CHAPTER 8

PAVEMENT DESIGN AND ECONOMICAL ANALYSIS

8.1 Preamble

Various bituminous concrete mixes designed in previous chapters were intended to be utilized as the surface course in the flexible pavements facing heavy traffic. To achieve this objective, the design of flexible pavement was done for heavy traffic using IRC 37 (2018) guideline and IITPAVE software. Analysis was done to compute the minimum surface layer thickness made with these mixes that can satisfactorily support the intended traffic over the entire service life of the pavement. The calculated layer thicknesses were used in the economic evaluation of all mixes. It was done by comparing the material cost needed to construct 1 km of two lanes flexible pavement having granular base and subbase and utilizing these mixes as surface course. These analyses were helpful in analyzing the structural suitability and economic viability of conventional and waste modified mixes.

8.2 Principles and Design Approach

Flexible pavements can be made by utilizing different combinations of the materials in different layers. However, in this investigation the analysis is done on the bituminous pavement having granular base and subbase. Hence discussion is focused on this particular category of pavement only. The purpose of pavement design methodology is to design flexible pavements which deliver satisfactory structural and functional performance during their intended service life. The performance of pavement can be analyzed either by: empirical methods (depend upon past experiences) or by mechanistic-empirical methods. The mechanistic-empirical approach evaluates distresses based on mechanistic parameters like stress, strain, and deformation using specific theory and procedures. Majority of the popular pavement design guidelines (AUSTROADS, 2010; French design manual, 1997; IRC 37, 2018; South African pavement design manual, 2013) have opted for the mechanistic-empirical principle to analyze the behavior of the pavement. The materials used in different pavement layers (bituminous layer, unbound granular layer, and subgrade layer) don't display linearly elastic behavior for entire climatic and loading conditions. Still, linear elastic layer model is the most widely used theoretical model for the flexible pavement analysis (Reddy 2017). It is due to the simplicity of the model, availability of large number of softwares for the analysis, and ease with which inputs needed for the pavement analysis can be obtained in laboratories are primary reasons for the preference of this theory for pavement design and evaluation.

In this study, the analysis is done according to IRC 37 (2018) guideline, which assumes pavement as a multi-layer system and adopts "linear elastic layered theory" for its analysis. The bottom most subgrade layer is assumed to be semi infinite, while the upper layers are considered to be finite in thickness and infinite in horizontal extent. The safety criteria of any pavement are decided by its serviceability thresholds (acceptable rutting and cracking), which should not be exceeded their critical values.

Fatigue cracking is known to originate at the bottom of the bottom-most bituminous layer, which progresses upwards with the repeated traffic loading and appears on the surface in the form of alligator cracks. Hence flexural tensile strain at the bottom of the bituminous layer should be controlled. This could be done by (a) providing a stiffer mix to reduce tensile strain, (b) providing strong support from the underlying layer to control deflection, (c) use of adequately elastic mix. The mixes that don't have adequate tensile strength at higher temperatures can also produce tensile strain near the surface close to the wheel's edge, which can be sufficiently large to initiate longitudinal surface cracking. The rutting in the pavement can occur in two regions: (a) Due to deformation in subgrade and other granular layers and (b) due to deformation in bituminous layers. According to IRC 37 (2018), controlling vertical compressive strain on the top of subgrade can also indirectly control the strain in granular layers. The other distresses such as rutting within the bituminous layers, moisture damage, and brittle cracking due to excessive age hardening can be prevented by including the volumetric parameters of mix into performance models, providing adequate drainage layer and by judicious selection of bitumen and type of mixes. The Figure 8.1 displayed a typical composition of bituminous pavement with granular base and subbase, displaying critical strain locations. The performance criteria for rutting and fatigue cracking are described below.

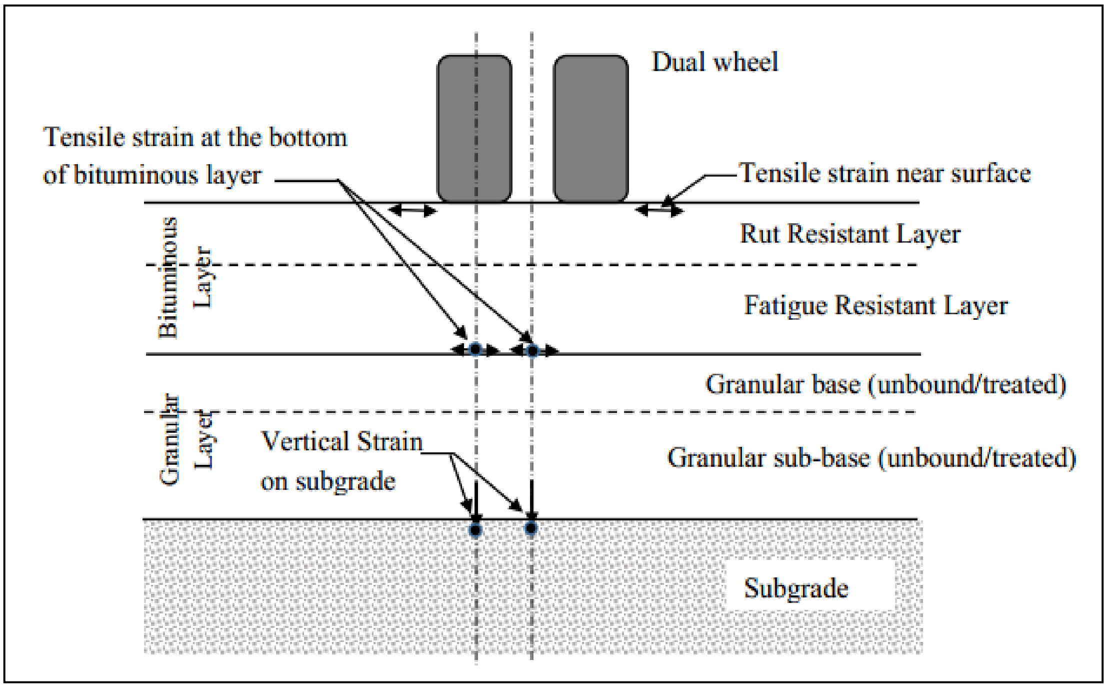


Figure 8.1 Section of bituminous pavement having granular base and subbase showing locations of critical strain

8.2.1 Criteria for Rutting in Subgrade

IRC: 37 (2018) considers the maximum average rut depth of 20 mm along the wheel path as the critical or failure rutting condition. The equivalent number of load repetitions of standard axle load (80 kN) that can be sustained by the pavement, before the rutting failure can be determined using the rutting performance models given in Equation 8.1 and 8.2, having 80% and 90% of reliability levels respectively.

$$N_r = 4.1656 \times 10^{-8}[1/\varepsilon_v]^{4.5337} \qquad [8.1]$$

$$N_r = 1.4100 \times 10^{-8}[1/\varepsilon_v]^{4.5337} \qquad [8.2]$$

Where,

N_r = Rutting life of subgrade (Cumulative equivalent number of standard axle of weight 80kN)

ε_v = Vertical compressive strain at the top of subgrade

8.2.2 Criteria for Fatigue Cracking in Bituminous Layer

The critical condition of fatigue cracking is considered to be reached when the fatigue cracking (in the form of inter connected cracks) is observed on the minimum 20% of the surface area under consideration. Similar to the rutting criteria, the equivalent number of load repetitions sustained by the pavement, before the fatigue failure can be calculated using the fatigue performance models given in Equation 8.3 and 8.4, having 80% and 90% reliability of levels respectively.

$$N_f = 1.6064 \times C \times 10^{-4} \times [1/\varepsilon_t]^{3.89} \times [1/M_R]^{0.854} \qquad [8.3]$$

$$N_f = 0.5161 \times C \times 10^{-4} \times [1/\varepsilon_t]^{3.89} \times [1/M_R]^{0.854} \qquad [8.4]$$

Where,

$C = 10^{M}$, and $M = 4.84 \times \left(\frac{V_{be}}{V_a + V_{be}} - 0.69\right)$

V_a = Volume of air voids in bottom bituminous layer

V_{be} = Volume of effective bitumen in bottom bituminous layer

N_f = Fatigue life of bituminous layer (cumulative equivalent number of 80 kN standard axle loads)

ε_t = Maximum horizontal tensile strain at bottom of the bottom most bituminous layer

M_R = Resilient modulus (MPa) of bituminous mix used in bottom most bituminous layer

The factor “C” is termed as the adjustment factor which is used to take account for the effect of variation in the volumetric parameters (air voids and effective bitumen volume) on fatigue life of bottom most bituminous mix.

As per IRC 37 (2018), the 90% reliability performance equations should be used for design traffic equal or higher than 20 msa (million standard axles).

8.2.3 Analysis of Flexible Pavements

The IITPAVE software was used in this study to analyze the linear elastic layer pavement system. This software calculates stress, strain, and deformation at the critical locations of the pavements caused by a uniformly distributed single load applied over a circular contact area. It uses elastic modulus, Poisson’s ratio, and thickness of various layers as input parameters. The elastic modulus of the subgrade is recommended to be calculated from its effective CBR values according to the Equation 8.5 and 8.6. The Equation 8.5 is valid for subgrade having $\mathrm{CBR} \le 5\%$, while Equation 8.6 is valid for subgrade having $\mathrm{CBR} > 5\%$.

$$M_{RS} = 10 \times \mathrm{CBR} \tag{8.5}$$

$$M_{RS} = 17.6 \times [\mathrm{CBR}]^{0.64} \tag{8.6}$$

Where,

M_{RS} = Resilient modulus of subgrade soil (MPa)

CBR = California bearing ratio of subgrade (%)

The elastic or resilient modulus value of granular layer depends on its layer thickness and the resilient modulus of the supporting layer on which it rests. It can be calculated according to the Equation 8.7.

$$M_{RG} = 0.2 \times [\mathrm{h}]^{0.45} \times M_{RSP} \qquad [8.7]$$

Where,

M_{RSP} = effective resilient modulus of supporting layer (MPa)

h = thickness of granular layer (mm)

M_{RG} = resilient modulus of granular layer (MPa)

The resilient modulus value of bituminous layers used in surface and binder course layers can be calculated in laboratory at 35°C as per ASTM D4123-82 (1995) specification. The Poisson's ratio for all layers can be taken 0.35 for the analysis. After providing all necessary inputs in the IITPAVE software, compressive and tensile strain at every critical location can be computed, which should not be higher than critical values.

8.3 Calculation of Pavement Layer Thickness

The objective of this section is to design the bituminous pavements with granular base and subbase and to utilize various bituminous concrete mixes prepared in previous chapters as surface course. The minimum surface layer thicknesses of all 16 types of mixes, which can successfully support the same traffic volume throughout the service life of pavements, were calculated as per IRC 37: (2018). A similar pavement structure is designed for hypothetical traffic volume and service life, which constituted of the same type of subgrade, granular sub-base, and binder layers with similar layer thickness. For every mix, the resilient modulus value of surface courses was taken, which were experimentally determined at 35°C in previous chapter.

A bituminous pavement was designed for four lane divided carriageway using the following input data, taken from Annexure II of IRC 37: (2018).

(a) Initial traffic in the year of completion of construction (A) = 5000 cvpd (two-way)

(b) Traffic growth rate per annum (r) = 6%

(c) Vehicle Damage Factor (*VDF)* = 5.2 (taken to be same for both direction)

(d) Lateral Distribution Factor (LDF) = 0.75

(e) Design life period (n) = 20 years

(f) Effective CBR of subgrade = 7%

(g) Dense bituminous macadam (DBM) mix was used in bottom bituminous layer for an air void content of 3% resulted in effective bitumen content (by volume) of 11.5%, and resilient modulus of 3000 MPa.

8.3.1 Calculations

The following steps were followed in the design of the required pavement. This calculation was done to describe the procedure to calculate various pavement layer thicknesses of pavement utilizing bituminous concrete mix with 4% stone dust (SD 4) as filler. Same procedure will be followed for the other 15 types of mixes used in the study.

Step I: Calculation of cumulative number of standard axles (N) or design traffic is done as per Equation 8.8

$$N = \frac{365 \times [(1 + \mathrm{r})^{n} - 1]}{r} \times A \times VDF \times LDF \qquad [8.8]$$

The design traffic came out to be equal to 131 msa

Step II: Calculation of allowable strains in pavements for design traffic

The allowable vertical compressive strain on the subgrade and allowable horizontal tensile strain at the bottom of bituminous layer can be calculated using the performance models specified in Equation 8.2 and 8.4 in this section. Since, the design traffic is 131 msa (>20 msa), performance models corresponding to 90% reliability is used in the analysis.

Allowable vertical compressive strain on the subgrade (Equation 8.2) = 0.301×10^{-3}

Allowable horizontal tensile strain at the bottom of the bituminous layer (Equation 8.4) = 0.150×10^{-3}

To ensure the safe design of pavement, the material and different layer thickness should be selected in such a manner that the strain obtained at the critical locations should not exceed the allowable strains. To ensure the further safety of the pavement, the allowable strains were further reduced by multiplying them with an additional factor of safety of 0.95. Hence the modified allowable strain values came out to be,

Allowable vertical compressive strain on the subgrade = $0.301 \times 10^{-3} \times 0.95$

= 0.286×10^{-3}

Allowable horizontal tensile strain at the bottom of the bituminous layer

= $0.150 \times 10^{-3} \times 0.95 = 0.1425 \times 10^{-3}$

Step III: Selection of trial section (excluding surface course)

A trial section is chosen which consisted of 70 mm thick DBM-II and 80 mm thick bottom rich DBM-I as binder course; 250 mm thick granular base (WMM) and 230 mm thick granular sub-base (GSB). Total thickness of granular layer is equal to 480 mm. From this point forward, this chosen section is fixed for all type mixes and only alteration will be done for the surface courses

Step IV: Selection of trial thickness of surface course

The SD 4 mix is chosen as the surface course with a trial thickness of 57 mm

Step V: Calculation of input parameters

Effective resilient modulus of subgrade (Equation 8.6) = $17.6 \times (7.0)^{0.64} = 62$ MPa

Resilient modulus of granular layer (Equation 8.7)= $0.2 \times (480)^{0.45} \times 62 = 200$ MPa

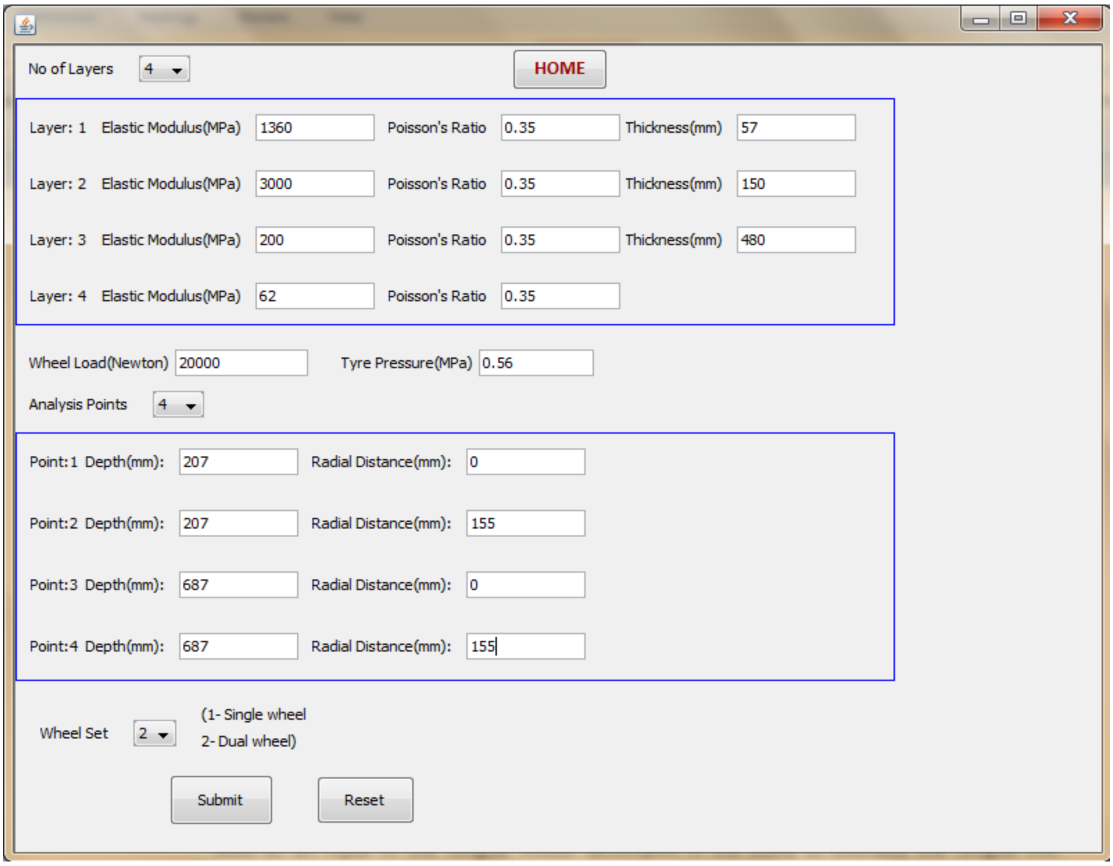
Resilient modulus of binder course (given) = 3000 MPa

Resilient modulus of surface course made with SD4 mixes (determined experimentally) = 1360 MPa

Poisson’s ratio for all layers = 0.35

Step VI: Analysis of pavement using IITPAVE

The Plate 8.1and 8.2 displayed the screen shots of input and output pages of IITPAVE respectively. The input parameters were taken from Steps III to V. Standard axle load of 80 kN having dual tyre configuration was chosen for the pavement design. Tyre pressure was taken to be 0.56 MPa, and the poisons ratio for all the layers was assumed to be 0.35. The strains were calculated on the top of subgrade layer and at the bottom of the binder layer.



No of Layers 4

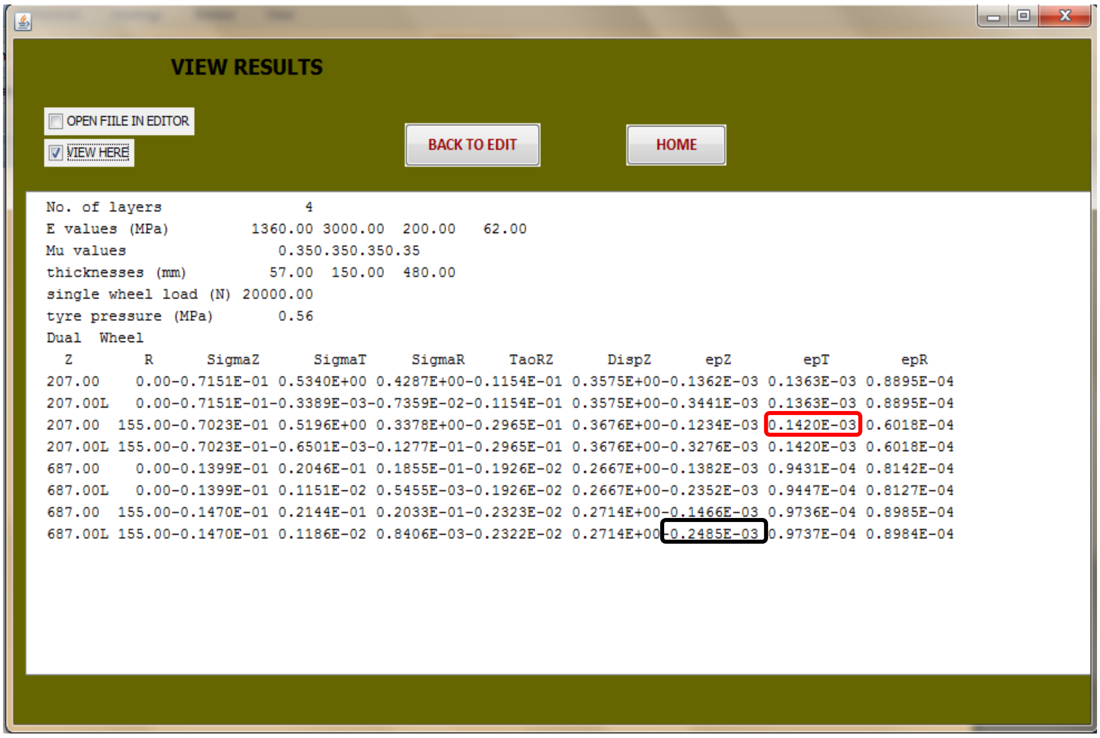
Layer: 1 Elastic Modulus(MPa) 1360 Poisson's Ratio 0.35 Thickness(mm) 57
Layer: 2 Elastic Modulus(MPa) 3000 Poisson's Ratio 0.35 Thickness(mm) 150
Layer: 3 Elastic Modulus(MPa) 200 Poisson's Ratio 0.35 Thickness(mm) 480
Layer: 4 Elastic Modulus(MPa) 62 Poisson's Ratio 0.35

Wheel Load(Newton) 20000 Tyre Pressure(MPa) 0.56
Analysis Points 4

Point:1 Depth(mm): 207 Radial Distance(mm): 0
Point:2 Depth(mm): 207 Radial Distance(mm): 155
Point:3 Depth(mm): 687 Radial Distance(mm): 0
Point:4 Depth(mm): 687 Radial Distance(mm): 155

Wheel Set 2 (1- Single wheel
2- Dual wheel)

Plate 8.1 Input screen of IITPAVE



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No. of layers                4
E values (MPa)         1360.00 3000.00  200.00   62.00
Mu values                  0.350.350.350.35
thicknesses (mm)          57.00  150.00  480.00
single wheel load (N) 20000.00
tyre pressure (MPa)        0.56
Dual  Wheel
  Z         R      SigmaZ      SigmaT      SigmaR      TaoRZ      DispZ      epZ        epT        epR
207.00    0.00-0.7151E-01 0.5340E+00 0.4287E+00-0.1154E-01 0.3575E+00-0.1362E-03 0.1363E-03 0.8895E-04
207.00L   0.00-0.7151E-01-0.3389E-03-0.7359E-02-0.1154E-01 0.3575E+00-0.3441E-03 0.1363E-03 0.8895E-04
207.00  155.00-0.7023E-01 0.5196E+00 0.3378E+00-0.2965E-01 0.3676E+00-0.1234E-03 0.1420E-03 0.6018E-04
207.00L 155.00-0.7023E-01-0.6501E-03-0.1277E-01-0.2965E-01 0.3676E+00-0.3276E-03 0.1420E-03 0.6018E-04
687.00    0.00-0.1399E-01 0.2046E-01 0.1855E-01-0.1926E-02 0.2667E+00-0.1382E-03 0.9431E-04 0.8142E-04
687.00L   0.00-0.1399E-01 0.1151E-02 0.5455E-03-0.1926E-02 0.2667E+00-0.2352E-03 0.9447E-04 0.8127E-04
687.00  155.00-0.1470E-01 0.2144E-01 0.2033E-01-0.2323E-02 0.2714E+00-0.1466E-03 0.9736E-04 0.8985E-04
687.00L 155.00-0.1470E-01 0.1186E-02 0.8406E-03-0.2322E-02 0.2714E+00-0.2485E-03 0.9737E-04 0.8984E-04
```

Plate 8.2 Output screen of IITPAVE showing computed horizontal tensile strain (red box) and vertical subgrade strain (black box)

The computed strains are highlighted in the output screen (Figure 8.3). Both computed strains were found to be just smaller than allowable strains.

Computed vertical compressive strain = $0.2485 \times 10^{-3} < 0.286 \times 10^{-3}$, and hence found to be satisfactory

Computed horizontal tensile strain = $0.1420 \times 10^{-3} < 0.1425 \times 10^{-3}$, and hence found to be satisfactory

It is inferred that the bituminous pavement utilizing with SD 4 mix as surface course with layer thickness of 57 mm can satisfactorily support design traffic of 131 msa. Similarly, the layer thickness for the other 15 types of mixes was calculated by repeating the steps IV to VII and opting for different trial thicknesses. To ensure the minimum design thickness, the thickness should be chosen in such a way that computed horizontal tensile strain should be close to allowable horizontal tensile strain. The satisfactory layer thickness of various mixes along with computed strains are stated in Table 8.1. Computed strains for all mixes were found to be lower than critical strains.

Table 8.1 Adopted thickness and computed strains of various mixes

Type of mix	Resilient Modulus at 35°C (MPa)	Adopted thickness of Surface Course (mm)	Computed vertical compressive strain	Computed horizontal tensile strain
SD 4	1360	57	0.2490×10^{-3}	0.1420×10^{-3}
SD 5.5	1991	50	0.2448×10^{-3}	0.1425×10^{-3}
SD 7	2630	46	0.2411×10^{-3}	0.1423×10^{-3}
SD 8.5	2930	45	0.2391×10^{-3}	0.1419×10^{-3}
GP 4	1610	54	0.2467×10^{-3}	0.1421×10^{-3}
GP 5.5	2134	49	0.2439×10^{-3}	0.1424×10^{-3}
GP 7	2834	45	0.2401×10^{-3}	0.1423×10^{-3}
GP 8.5	3072	44	0.2389×10^{-3}	0.1422×10^{-3}
KS 4	1491	55	0.2479×10^{-3}	0.1423×10^{-3}
KS 5.5	2284	48	0.2430×10^{-3}	0.1424×10^{-3}
KS 7	3037	44	0.2392×10^{-3}	0.1423×10^{-3}
KS 8.5	3320	43	0.2378×10^{-3}	0.1422×10^{-3}
GL 4	2042	50	0.2441×10^{-3}	0.1422×10^{-3}
GL 5.5	2542	47	0.2410×10^{-3}	0.1419×10^{-3}

GL 7	3111	44	0.2385×10^{-3}	0.1421×10^{-3}
GL 8.5	3512	42	0.2374×10^{-3}	0.1424×10^{-3}

Table 8.2 Comparison of surface layer thickness of different mixes

Filler type	Surface layer thickness of mixes with respect to SD 4 mix (%)			
	Filler content			
	4%	5.5%	7%	8.5%
Stone dust	100	87.72	80.70	78.95
Glass powder	94.74	85.96	78.94	77.19
Kota stone	96.49	84.21	77.19	75.43
Glass lime	87.71	82.46	77.19	73.68

It was observed that the increase in filler content significantly improved the stiffness of the mixes, which ultimately resulted in a considerable reduction in the required thickness. The percentage reduction in layer thickness with respect to SD 4 as the conventional mix is reported in Table 8.2. GL mixes displayed lowest layer thickness followed by KS, GP, and SD mixes. Increase in the filler content in the same type of mixes may result in the 16-21% decrease in thickness. Utilization of glass lime filler at 8.5% resulted in considerable savings of about 24%. This will result in momentous saving in material cost and workmanship.

8.4 Economic Evaluation

The economic benefit of utilizing wastes as fillers was assessed by comparing the material cost of all mixes. The unit cost of different ingredients (coarse aggregates, fine aggregates, stone dust (SD), hydrated lime, and bitumen) of the mixes was taken from the schedule of rates of Central Public Works Department (CPWD), Delhi, India (CPWD, 2018). The costs of ingredients are mentioned in Table 8.3. The analysis is limited to comparing the material cost of various mixes without taking the expenditures related to workmanship and machinery in to consideration. Since GP and KS were directly obtained from the dumping grounds as waste materials, their material cost is assumed to be zero. The transportation cost incurred in transferring SD from quarries to the production site of bituminous mix is assumed to be the same as that of transferring waste fillers from their dumping ground to the production site. GP and KS used in this study needed no processing since it was already found to be fine in nature. However, in the worst case scenario, the processing cost (cost incurred in sieving) of these fillers was taken as 0.5% of the total material cost.

The material cost required to manufacture 1 km of two lanes (7.00 m) pavement surface course that can support 131 msa of traffic was calculated. The layer thickness for different mixes was taken according to the previous section. The procedure given below illustrates the calculation of the cost of the surface course made with different mixes. This procedure was suggested in a recent study by Azzam and Al-Ghazawi (2015) for cost comparison of standard and waste modified bituminous mixes. The calculation of cost of the surface course made with conventional SD 4 mix is also done alongside for further explanation.

Step I: Volume of 1 km of pavement having two lanes of total width of 7m (V)

V=1000 × 7.00 ×t

Where, t = thickness of the bituminous mix determined in previous section V= Volume of 1 km of pavement

Volume of 1 km of pavement having two lanes with SD 4 mix

= 1000 × 7 × 0.057 = 399 m^3/km

Step II: Quantity of total mix in 1 km of pavement (M_T)

$M_T = V \times G_{mb}$

Where, t = thickness of the bituminous mix determined in previous section

G_{mb}= Bulk specific gravity of the mix (ton/m^3)

Quantity of total mix having SD 4 mix

= 399 × 2.43 = 969.57 ton/km

Step III: Quantity of bitumen in 1 km of pavement (M_B)

$M_B = M_T \times \frac{OBC}{(100-OBC)}$

Quantity of bitumen in pavement with SD 4 mix

$= 969.57 \times \frac{6.2}{(100-6.2)} = 64.09$ ton/km

Step IV: Quantity of total aggregates 1 km of pavement (M_A)

$M_A = M_T - M_B$

Quantity of total aggregates in pavement with SD 4 mix

= 969.57 - 64.09 = 905.48 ton/km

Step V: Quantity of coarse aggregates in 1 km of pavement (M_{CA})

$M_{CA} = P_{CA} \times M_T \times 0.01$

Where, P_{CA} = Percentage of coarse aggregates in the total aggregates

Quantity of fine aggregates in 1 km of pavement (M_{CA})

$M_{FA} = P_{FA} \times M_T \times 0.01$

Where, P_{FA} = Percentage of fine aggregates in the total aggregates

Quantity of filler in 1 km of pavement (M_F)

$M_F = P_F \times M_T \times 0.01$

Quantity of coarse aggregates in 1 km of pavement with SD 4 mix

= 38 × 905.48 × 0.01 = 344.08 ton/km

Quantity of fine aggregates in 1 km of pavement with SD 4 mix

= 58 × 905.48 × 0.01 = 525.18 ton/km

Quantity of filler in 1 km of pavement with SD 4 mix

= 4 × 905.48 × 0.01 = 36.22 ton/km

Step VI: Cost of Bitumen used in 1 km of pavement (C_B)

$$C_B = M_B \times Cost\ of\ per\ unit\ of\ bitumen$$

Cost of per unit of bitumen = INR 39570/ton (1 $ ≈ 70.69 INR)

Cost of Bitumen used in 1 km of pavement with SD 4 mix

= 64.09 × 39570 = INR 25,36,041 per km

Cost of coarse aggregate used in 1 km of pavement(C_{CA})

$$C_{CA} = \frac{M_{CA}}{G_{CA}} \times Cost\ of\ per\ unit\ of\ coarse\ aggregate$$

Cost of per unit of coarse aggregates = INR 1350/m^3

Where, G_{CA} = Bulk specific gravity of coarse aggregates

Cost of coarse aggregate used in 1 km of pavement with SD 4 mix

$$= \frac{344.08}{2.795} \times 1350 = \text{INR } 1{,}66{,}193 \text{ per km}$$

Cost of fine aggregate used in 1 km of pavement (C_{FA})

$$C_{FA} = \frac{M_{FA}}{G_{FA}} \times Cost\ of\ per\ unit\ of\ fine\ aggregate$$

Cost of per unit of fine aggregates = INR 1350/m^3

Where, G_{FA} = Bulk specific gravity of coarse aggregates

Cost of fine aggregate used in 1 km of pavement with SD 4 mix

$$= \frac{525.18}{2.725} \times 1350 = \text{INR } 2{,}60{,}181 \text{ per km}$$

Cost of filler used in 1 km of pavement (C_F)

$$C_F = \frac{M_F}{G_F} \times Cost\ of\ per\ unit\ of\ Filler$$

Where, G_F = specific gravity of filler

Cost of per unit of stone dust = INR 1400/m^3

Cost of per unit of waste fillers = INR 0

Cost of per unit of hydrated lime = INR 2900/ton

Cost of stone dust used in 1 km of pavement with SD 4 mix

$= \frac{36.22}{2.698} \times 1400$ = INR 18,794 per km

<u>Step VII</u>: Total material cost of the mix used in 1 km of pavement (C_T)

$= C_{CA} + C_{FA} + C_F + C_B$

Total material cost of SD 4 mix used in 1 km of pavement

= INR 29,81,209/ km

<u>Step VIII</u>: Final material cost of the mix used in 1 km of pavement (C)

$= C_T + Processing\ Cost$

Processing Cost = 0.5% of C_T

$C = C_T + 0.05 \times C_T$

Final material cost of SD 4 mix used in 1 km of pavement

= INR 29,96,115/ km

Utilizing the above procedure, the final material cost of different mixes can be compared. The final costs of all mixes are stated in Table 8.3. The comparison of the total cost of mixes with respect to SD 4 mix is reported in Table 8.4. In case of SD mix, the increase in SD in the mix from 4 to 8.5% has resulted in cost reduction of up to 30%. GL mixes were found to most economical mixes at lower filler contents (4 and 5.5%) followed by KS, GP, and SD mixes. On the other hand, KS mixes exhibited lowest material cost at higher filler contents (7 and 8.5%) followed by GL, GP, and SD mixes. Amongst all mixes, KS 8.5 was found to be most economical which displayed significant savings of about 39% in comparison to conventional SD 4 mix. Since bitumen is the most expensive ingredient, the cost reduction in different mixes was attributed to the saving in the bitumen consumption.

Table 8.3 Quantity of ingredients and cost analysis of various mixes

Type of mix	Thickness of surface course (mm)	OBC (% of total weight of mixes)	Quantity of bitumen (ton/km)	Quantity of coarse aggregate (m^3/km)	Quantity of fine aggregate (m^3/km)	Quantity of SD (m^3/km)	Quantity of waste filler (m^3/km)	Quantity of hydrated lime (ton/km)	Total material cost (INR/km)	Processing cost (0.5% of material cost) (INR/km)	Final cost (INR/km)
CPWD Rates			INR 39570/ton	INR 1350/m^3	INR 1350/m^3	INR 1400/m^3	0	INR 2900/ton			
SD 4	57	6.20	64.09	123.11	192.73	13.42	0	0	29,96,115	0	29,81,081
SD 5.5	50	5.95	54.12	108.94	166.14	16.33	0	0	25,35,602	0	25,35,602
SD 7	46	5.38	44.91	101.28	150.36	19.33	0	0	21,43,901	0	21,43,901
SD 8.5	45	5.34	43.82	99.65	143.90	23.09	0	0	20,95,111	0	20,95,111
GP 4	54	6.03	58.87	116.72	182.73	0	14.49	0	27,33,731	13,669	27,47,400
GP 5.5	49	5.81	51.43	106.37	162.22	0	18.16	0	23,97,847	11,989	24,09,836
GP 7	45	5.48	44.58	98.48	146.20	0	21.39	0	20,94,322	10,472	21,04,794
GP 8.5	44	5.26	41.86	96.82	139.81	0	25.54	0	19,75,908	9,880	19,85,788
KS 4	55	5.96	59.22	118.99	186.28	0	13.21	0	27,55,416	13,777	27,69,193
KS 5.5	48	5.53	48.53	106.19	161.94	0	16.21	0	22,83,541	11,418	22,94,959
KS 7	44	4.98	39.86	97.97	145.44	0	19.03	0	19,05,680	9,528	19,15,208
KS 8.5	43	4.89	38.21	95.84	138.40	0	22.61	0	18,28,182	9,141	18,37,323
GL 4	50	5.65	51.31	109.51	171.44	0	6.80	16.11	24,56,272	12,281	24,68,553
GL 5.5	47	5.38	45.96	103.65	158.07	0	11.26	15.25	22,16,271	11,081	22,27,352
GL 7	44	5.12	40.80	97.26	144.38	0	15.09	14.31	19,82,291	9,911	19,92,202
GL 8.5	42	5.05	38.34	92.80	134.00	0	18.72	13.65	18,62,926	9,315	18,72,241

Note: 1 $ ≈ 70.69 INR (on 14/12/2019)

Table 8.4 Comparison of final cost of different mixes

Filler type	Total cost of mixes with respect to SD 4 mix (%)			
	Filler content			
	4%	5.5%	7%	8.5%
Stone Dust	100	85.06	71.92	70.28
Glass Powder	91.70	80.44	70.25	66.28
Kota Stone	92.43	76.60	63.92	61.33
Glass Lime	82.40	74.34	66.50	62.49

8.5 Summary

This chapter compares the structural suitability and economic viability of various mixes as a surface course in flexible pavement having granular subbase and base course. The minimum layer thickness of surface course made with various mixes that can support design traffic of 131 msa was determined. Analysis was done following mechanistic-empirical design principles with IRC 37 (2018) guidelines and IITPAVE software. The increase in filler content in bituminous mixes tends to increase their stiffness and a significant reduction in layer thickness for all mixes. GL mixes required minimum layer thickness to support the intended traffic followed by KS, GP, and SD mixes. It was observed that the replacement of stone dust with various waste fillers can result in up to 24% reduction in thickness. The economic evaluation for the pavements with the computed thickness was also done after comparing the material cost of all mixes. The cost of surface course made with mixes having waste fillers was found to be significantly lower than that of conventional mixes. Surface courses having KS mixes was most economic followed by GL, GP, and SD mixes. Replacement of SD mixes with the waste fillers at optimum proportion was resulted in considerable saving of up to 39% of surface layer cost. In conclusion, it can be inferred that, the replacement of SD filler with waste fillers can produce superior performing mixes in a much economical and ecofriendly manner.