained soil as -0.3123, 0.3, 6.8157 respectively. The degree of saturation is obtained as the difference between the soil moisture content and optimum moisture content. The soil moisture content can be calculated knowing suction. Equation 2 gives the formula for soil suction (Huang, 2004).

$$S = \beta p + (Z \times \gamma_w), \tag{2}$$

where 'β' is the compressibility factor, 'p' is the overburden pressure, 'Z' is the distance between ground and the ground water table and 'γ_w' is the unit weight of water. The overburden pressure was taken as zero considering no vehicle on the pavement. From the graph relating soil suction and moisture content from AASHTO (NCHRP 1-37A, 2004), the moisture content was obtained knowing the suction. Taking optimum moisture content as 0.4, the degree of saturation was calculated as the difference between the field moisture content and the optimum moisture content. The soil type was considered as sand for this analysis. The seasonal variation in the subgrade modulus with soil moisture is given in Table 3.

Table 3. Subgrade and bituminous mixture modulus variation with climatic data

Month	Water Table (m)	Moisture Content (%)	Subgrade Modulus (MPa)	Air Temperature (ºC)	Pavement Surface Temperature (ºC)	Pavement Temperature at (ºC)		Dynamic Modulus (MPa)			
						depth = 25 mm	depth = 112.5 mm	7-day average maximum		One day minimum	
						BC	DBM	BC	DBM	BC	DBM
January	1.55	0.25	78.69	31.01	41.35	38.07	30.92	2559	4035	8517	10998
February	1.64	0.25	78.82	31.04	41.39	38.10	30.95	2563	4022	8445	10803
March	1.73	0.24	78.94	33.50	44.59	41.12	33.58	2130	3449	8445	10647
April	1.82	0.24	79.07	35.31	46.95	43.35	35.53	1818	3031	6097	8185
May	1.91	0.23	79.19	34.48	45.87	42.33	34.64	1936	3198	5926	7988
June	1.99	0.22	79.36	29.90	39.90	36.70	29.72	2818	4315	6273	8357
July	2.06	0.24	79.53	30.85	41.14	37.86	30.74	2584	4102	6356	8445
August	2.14	0.21	79.69	29.44	39.30	36.13	29.23	2899	4424	6677	8650
September	1.95	0.23	79.29	28.97	38.69	35.55	28.73	3015	4575	6591	8681
October	1.75	0.24	78.89	29.95	39.97	36.76	29.78	2788	4326	8241	10320
November	1.56	0.26	78.44	28.97	38.69	35.55	28.73	3006	4589	8681	10945
December	1.37	0.27	78.32	28.18	37.66	34.58	27.88	3216	4825	10107	12664

For bituminous layers, the resilient modulus of the mixture is specified at different temperatures in IRC:37-2012. Bituminous mixtures exhibit viscoelastic response and the choice of an appropriate material function which can cater to the influence of time and temperature is subject to controversies. At this point of time, the best known material function which could be used for stress analysis is dynamic modulus and in this work, the same will be used. The correctness of using dynamic modulus with haversine compression loading or resilient modulus using indirect tensile testing or stiffness modulus using beam bending test as an appropriate material property will fall outside the scope of this paper.

The dynamic modulus is calculated as the ratio of the peak stress to peak strain when the material is subjected to a haversine compression loading. The phase angle of the material is also calculated in addition, which indicates the lag between the applied stress and the strain response. The dynamic modulus test is performed using an Asphalt Mix Performance Tester (AMPT) as per the provisional AASHTO standard given as part of NCHRP 9-29 project (PT 01, 2008). The dynamic modulus test can be performed at different temperatures and frequencies. The dynamic modulus values obtained at different temperatures and frequencies is used to construct a master curve. The principle of time temperature superposition is used to shift properties measured at different temperatures to a selected reference temperature. The shift factors for each temperature can be obtained from William-Landel-Ferry (WLF) equation as shown in Equation 3.

$$Log\ a_T = -\frac{(C_1)\times(T-T_0)}{C_2+(T-T_0)}, \tag{3}$$

where a_T is the shift factor, C_1 and C_2 are the WLF constants, T is the actual temperature and T_0 is the reference temperature.

The dynamic modulus values measured using AMPT available at pavement engineering laboratory, IIT Madras was used in this paper. The binders used to prepare the mix were VG30 and a modified binder, PMB-40. The dynamic modulus was calculated separately for BC and DBM mixes (Grade II) at frequencies ranging from 25 Hz to 0.01 Hz and at different temperatures from 5 to 55ºC. The software RHEA was used to construct the master curve using dynamic modulus values. RHEA provides modified C_1 and C_2 values from which the shift factors can be calculated using Equation 3 to construct the master curve. The dynamic modulus for any desired temperature and frequency can be obtained from this master curve.

The pavement temperature has a seasonal variation and also spatial variation along the depth. The pavement temperature was calculated from air temperature using the regression equation developed for India (Nivitha and Krishnan, 2014) as shown in Equation 4.

$$\textit{Pavement temperature} = -0.7147 + 1.3023 \times \textit{air temperature} + 0.1103 \times \textit{latitude} \tag{4}$$

The air temperature for Bangaluru (nearest point of data availability for the location chosen for NH13) was collected from Indian Meteorological Department (IMD), Pune. Daily maximum and minimum air temperatures were collected for a period of 2 years which were then used to calculate the pavement temperature using Equation 4.

It is well known that air temperature varies across different periods in a year and consideration of an average air temperature to calculate the pavement temperature can under/over-estimate the damage in the pavement. For instance, a location in southern part of India having moderate climate throughout the year will have a higher annual average pavement temperature (AAPT) compared to another location in northern part of India having extreme climates. The location having extreme climate will be more critical to both rutting and fatigue cracking compared to one with moderate climate. In this paper, the monthly variation in air temperature was considered for design. Rutting is mainly caused at high temperatures and cracking at low temperatures. To evaluate the damage due to rutting, the modulus values corresponding to 7-day maximum average pavement temperature as per SHRP (Kennedy et al., 1994) was used in analysis on a monthly basis. For fatigue cracking, the modulus value corresponding to the minimum pavement temperature was calculated for every month to evaluate the damage. The spatial variation along the depth is given by Equation 5 from SHRP (Kennedy et al., 1994).

$$T_{d(max)} = [T_{s(max)} + 17.8][1-2.48(10^{-3})d + 1.085\ (10^{-5})d^2 - 2.441\ (10^{-8})d^3] - 17.8, \tag{5}$$

where $T_{d(max)}$ is the pavement temperature (ºC) at depth 'd' and $T_{s(max)}$ is the pavement surface temperature (ºC) and 'd' is the depth from the surface (mm). The dynamic modulus values are shown in Table 3. From this Table, a considerable variation in pavement temperature (upto 10ºC) can be observed between the surface and a depth of 112 mm from the surface. A high temperature on surface will make BC layer more susceptible to rutting and the increased modulus for DBM layer will increase the fatigue damage. This variation in pavement temperature has to be considered in calculating the dynamic modulus. One valid criticism of the manner in which the environmental factors have been considered here based on SHRP approach is that these are not applicable for Indian conditions. However, due to the non-availability of such field data, recourse is taken to rational approach available. The main idea is to qualitatively check for the influence of overloading and whether the existing pavement sections can handle such effect.

3. Design based on IRC:37-2012

The first step here is the choice of a section based on the traffic data. The design was performed only for the selected location along NH 13. The traffic on NH13 was calculated in terms of ESAL and an appropriate section was chosen from the IRC:37-2012 catalogue assuming a CBR value. The pavement design performed is discussed for the following three cases.

Case 1: IRC method of design with the properties and values as specified in IRC:37-2012. This step will help in evaluating the capacity of the section for the specified traffic. The material properties used correspond to Table 4 here.

Case 2: In the second stage, the same IRC method of design is adopted but detailed material properties are taken into consideration as discussed in Section 2. This step will indicate the effect of approximations of material properties on the distresses. The material properties used correspond to Table 3 here.

Case 3: The third is the use of AASHTOWare which takes into consideration detailed material properties and traffic data.

The first two cases are discussed in this section and the third is discussed in Section 4.

The pavement was designed based on IRC:37-2012 using the material parameters specified by the standard. The VDF for NH 13 was obtained as 5.46. A design life of 15 years, annual growth rate of 5% and a lane distribution factor of 0.4 (4 lane road) were used to calculate the design traffic for NH 13. The design traffic calculated for this stretch is 200 msa. Since IRC suggests cross-sections only up to traffic of 150 msa, the design life was reduced to 13 years to get the traffic as 148 msa. An average CBR of 10% was assumed for NH 13 stretch since the CBR value is not readily available for this section. The modulus values for subgrade and granular layers were calculated using the equations available in IRC:37-2012. The AAAT for NH 13 was calculated as 24.26˚C and using Equation 4, the corresponding pavement temperature was calculated to be 35˚C. The modulus value for the bituminous layer corresponding to 35˚C was obtained as 3000 MPa from IRC:37-2012. The section corresponding to 150 msa traffic has the thickness for BC, DBM, subbase and subgrade as 50, 125, 250 and 200 mm respectively.

Table 4. Material parameters for different layers

Layer	Thickness (mm)	Modulus value (MPa)	Poisson's ratio
BC	50	3000	0.35
DBM	125	3000	0.35
Base	250	234	0.35
Subbase	200	234	0.35
Subgrade	500	77	0.45

The critical strains were calculated using the stress analysis software, KENLAYER. The critical strains for rutting and fatigue cracking were calculated at the locations suggested by IRC:37-2012 as shown in Table 5. When these strains were converted into the number of repetitions using the distress equations provided in IRC:37-2012, it was seen that the chosen section was safe in rutting but failed by fatigue cracking. The rutting capacity of the section was overestimated as only the rutting of the subgrade was considered in calculation of the strains. The influence of variation in material parameters on the distresses are also evident (Case 2) on the overloaded section. There is almost a decade difference in the horizontal tensile strain and almost two decades in vertical compressive strain when variation in material parameters was considered. When the strains were translated into the number of repetitions, the number of repetitions to failure was found to be abysmally low. This shows that the damage analysis performed using KENLAYER considerably under-estimates the strains especially when conservative material parameters were used (Table 4). The effect of overloading was also not reflected in the damage evaluated with detailed material consideration. From Section 2.1, the variation in VDF between overloaded and non-overloaded section was observed and this is expected to be reflected in the damage. However, from the results, it can be understood that the magnitude of change in VDF upon limitation of overloaded axles is insensitive to the damage calculated using KENLAYER.

Table 5. Critical strains from damage analysis

Condition	Horizontal Tensile Strain	Vertical Compressive Strain	No. of repetitions to failure (Fatigue Cracking)	No. of repetitions to failure (Rutting)
Case 1: IRC inputs	1.496 E-04	1.416 E-04	5E6	3973E6
Case 2: Modified IRC inputs (with overloading)	4.607 E-03	1.495 E-02	8	3
Case 2: Modified IRC inputs (without overloading)	4.554 E-03	1.483 E-02	9	3

4. Design based AASHTO method of pavement design

The traffic data required in this method of design are Annual Average Daily Traffic (AADT), axle configurations and axle load distributions for various axle types, axle configurations (general information regarding axle width, dual tyre spacing, tyre pressure, spacing for different axle types etc.), lateral wandering, information regarding wheel base and speed of the vehicle. The axle configuration and axle load data are required to be input separately for each vehicle class. The vehicle class specified by FHWA (2001) is used in this software and hence it is required to associate the axle configurations observed in the field under Indian conditions to specific FHWA classes. While there were identical axle configurations for most of the vehicle class, some cases, it was observed that the axle configuration of vehicles observed in India did not match with those of the axle configurations of the FHWA vehicle class. In order to incorporate those vehicles in design, the axles per truck option in AASHTOWare was used to convert one vehicle class to another. The percentage of vehicles in each vehicle class alone was then calculated. The axle load distributions were calculated separately for each vehicle class for each month in a year. For this purpose, class intervals are specified by AASHTO (NCHRP 1-37A, 2004) and the percentage of axles in each load interval were estimated. All these data were calculated from the traffic data available for NH 13. In this method of design, each axle load group was used directly to evaluate the damage eliminating the use of equivalency factors.

The material properties considered for the subgrade are Poisson's ratio, coefficient of lateral earth pressure, resilient modulus, soil gradation and other engineering properties. For bituminous layers, the dynamic modulus of the mix measured at different temperatures and frequencies are required. In addition, the binder properties can also be selected depending on the grading method used. Using this information, a master curve is developed by AASHTOWare. The mix properties used in this paper were obtained using AMPT and the binder properties such as the $|G^*|$ and phase angle (δ) at different temperatures were obtained from oscillatory tests performed in a dynamic shear rheometer available at IIT Madras.

The different distress values obtained for NH 13 with and without overloading are provided in Table 6. The design life was kept as 5 years for all the analysis using AASHOTWare to enable optimization with reasonable thicknesses. The target values for total deformation and fatigue cracking were limited to 20 mm and 20% respectively. For all other distresses, the values specified by AASHTO (NCHRP 1-37A, 2004) were adopted. Only bottom-up cracking and rutting were considered as the critical distresses in IRC method of design. However, from AASHTOWare results, it is clear that rutting in bituminous layers and top-down cracking also play an equally significant role.

The difference in distresses between the overloaded and non-overloaded section is evident in this method of design. The reduction in distresses for the non-overloaded case is more significant for bottom-up and top-down cracking compared to rutting. However, both these section do not serve the design life of 5 years. To identify an optimal thickness of the pavement for a design period of 5 years, the thickness and material used for bituminous layers were varied. Since deformation in bituminous layers and top down cracking were observed as the critical distresses, a modified binder was used for both the bituminous layers. The material properties related to the modified binders and the mixtures were used from the internal database of IIT Madras (Krishnan and Veeraragavan, 2014) and for want of space, they are not provided here. For overloaded case, when the layer thickness of BC layer was increased to 100 mm and that of DBM to 250 mm, the pavement section was expected to serve without any damage. For the section without overloading, a reduction in DBM thickness of 12.5 mm was observed compared to the overloaded section. For the optimized thickness, one can observe that all the distresses were within the target values.

Table 6. Material Parameters for different layers for NH 13

Distress	Target	With overloading	Without overloading	Optimization With overloading	Optimization Without overloading
Terminal IRI	2.70	2.4	2.1	1.9	1.6
Permanent Deformation (total) mm	20	28.5	21.4	15.8	12.5
AC bottom-up fatigue cracking (%)	20	27.2	20.65	1.6	1.5
AC thermal cracking (m/km)	189	5.2	5.15	5.2	5.2
AC top-down fatigue cracking (m/km)	378	1878	1053	56.3	52.3
Permanent Deformation - AC only (mm)	6	14	11.6	5.9	5.6

5. Summary

A critical factor causing considerable damage to the pavement is the axle overloading. In this paper, the effect of overloading on the distresses was analysed with detailed consideration of material properties. The traffic data was analysed and the corresponding section suggested by IRC:37-2012 was chosen for the analysis. The distresses for this location were evaluated using KENALYER based on the IRC method of design for the properties specified by IRC:37-2012. The section failed by fatigue cracking, but was safe in rutting. When the realistic material properties such as seasonal variation in subgrade and binder and mixture modulus were taken into account, the strains were found to be considerably under-estimated when analysed using KENLAYER. There was also no significant difference observed between the overloaded and non-overloaded section. The clear difference in the distresses between overloaded and non-overloaded section were however quantified using AASHTOWare. The top-down cracking and rutting in bituminous layers were observed to be critical distresses, in some cases, even more significant than total permanent deformation and bottom-up cracking. The effect of axle overloading had significant influence on top-down and bottom-up cracking compared to rutting. Optimization carried out using AASHTOWare resulted in increased thicknesses for the pavement.

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