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Estimating the benefits of improved drainage on pavement performance

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Abstract

The drainage quality is an important parameter which affects the performance of highway pavements. In India, since last few years considerable importance has been given to the drainage as per of pavement. A poor quality of drainage results in premature deterioration of the pavement structure and necessitating large amount of costly repairs or replacement, before they reach their design life. This study presents investigations for premature deterioration of a stretch on National Highway (NH 58) between Rishikesh (km 231) and Shivpuri (km 242) due to poor sub-surface drainage. The sections at km 233.800 and km 235.900 were identified for this study. Investigations were carried out by field measurements and laboratory tests on samples of permeable base (water bound macadam – WBM) and sub-base (granular sub-base – GSB) layer materials. Laboratory investigations included determination of gradation, optimum moisture content, maximum dry density, and permeability. Three samples were prepared for each test for both WBM and GSB material and average results were used. The pavement sections were evaluated structurally by deflection measurements and functionally by measuring the road roughness. In this study, the benefits of providing good drainage over the service life of the pavement were quantified in terms of vehicle operating cost (VOC). Performances in terms of deflection and roughness were predicted for do-nothing and after applying required maintenance. Vehicle operating costs were computed based on the maintenance strategy for good and poor drainage pavement sections and benefits due to maintenance strategy were estimated. Afterwards, economic benefits of good drainage and poor drainage for identified pavement section were compared.

Keywords: Pavement sub-surface drainage, Pavement performance, Vehicle operating cost.

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1. Introduction

Excessive water content in the pavement base, sub-base and sub-grade soil can cause early distress and lead to a structural or functional failure of pavement. In spite of this, adequate priority for drainage system has not been given either in the planning, organization, fund allocation or monitoring stages of highway development. It is essential to give due priority to this area of development and satisfactory arrangements ensured by way of proper design and planning. Provision of fully permeable pavements can be an alternative to prevent pavement damage due to poor drainage. Fully permeable pavements are those in which all layers are intended to be permeable and the pavement structure serves as a reservoir to store water during storm periods to minimize the adverse effects of storm water runoff. Fully permeable pavements are currently used primarily for light traffic (e.g., parking lots that only allow cars, not trucks). Li *et al*. (2012) and Li *et al*. (2013) give the mechanistic–empirical design procedures and the use of fully permeable pavement under heavy traffic has been discussed.

In the present study, section of National Highway (NH 58) was analyzed for the premature deterioration observed on this stretch. The overlay between the stretch km 231.000 (Rishikesh) and km 242.000 (Shivpuri) was done in the year 2011 and was designed for 5 years. These chainage are w.r.to New Delhi, National Capital of India. After 2 years the pavement section was found undergoing deformation, with development of cracks, potholes and rutting. Field tests such as Benkelman Beam Deflection (BBD), roughness study, and materials testing were conducted, to determine the causes of the problems. The investigations revealed that the primary cause of pre-mature pavement failure was attributable to poor sub-surface drainage. High proportion of fines in the portion of GSB (granular sub-base) towards the pavement edge and shoulders had resulted in GSB layer to be totally ineffective as a drainage layer. Also the permeability of GSB and base layer was evaluated to conclude about drainage quality of these layers. Economic benefits of good drainage over poor drainage for identified sections were analyzed by determining VOC.

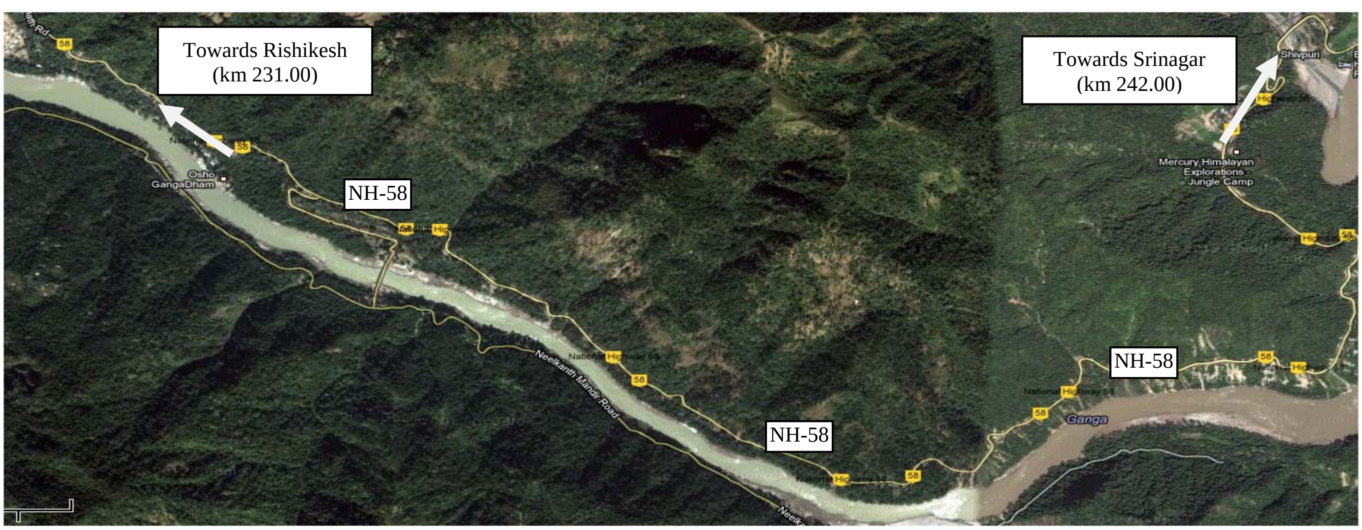
Looking to the problem defined above following objectives were taken for this study: (i) to identify the section of a National Highway with good and poor drainage condition on the basis of laboratory investigation; (ii) to study the effect of drainage on pavement performance and maintenance needs; and (iii) to quantify the benefits in terms of cost due to the improved drainage condition.

2. Literature Review

Water-related damage can cause one or more of the following forms of deteriorations: a) Reduction of sub-grade and base/sub-base strength, b) Differential swelling in expensive sub-grade soil, c) Stripping of asphalt in flexible pavements, d) Frost heave and reduction of strength during frost melt, and e) Movement of fine particles into base or sub-base course materials resulting in a reduction of the hydraulic conductivity considerably (Jain *et al.*, 1992). Effective surface water drainage of highway pavement is essential for maintaining a desirable level of service and traffic safety. Poor surface drainage contributes to accidents resulted from hydroplaning and loss of visibility from splash and spray. The techniques like controlling the pavement geometry, the use of textured surfaces to include the porous asphalt surface and grooved surfaces, and the more effective use of drainage appurtenances were suggested for reducing the water film thickness (Anderson *et al.*, 1998). In addition to surface drainage, pavement must be designed to allow adequate subsurface drainage. Long-term accumulation of water inside the pavement reduces strength of unbounded granular materials and sub-grade soils, and causes pumping of fine materials with subsequent pavement rapid deterioration. The detrimental effects can be reduced by preventing water from entering the pavement providing adequate drainage to remove infiltration or building the pavement strong enough to resist the combined effect of load and water. Pavement service life can be increased by 50% if infiltration water can be drained without delay (Rokade *et al.*, 2012). Therefore, pavement drainage design should be at the forefront of pavement design and not an afterthought. It is also noticeable that funds required for a drainage system are small as compared to the development of infrastructure and the recurring losses which the society and the government have to suffer from year to year (IRC: SP 50, 1999).

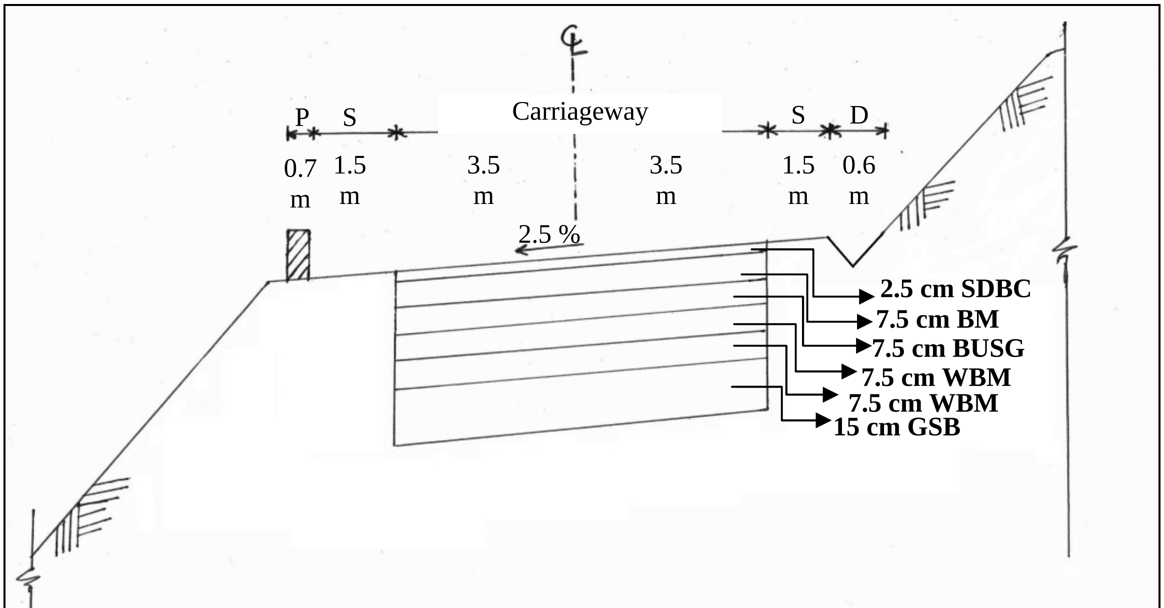
3. Identification of Study Sections

The stretch of NH-58 between Rishikesh and Mana is very important from tourism point of view and due to Char- Dham Yatra in Uttarakhand. During the Yatra season many pilgrims from abroad use to visit the Char-Dham and use to ply on this road. It was observed that the performance of the certain section of stretch between Rishikesh (km231) and Shivpuri (km242) of NH-58 was deteriorating faster than the other section of the same stretch. Specifically two locations near chainage km 235.90 and km 233.80 were identified for the study. The sections of 200m each at chainage km 235.90 and km 233.80 were selected for study as shown in Figure. 1. The detailed cross section of the selected stretches of NH-58 is as shown in Figure 2.



(Figure not to scale)

Figure 1: Map Showing Study Area



Note: P – Parapet wall, S – Shoulder, D – Ditch, SDBC – Semi Dense Bituminous Concrete, BM – Bituminous Macadam, BUSG – Built-up Spray Grout, WBM – Water Bound Macadam, GSB – Granular Sub-base.

Figure 2: Typical Cross Section of Selected NH – 58 Sections

4. Data Collection

Following laboratory and field studies were under taken to study the effect of drainage on pavement performance. Photographs showing various field data collection, sample collection and laboratory testing are given in Fig 3 (a to h).

(a) Water Logging Near Chainage km 233.800

(b) WBM & GSB Sample Collection

(c) Measurement of Deflection using Benkelman Beam

(d) Test Pit to Determine Pavement Layer Thickness

(e) Measurement of Roughness using Bump Integrator

(f) Determination of OMC & MDD for WBM

(g) Gradation of GSB Material

(h) Permeability Test by Constant Head Method

Figure 3: Field Survey and Laboratory Investigations

4.1 Laboratory Studies

WBM (water bound macadam) & GSB (granular sub-base) are two layers which contribute to the drainage for selected pavement sections of NH-58. Samples of WBM & GSB layer material were collected from both the stretches under observation to analyse the gradation, OMC (optimum moisture content) & MDD (maximum dry density), and permeability. Samples were collected by digging a test pits as both the locations and were packed in airtight plastic bags to maintain the moisture while transporting them to laboratory. Constant head permeability test was adopted to determine the permeability of the collected samples. Three samples for each test were prepared for both WBM and GSB materials and the results were averaged. Results of the gradation, OMC & MDD, and permeability of the GSB & WBM layers are given in Tables 1 to 8. Gradation of WBM & GSB samples were done to check whether proportion of material passing certain sieve size is within specified limits of MoRT&H. Particle size distribution, or gradation, of an aggregate is an important aggregate characteristic in determining performance of pavement. Permeability, moisture susceptibility, stability, stiffness, durability are some of the important properties which are governed by aggregate gradation. Ggradation of screenings is to check that percentage of fines present in the mix is not too high to prevent the drainage ability of the layer.

Table 1. Gradation of GSB Component Layer Material (km 235.900)

Sieve size (mm)	% Passing	Limit (MoRT&H) (%passing)
75	100	100
53	84.56	80-100
26.5	77.20	55-90
9.5	66.09	35-65
4.75	48.30	25-55
2.36	43.68	20-40
0.425	26.63	10-25
0.075	3.71	3-10

Table 2. Gradation of WBM Component Layer Material (km 235.900)

Sieve size (mm)	% Passing	Limit (MoRT&H) (%passing)
90	100.00	100
63	99.01	90-100
53	74.56	25-75
45	13.70	0-15
22.4	8.36	0-5

Table 3. Gradation of Screening Material of WBM Component Layer (km 235.900)

Sieve size (mm)	% Passing	Limit (MoRT&H) (%passing)
13.2	100.00	100
11.2	96.03	95-100
5.6	25.01	15-35
180µ	11.21	0-10

Table 4. Gradation of GSB Component Layer Material (km 233.800)

Sieve size (mm)	% Passing	Limit (MoRT&H) (%passing)
75	100	100
53	91.06	80-100
26.5	82.69	55-90
9.5	63.58	35-65
4.75	54.55	25-55
2.36	48.39	20-40
0.425	20.89	10-25
0.075	4.85	3-10

Table 5. Gradation of WBM Component Layer Material (km 233.800)

Sieve size (mm)	% Passing	Limit (MoRT&H) (%passing)
90	100.00	100
63	90.25	90-100
53	72.13	25-75
45	17.73	0-15
22.4	5.00	0-5

Table 6. Gradation of Screening Material of WBM Component Layer (km 233.800)

Sieve size (mm)	% Passing	Limit (MoRT&H) (%passing)
13.2	100.00	100
11.2	97.61	95-100
5.6	34.05	15-35
180µ	13.67	0-10

Table 7. OMC & MDD of WBM & GSB Component Layer Martial

Sr. No.	Properties	km 233.800		km 235.900	
		WBM	GSB	WBM	GSB
1	OMC (%)	6.000	6.000	6.000	6.000
2	MDD (gm/mm^3)	2.265	2.206	2.260	2.204

Table 8. Calculation of Permeability of GSB Layer of km 233.800 and km 235.900

Sr. No.	Chainage	Permeability (cm/min)	Permeability (m/day)
1	Km 233.800	1.160043	16.70455
2	Km 235.900	0.00075	0.010805

4.2 *Field Study*

4.2.1 Benkelman Beam Deflection Study

Benkelman Beam Deflection Survey was carried out on the sections under consideration. The corrected characteristic deflection was calculated on the basis of IRC 81-1997, applying the correction for temperature variation and seasonal variation. The corrected characteristic deflections are given in the Table 9.

Table 9. Corrected Characteristic Deflections at Different Locations

Location	Between Km 233.600 and 233.800		Between Km 235.900 and 236.095	
Direction	Rishikesh to Shrinagar	Shrinagar to Rishikesh	Rishikesh to Shrinagar	Shrinagar to Rishikesh
Corrected Characteristic Deflection (mm)	0.41	0.41	0.61	0.48

4.2.2 Traffic Volume Count

The details of traffic volume for the year 2012 were collected from Average Annual Daily Traffic based on Weekly Traffic Census as given in the Table 10.

Table 10. Average Annual Daily Traffic Based on Weekly Traffic Census

Average Annual Daily Traffic Based on Weekly Traffic Census							
Date	Motorized vehicles					Slow Vehicles	
	Cars, Jeeps, Vans, Three Wheelers	Buses	LCV	HCV	Motor Cycles and Scooters	Animal drawn vehicles	Cycles
09-04-2012	2503	1376	450	676	1471	0	276
10-04-2012	1881	1449	444	667	1444	0	339
11-09-2012	1485	1303	392	589	1248	0	304
12-09-2012	1431	1248	375	562	1297	0	278
13-04-2012	1410	1382	328	491	1319	0	247
14-04-2012	1323	1363	333	500	1203	0	307
15-04-2012	1273	1137	346	518	1212	0	313
Total Traffic	11306	9258	2668	4003	9194	0	2064
Avg. Traffic	1615	1322	381	572	1313	0	295

Note: LCV - Light commercial vehicles, HCV - two axle heavy commercial vehicles

5. Analysis of Results and Discussion

Sample of pavement layer, which were collected from field, were tested in the laboratory. Also data of pavement deflection, traffic census, and roughness were measured for the year 2012 and predicted using relevant prediction models. On the basis of predicted value, VOC and overlay requirement were calculated and benefit of providing good drainage over poor drainage for the pavement section were quantified.

5.1 Classification of Sub- Surface Drainage

Sub-surface drainage condition of pavement was evaluated on the basis of the permeability results of GSB layer. Markow (2001) has classified sub-surface drainage quality of a pavement based on permeability of sub-base is given in Table 11.

Table 11. Classification of Sub- Surface Drainage

Condition of sub-drainage	Permeability of sub-base
Poor	0.1 ft/day (0.03 m/day)
Fair	100 ft/day (30.5 m/day)
Good	10,000 ft/day (3050 m/day)

(Source: Markow, 2001)

It was further stated that a minimally acceptable value of sub-base permeability should lie between poor and fair values [0.1-100 ft/day (0.03-30.5 m/day)] if rainfall infiltration is not to cause substantial damage to the road pavement, and this should be aimed at in the selection of sub-base material.

Grover and Veeraragavan (2010) mentioned that GSB layer should satisfy the permeability criteria of minimum 20m/day. In the present study, based on the permeability of GSB layer, section km 235.900 was classified as poor drainage section and section km 233.800 was classified as good drainage section. Various possible sources of moisture/water entry in the pavements as observed include surface infiltration through cracks, rising ground water, seepage water through cut sections where ditches are shallow, and water penetrating through shoulders.

5.2 Prediction of Pavement Performance

In this study deflection and roughness have been taken as pavement performance parameters. Deflection and roughness values for year 2012 of the sections under study have been measured. Since the past cyclic data related to roughness and deflection was not available the prediction models developed by Reddy 1996, for National Highways and were adopted for this study.

5.3 Deflection Progression Model

The model developed by Reddy (1999) as given below was used for deflection prediction.

$$D_i = iDEF + 0.07884\,[(N_t \text{ x } Age)^{iDEF}],\ 0.44 < iDEF < 0.6 \quad (1)$$

where, iDEF = initial deflection (mm), D_t = Corrected characteristic rebound deflection (mm) at any time t, N_t = cumulative standard axles (millions) at t.

5.3.1 Roughness Progression Model

Roughness progression model as developed by Reddy (1996) as given below was used for prediction of roughness. Roughness progression model is a function of initial roughness, age, deflection and traffic. Cumulative standard axles have been calculated as per IRC: 37- 2001. The lane distribution factor is taken as 0.75, the vehicle damage factor is taken as 4.5 and annual traffic growth is taken as 7.5%.

$$UIt = iUI[\,1+0.3012(\,N_t{*}DEF_0\,)^{0.08Age}] \quad (2)$$

Where, UIt = Roughness index at any time t (mm/km), iUI = Initial roughness index (mm/km), Age = Age of the pavement (years) , Nt = Cumulative standard axles (millions) t, DEF_0 = Deflection in mm

Using above prediction models deflection and roughness of road sections for ten years was predicted for good and poor drainage section separately, the trends of which are shown in Figure 4 & 5 respectively. It can be observed from the Figure 4 that predicted deflection value for year 2022 for good drainage section is 1.39 mm and for poor drainage section is 3.642 mm, which is about 162% more than that of good drainage section. Also Figure 5 indicates the roughness values for year 2022 for good drainage section is 8374 mm/km and for poor drainage section is 5787 mm/km, which is about 45% more than that of good drainage section. This indicates that poor drainage affects significantly to the deterioration of pavement condition. Maximum permissible values of roughness as per IRC: SP: 16-2004, for road surfaces are given in Table 12.

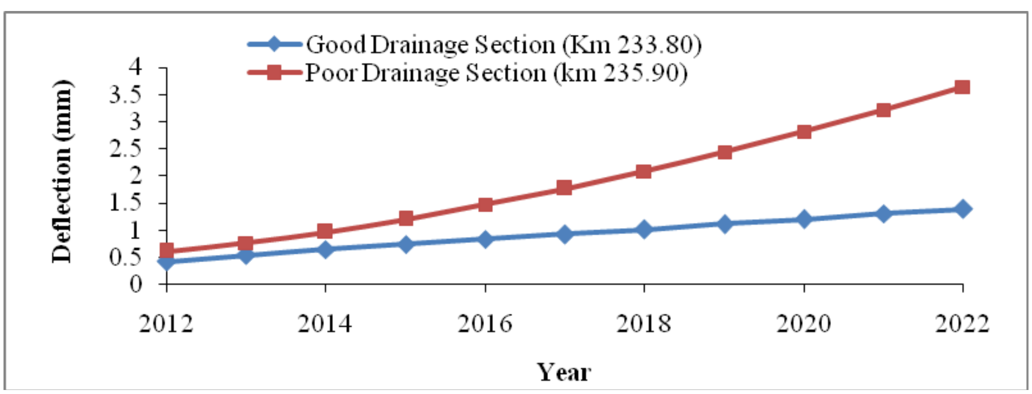


Figure 4: Predicted Deflections and Roughness for Good Drainage Section (km 233.800)

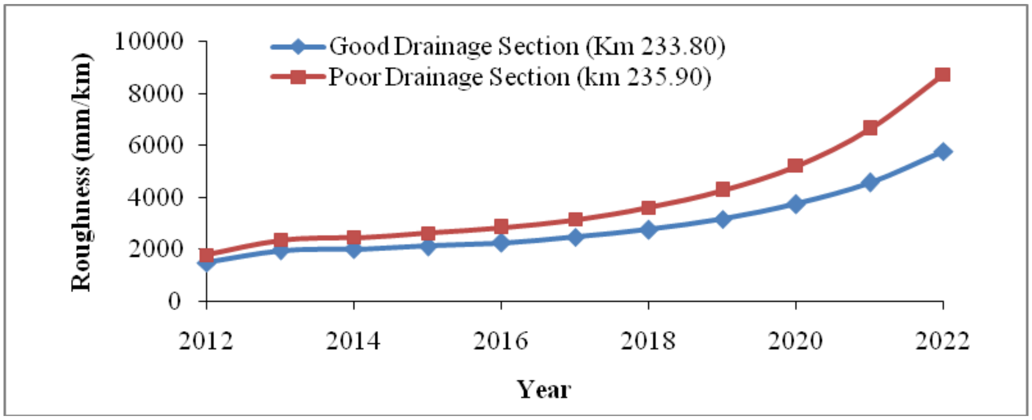


Figure 5: Predicted Deflections and Roughness for Poor Drainage Section (km 235.900)

Table 12. Maximum Permissible Values of Roughness (mm/km) for Road Surface

S. No.	Type of Surface	Condition of Road Surface		
		Good	Average	Poor
1	Surface dressing	<3500	3500 – 4500	> 4500
2	Open Graded premix Carpet	< 3000	3000 – 4000	> 4000
3	Mix Seal surfacing	< 3000	3000 – 4000	> 4000
4	Semi-Dense Bituminous Concrete	< 2500	2500 – 3500	> 3500
5	Bituminous Concrete	< 2000	2000 – 3000	> 3000
6	Cement Concrete	< 2200	2200 – 3000	> 3000

(Source: IRC: SP: 16-2004)

The suitable maintenance strategies have been selected for the section based on the trigger values of roughness and deflection. The trigger value for roughness and deflection as adopted for assigning the thin overlay treatment were 2500 mm/km and 1mm respectively.

5.4 Overlay Requirement

Thin overlay is required as soon as the pavement performance reaches the trigger point i.e deflection of 1 mm and roughness value of 2500 mm/km. The overlay requirement of good and poor drainage pavement section has been estimated and given in Figure 6 and Figure 7 respectively. It can be observed that frequency of overlay required for good drainage pavement sections was one during the design period of 10 years i.e in year 2018, while for poor drainage pavement section was two i.e. in year 2015 & 2019. The roughness values measured in year 2012 was after one year of laying overlay. Hence for the year 2018 (for good drainage section) and 2015 & 2019 (for poor drainage section) after the construction of an overlay, it was assumed that the roughness values will be lower than that measured in year 2012.

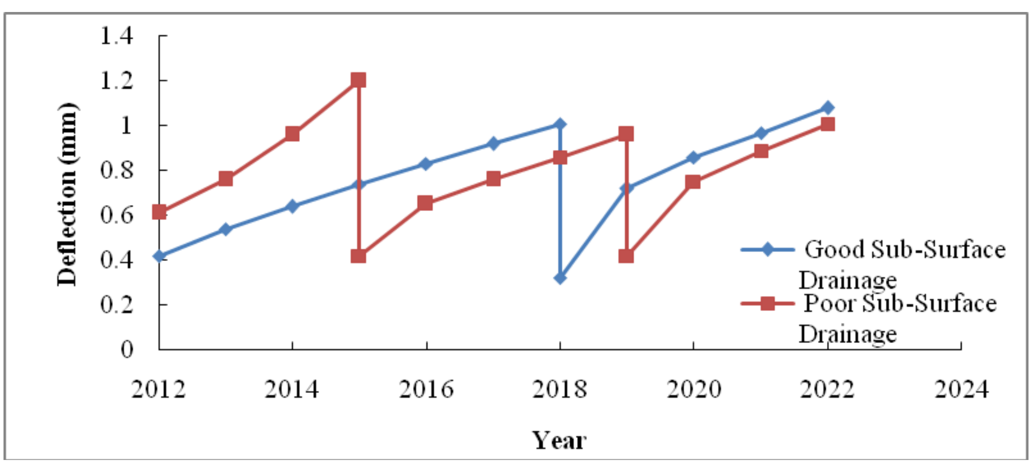


Figure 6: Deflection Progression for Thin Overlay Strategy with Good & Poor Sub-Surface Drainage

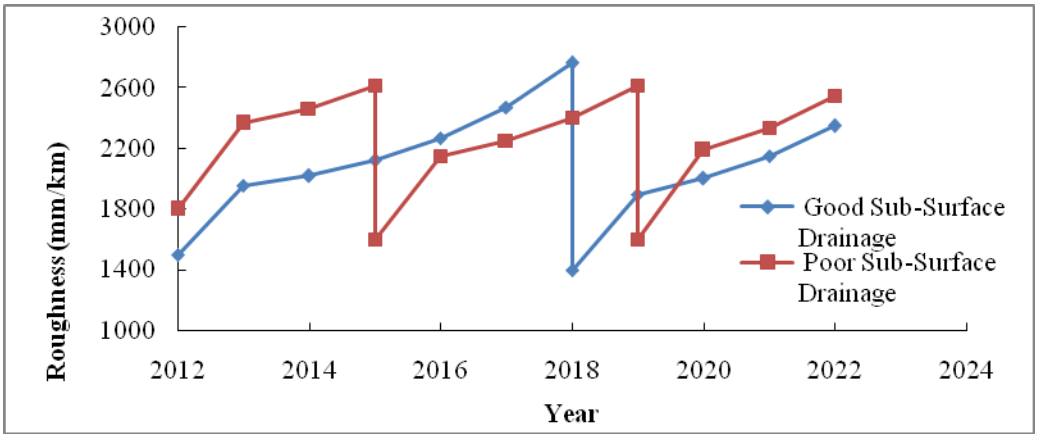


Figure 7: Roughness Progression for Thin Overlay Strategy with Good & Poor Sub-Surface Drainage

5.5 Estimation of VOC

Vehicle operating cost equations developed by Reddy *et al*. (2003) for different classes of vehicle were used in the computation of vehicle operation cost per km. The vehicle classifications covered are new brand cars, old brand cars, two-wheelers, buses, LCV, HCV, and multi axle heavy commercial vehicles (MAV). The rise and fall value is taken as 2.5m/km. The equation used for two lanes undivided National Highway is given in Table 13.

Table 13. Equations for Calculating Vehicle Operating Cost (Rs/Km/Vehicle) for Two-Lane Highway

Vehicle Type	VOC equations
New technology cars	loge VOC=.93-0.134*W+0.00009256*RG+0.01411*RF
Buses	loge VOC=1.705-0.073*W+0.00004718*RG+0.01225*RG
Old Technology cars	loge VOC=1.112-0.114*W+0.00009774*RG+0.01251**RF
Light commercial vehicles	loge VOC=1.849-0.041*W+0.00002822*RG+0.01212*RF
Heavy commercial vehicles	loge VOC=2.092-0.061*W+0.00004047*RG+0.00938*RF
Multy-Axle commercial-vehicle	loge VOC=2.561-0.053*W+0.00003039*RG+0.01337*RF
Two wheelers	loge VOC=-0.253-0.118*W+0.00001282*RG+0.01312*RF

Note: RG – Roughness (mm/km), RF – Rise & Fall *(Source: Reddy et al., 2003)*

VOC has been calculated considering a VOC growth rate of 9% and then a discount rate of 10% is applied (Grover and Veeraragavan 2010). The cost associated with each treatment at different time periods during the design life is converted to present worth at discount rate of 10%. Difference in VOC for do-nothing strategy and post treatment strategy is considered as the benefit. VOC (in Lacks) for Do- Nothing Strategy for pavement section with good drainage is given in Table 14. VOC for Do- Nothing Strategy for pavement section with poor drainage has been given in Table 15. Pavement sections for do nothing strategy for good drainage section was found to reach the threshold value of roughness in 2018 that is after six years, and for poor drainage section in 2015 and 2019. Thin overlay will be applied at that time. VOC for both the cases has been calculated considering the future maintenance and is given in the Table 16 & 17. The comparison of present worth of total VOC for both good and poor drainage sections and for both maintenance strategies applied is shown in Figure 8. It can be observed that the VOC value does not vary much in case of Do-nothing strategy for both type of drainage section, but in case of Thin-overlay treatment the total VOC value for poor drainage section is about 19% more than that of good drainage section. This is because the pavement deteriorates faster due to poor drainage and the frequency of maintenance treatment required for poor drainage section is more than good drainage section.

Table 14. Vehicle Operating Cost (In Lacks) for Do- Nothing Strategy for Pavement Section with Good Drainage

Year	VOC (Rs./km/year) (in lacks)					Total VOC	VOC at growth rate of 9% and Inflation factor1.8	Present Worth at discount rate of 10%
	Cars, Jeeps, Vans, Three Wheelers (new technology)	Buses	Light commercial Vehicle	Heavy commer cial Vehicle	Motor Cycles and Scooters			
2012	6.92	17.48	7.13	12.00	2.04	45.57	82.03	82.03
2013	7.76	18.88	7.77	13.15	2.33	49.87	97.85	88.96
2014	8.39	20.39	8.36	14.17	2.52	53.84	115.14	95.15
2015	9.10	22.04	9.02	15.29	2.75	58.20	135.68	101.93
2016	9.92	23.83	9.73	16.54	3.01	63.03	160.16	109.39
2017	10.87	25.78	10.52	17.93	3.32	68.42	189.50	117.67
2018	12.00	27.90	11.40	19.50	3.71	74.51	224.94	126.97
2019	13.40	30.21	12.40	21.31	4.20	81.52	268.25	137.65
2020	15.20	32.73	13.55	23.45	4.87	89.80	322.06	150.24
2021	17.64	35.48	14.91	26.07	5.82	99.93	390.67	165.68
2022	21.20	38.48	16.59	29.43	7.31	113.01	481.56	185.66
						Total	**2467.84**	**1361.35**

Table 15. Vehicle Operating Cost (in Lacks) for Do- Nothing Strategy for Pavement Section with Poor Drainage

Year	VOC (Rs./km/year) (in lacks)					Total VOC	VOC at growth rate of 9% and Inflation factor 1.8	Present Worth at discount rate of 5%
	Cars, Jeeps, Vans, Three Wheelers (new technology)	Buses	Light commercial Vehicle	Heavy commerci al Vehicle	Motor Cycles and Scooters			
2012	7.11	17.48	7.19	12.15	2.12	46.05	82.90	82.89
2013	8.06	18.88	7.86	13.36	2.45	50.61	99.29	90.264
2014	8.74	20.39	8.47	14.42	2.67	54.70	116.98	96.67
2015	9.53	22.04	9.14	15.60	2.93	59.25	138.11	103.76
2016	10.46	23.83	9.89	16.92	3.24	64.35	163.49	111.67
2017	11.58	25.78	10.73	18.43	3.63	70.15	194.27	120.62
2018	12.99	27.90	11.68	20.18	4.14	76.89	232.10	131.01
2019	14.84	30.21	12.79	22.28	4.84	84.96	279.56	143.46
2020	17.43	32.73	14.13	24.90	5.89	95.07	340.98	159.07
2021	21.34	35.48	15.80	28.34	7.58	108.55	424.36	179.97
2022	27.85	38.48	18.02	33.16	10.68	128.19	546.27	210.61
						Total	**2618.30**	**1430.01**

Table 16. Vehicle Operating Cost (in Lacks) for Thin Overlay Strategy for Pavement Section with Good Drainage

Year	VOC (Rs./km/year) (in lacks)					Total VOC	VOC at growth rate of 9% and Inflation factor 1.8	Present Worth at discount rate of 10%
	Cars, Jeeps, Vans, Three Wheelers (new technology)	Buses	Light commercial Vehicle	Heavy commercial Vehicle	Motor Cycles and Scooters			
2012	6.92	17.48	7.13	12.00	2.04	45.57	82.03	82.03
2013	7.76	18.88	7.77	13.15	2.33	49.87	97.85	88.96
2014	8.39	20.39	8.36	14.17	2.52	53.84	115.14	95.15
2015	9.10	22.04	9.02	15.29	2.75	58.20	135.68	101.93
2016	9.92	23.83	9.73	16.54	3.01	63.03	160.16	109.39
2017	10.87	25.78	10.52	17.93	3.32	68.42	189.50	117.67
2018	10.68	27.90	11.00	18.53	3.15	71.26	215.12	121.43
2019	12.06	30.21	12.01	20.35	3.63	78.26	257.50	132.14
2020	13.10	32.73	12.95	21.98	3.96	84.71	303.84	141.74
2021	14.29	35.48	13.98	23.78	4.34	91.87	359.15	152.32
2022	15.67	38.48	15.13	25.78	4.80	99.86	425.53	164.06
						Total	**2341.50**	**1306.82**

Table 17. Vehicle Operating Cost (in Lacks) for Thin Overlay Strategy for Pavement Section with Poor Drainage

Year	VOC (Rs./km/year) (in lacks)					Total VOC	VOC at growth rate of 9% and Inflation factor 1.8	Present Worth at discount rate of 10%
	Cars, Jeeps, Vans, Three Wheelers (new technology)	Buses	Light commercial Vehicle	Heavy commercial Vehicle	Motor Cycles and Scooters			
2012	7.11	17.48	7.19	12.15	2.12	46.05	82.90	82.90
2013	8.06	18.88	7.86	13.36	2.45	50.61	99.29	90.26
2014	8.74	20.39	8.47	14.42	2.67	54.70	116.98	96.67
2015	8.67	22.04	8.88	14.97	2.57	57.14	133.20	100.08
2016	9.81	23.83	9.70	16.46	2.96	62.77	159.48	108.93
2017	10.65	25.78	10.46	17.77	3.23	67.89	188.02	116.75
2018	11.61	27.90	11.29	19.22	3.54	73.56	222.07	125.35
2019	11.58	30.21	11.86	20.00	3.43	77.09	253.65	130.16
2020	13.15	32.73	12.97	22.01	3.98	84.84	304.30	141.96
2021	14.33	35.48	14.00	23.81	4.36	91.98	359.59	152.50
2022	15.71	38.48	15.14	25.81	4.82	99.96	425.95	164.22
						Total	**2345.44**	**1309.79**

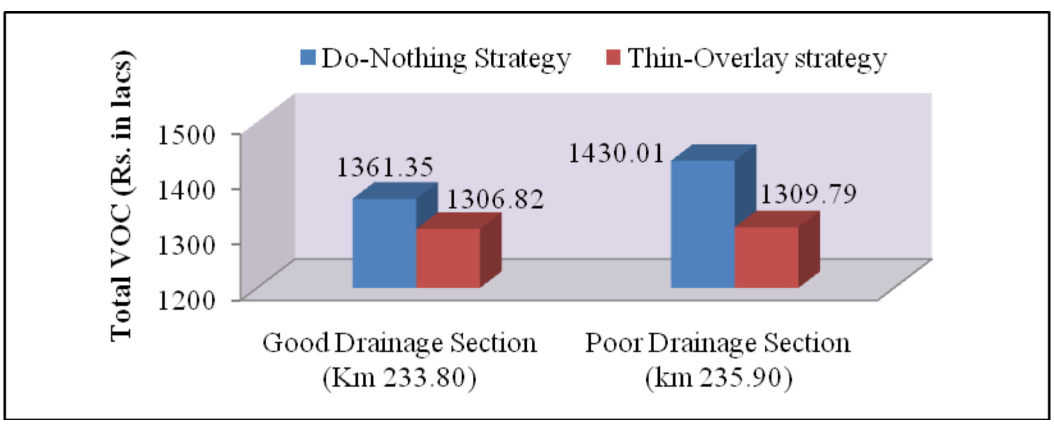


Figure 8: VOC for Good & Poor Drainage Sections

5.6 Quantification of Benefits due to Timely Maintenance by computation of Road User Costs for Pavement Section with Poor and Good Drainage

Agency cost per km of pavement for thin overlay has been calculated and are given in Table 18.

Table 18. Agency Cost for Thin Overlay per km of Pavement

Sr. No.	Year	Discounted Cost at 10% in Lack per two lanes km	Years	Overlay Cost & Discounted Cost at 10% in Lack per two lanes km		
1	2012	17.08	0.00			
2	2013	15.53	1.00			
3	2014	14.12	2.00			
4	2015	12.83	3.00	20.92		
5	2016	11.67	4.00	19.02		
6	2017	10.61	5.00	17.29		
7	2018	9.64	6.00	15.72	25.63	
8	2019	8.76	7.00	14.29	23.30	27.43
9	2020	7.97	8.00	12.99	21.18	24.93
10	2021	7.24	9.00	11.81	19.26	22.67
11	2022	6.59	10.00	10.74	17.51	20.61

The benefit per unit agency cost per km for overlay strategy for pavement section with good and poor drainage is calculated and is given in the Table 19 and 20 respectively.

Table 19. Benefit per Unit Agency Cost per km for Overlay Strategy for Pavement Section with Good Drainage

Sr. No.	Parameters	Rs. (lack)	Remarks
1	Vehicle Operating Costs (VOC) for Do -Nothing strategy	1361.35	----
2	Vehicle Operating Costs (VOC) for overlay strategy	1306.82	----
3	Benefit	54.53	Sl No.1- Sl No. 2
4	Agency cost for thin overlay per km of pavement (as shown in Table 18)	35.27	Cost of construction of 40 mm BC overlay (9.64+25.63)
5	Benefit per unit agency cost per km (during 10 years service life of pavement) due to timely maintenance	1.55	Sl No3/ Sl No 4

Table 20. Benefit per Unit Agency Cost per km for Overlay Strategy for Pavement Section with Poor Drainage

Sr. No.	Parameters	Rs. (lack)	Remarks
1	Vehicle Operating Costs (VOC) for Do -Nothing strategy	1430.01	----
2	Vehicle Operating Costs (VOC) for overlay strategy	1309.79	----
3	Benefit	120.22	Sl No. 1- Sl No. 2
4	Agency cost for thin overlay per km of pavement (as shown in Table 18)	61.18	Cost of construction of 40 mm BC overlay
5	Benefit per unit agency cost per km (during 10 years service life of pavement) due to timely maintenance	1.96	Sl No3/ Sl No 4

Comparisons of benefits of thin overlay between good drainage and poor drainage are given in Table 21.

Table 21. Comparison of Results of Quantification of Benefits Due to Thin Overlay Treatment for Pavement Sections with Good Drainage vs. Poor Drainage

Sr. No.	Quantification of Benefits	Good drainage	Poor drainage
1	Computation of road User Costs Method		
a)	VOC for Do- Nothing Strategy, Rs lack	1361.35	1430.01
b)	VOC for thin overlay Strategy, Rs lack	1306.82	1309.79
c)	Benefit per km, Rs Lack	54.53	120.22
d)	Agency Cost for Thin Overlay treatment per km	35.27	61.18
e)	Benefit per unit agency cost per km in lack	1.55	1.96

6. Conclusions and Recommendations

6.1 Conclusions

Based on the present study following conclusions have been drawn:

1. Primary cause of premature failure of the pavement sections was found to be poor sub-surface drainage due to water entering the pavement surface infiltration through cracks, rising ground water, seepage water through, and water penetrating through shoulders and large percentage of fines in GSB layer preventing the effective drainage of pavement layer.
2. The rate of pavement deterioration was observed faster in case of pavement sections with low values of permeability.
3. The agency cost as calculated for poor drainage section is Rs. 61.18 lacks/km and that of the good drainage surface is Rs. 35.27 lacks/km that indicates that the agency cost of poor drainage section is more than that of the good drainage surface.
4. The pavement section with good drainage requires thin overlay treatment only once in a design period of 10 years where as poor drainage pavement section needs the thin overlays treatments twice during the same design period.
5. It was observed that the VOC for Do- Nothing strategy of poor drainage section was Rs. 1430.01 lacks/km which is higher than that of the Do- Nothing strategy of good drainage section which was Rs. 1361.35lacks/km lacks. There was saving of Rs.68.66 lacks/km.
6. It was observed that the VOC for overlay strategy of poor drainage section was Rs. 1309.79 lacks/km which is higher than that of the overlay strategy of good drainage section which was Rs. 1306.82 lacks/km. In this case there was a saving of 2.97 lacks/km.
7. The hill side deflection of the half width of the pavement is observed more than that of other half of the pavement of same stretch of the poor drainage section.

6.2 Recommendations

1. Proper care should be given to the surface and sub-surface drainage of pavement during construction of the pavement.
2. Pavement deterioration model should be developed including the drainage parameter.
3. Periodic maintenance and inspection of the surface drainage system should be carried out and stretches where water stagnates either in the side drain or on the pavement surface should be identified for immediate corrective measures.

Nomenclature

NH – National Highway
WBM – Water Bound Macadam
GSB – Granular Sub-base
VOC – Vehicle Operating Cost
BBD – Benkelman Beam Deflection
IRC – Indian Roads congress
OMC – Optimum Moisture Content
MDD –Maximum Dry Density
MoRT&H – Ministry of Road Transport & Highways
AADT – Annual Average Daily Traffic
iDEF = initial deflection (mm)
D_t = Corrected characteristic rebound deflection (mm) at any time t
N_t = cumulative standard axles (millions) at t.
UIt = Roughness index at any time t (mm/km)

iUI = Initial roughness index (mm/km)
Age = Age of the pavement (years)
DEF_0 = Deflection in mm

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