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DESIGN AND COST COMPARATIVE STUDY OF A TYPICAL SIX-LANE EXPRESSWAY WITH FLEXIBLE AND RIGID PAVEMENTS OPTIONS.

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Abstract: Effective pavement design is one of the most important aspects of project design. The pavement is the portion of the highway which is most obvious to the motorist. The condition and adequacy of the highway is often judged by the smoothness or roughness of the pavement. Deficient pavement conditions can result in increased user costs and travel delays, braking and fuel consumption, vehicle maintenance repairs and probability of increased crashes. The present study envisages designing a 6-lane highway to cater the fast-moving traffic.

The objectives of the project include the understanding and applying the data collection techniques for the input parameters of the pavement design including design traffic, design period, effective subgrade-CBR, axle load survey and its analysis, Vehicle Damage Factor (VDF) calculations etc. To design the flexible pavement using IRC-37:2018 guidelines, design of rigid pavement using IRC-58:2015 and following IRC: SP 87-2019, the manual of six-laning of highways through PPP model and to design the pavement using mechanistic – empirical approach using IIT-PAVE software and IIT-RIGID tools.

The project corridor shall be divided into various homogeneous sections based on the design traffic. Based on the available resources and in the optimum utilization, we will provide cost effective pavement designs and shall compare the costings of flexible pavement and rigid pavement considering their respective effective design options.

IndexTerms - **Flexible Pavement Design, Rigid Pavement Design, IIT-PAVE, IIT-RIGID.**

I. INTRODUCTION

From the recent past, the road infrastructure in India is growing rapidly in line with the National Highway Development Programme (NHDP). Under this scheme, all the existing national highways with 2-lanes are widening into 4-lane rods & existing 4-lane rods are changing into 6-lanes and there by 8-lanes. Besides the prestigious Golden quadrilateral project, the North-South–East-West Corridor (NS-EW) is the largest ongoing highway project in India.

In combination with India's Golden Quadrilateral, and port connectivity highways, NS-EW Corridor forms a key part of Indian highway network connecting many of its important manufacturing, commerce and cultural centers. As of November 2023, India has completed and placed in use some 46,179 kilometers of such 6-lane highways.

Above such infrastructure projects are building under BOT (Built, Operate, Transfer), DBFOT (Design, Build, Finance, Operate, Transfer) and this brought the concessionaires to build the roads at cost effective way which made the pavement design even more significant in this new era of construction. Under this project, such an attempt is made to design the flexible pavement at a cost economical way by using IIT-PAVE software.

This journal article compares costs of flexible and rigid pavements, common road surfaces. We'll analyze factors like initial cost to aid engineers and planners in selecting the most cost-effective pavement for projects.

II. CASE STUDY & METHODOLOGY

The primary goal of this project is to analyze the flexible pavement design and rigid pavement design, for the cost comparing purposes of the most effective & long lasting 6-lane expressway along with the mix design of Bituminous concrete. For the case study (Pune to Satara) purposes flexible pavement and rigid pavement design scenario, design parameters like traffic data and axle load survey data were collected from the agencies for educational purposes. The methodology is presented in below figure.

FIGURE 2-1: METHODOLOGY OF THE PROJECT

III. MARSHALL MIX DESIGN OF FLEXIBLE PAVEMENT

The Marshall Mix Design procedure is a standard laboratory method used for determining and reporting the strength and flow of bituminous mixtures. It is a widely adopted method for the design of flexible pavements, including low to medium volume roads, high volume interstate highways, and airfield runways, taxiways, and aprons subjected to heavy aircraft gear/wheel loads. The Marshall Mix Design procedure involves several steps:

1.Selection of aggregate: The aggregate used in the mixture should be well-graded, clean, and durable. The gradation of the aggregate should be within the limits specified by the design criteria.
2.Selection of bitumen: The bitumen used in the mixture should be of the correct type and grade, as specified by the design criteria.
3.Mixing: The aggregate and bitumen are mixed together in a specified proportion to form a homogeneous mixture.
4.Compaction: The mixture is compacted in a Marshall compactor to a specified height and diameter.
5.Testing: The compacted specimen is tested in a Marshall stability tester to determine its strength and flow characteristics.
6.Adjustment: The mixture is adjusted based on the test results to achieve the desired strength and flow characteristics.
7.Verification: The final mixture is verified through further testing to ensure that it meets the design criteria.

The Marshall Mix Design procedure determines the optimal bitumen content (OBC) for a mixture by testing specimens with varying bitumen amounts. It also assesses the impact of fibers on strength and durability, calculating the optimum fiber content (OFC) based on test results. Widely used in asphalt industry, it's simple and effective for designing flexible pavements, though it has limitations like standard compaction efforts not always reflecting field conditions. Factors such as subgrade properties and expected traffic loads should also be considered in pavement design.

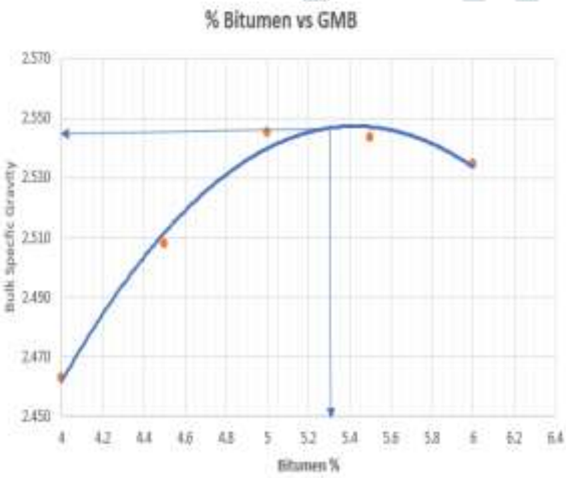
S. No	Binder Content (Pb) %	Wt. in Air (gm) (A)	Wt. in Water (gm) (B)	SSD Wt. (gm) (C)	Bulk Volume (cc) (D=B-C)	Bulk Sp. gravity of Specimen (Gmb) (E=A/D)	Theoretical Max. Sp. gravity of Specimen (Gmm)	% Air Voids (Pa)	VMA %	VFB %	Proving Ring Reading	Corrected Marshall Stability (KN)	Flow (mm)
MARSHAL MOULD CASTING WITH BITUMEN CONTENT – 4.00%													
1	4.00	1238.5	735.5	1240	504.5	2.455	2.709	9.4	16.8	44.1	235.0	15.9	1.8
2	4.00	1237	737	1238	501	2.469		8.9	16.3	45.7	225.0	15.2	2.0
3	4.00	1243	739.5	1244	504.5	2.464		9.1	16.5	45.1	245.0	16.5	1.9
Average Values						**2.463**		**9.1**	**16.5**	**45.0**	**235.0**	**15.9**	**1.9**
MARSHAL MOULD CASTING WITH BITUMEN CONTENT – 4.50%													
1	4.50	1249.5	751	1250	499	2.504	2.686	6.8	15.6	56.5	265.0	17.9	2.2
2	4.50	1252.5	754	1252.5	498.5	2.513		6.5	15.3	57.7	270.0	18.2	2.1
3	4.50	1250	751.5	1250	498.5	2.508		6.6	15.4	57.0	280.0	18.9	2.1
Average Values						**2.508**		**6.6**	**15.4**	**57.0**	**271.7**	**18.3**	**2.1**
MARSHAL MOULD CASTING WITH BITUMEN CONTENT – 5.00%													
1	5.00	1259.5	765	1259.5	494.5	2.547	2.664	4.4	14.6	69.8	305.0	21.6	2.3
2	5.00	1257.5	764	1258	494	2.546		4.4	14.6	69.6	285.0	20.2	2.5
3	5.00	1256.5	763	1257	494	2.544		4.5	14.7	69.2	290.0	20.5	2.4
Average Values						**2.545**		**4.5**	**14.6**	**69.5**	**293.3**	**20.8**	**2.4**
MARSHAL MOULD CASTING WITH BITUMEN CONTENT – 5.50%													
1	5.50	1265	769.5	1265.5	496	2.550	2.643	3.5	14.9	76.5	295.0	19.9	2.6
2	5.50	1268.5	769.5	1269	499.5	2.540		3.9	15.3	74.3	275.0	18.6	2.7
3	5.50	1264	767	1264.5	497.5	2.541		3.9	15.2	74.6	280.0	18.9	2.6
Average Values						**2.544**		**3.8**	**15.1**	**75.1**	**283.3**	**19.1**	**2.6**
MARSHAL MOULD CASTING WITH BITUMEN CONTENT – 6.00%													
1	6.00	1268.5	768.5	1268.5	500	2.537	2.621	3.2	15.8	79.7	235.0	15.9	3.2
2	6.00	1266	767	1266.5	499.5	2.535		3.3	15.9	79.2	255.0	17.2	2.9
3	6.00	1263.5	765	1264	499	2.532		3.4	16.0	78.7	235.0	15.9	2.9
Average Values						**2.535**		**3.3**	**15.9**	**79.2**	**241.7**	**16.3**	**3.0**
Specifications as per MoRTH 5th revision, Table 500-11								**3-5**	**Min 12**	**65-75**		**Min 12**	**2-4**

TABLE 3-1: SUMMARY OF MARSHALL TRAIL MIXES

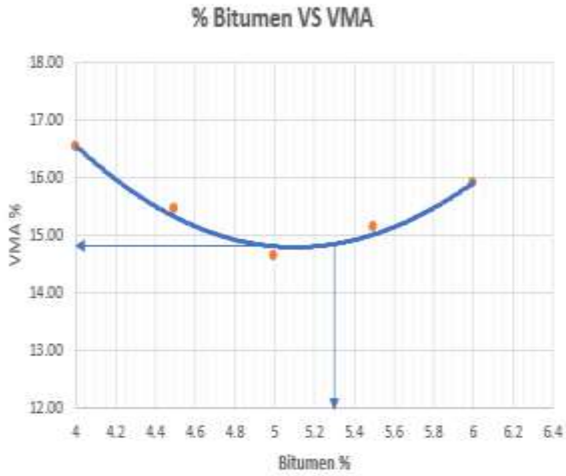
Binder Content %	Bulk Specific gravity	% Air Voids	%VMA	%VFB	Stability (KN)	Flow (mm)
4.00	2.463	9.1	16.5	45.0	15.9	1.9
4.50	2.508	6.6	15.4	57.0	18.3	2.1
5.00	2.545	4.5	14.6	69.5	20.8	2.4
5.50	2.544	3.8	15.1	75.1	19.1	2.6
6.00	2.535	3.3	15.9	79.2	16.3	3.0

TABLE 3-2: TEST RESULTS OF MARSHALL TRAIL MIXES

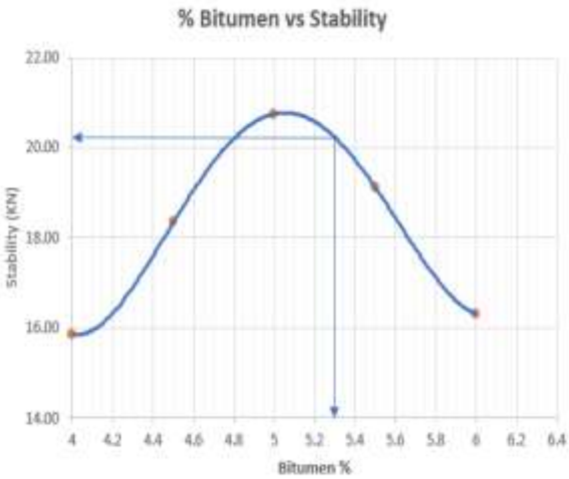
MARSHALL GRAPHS



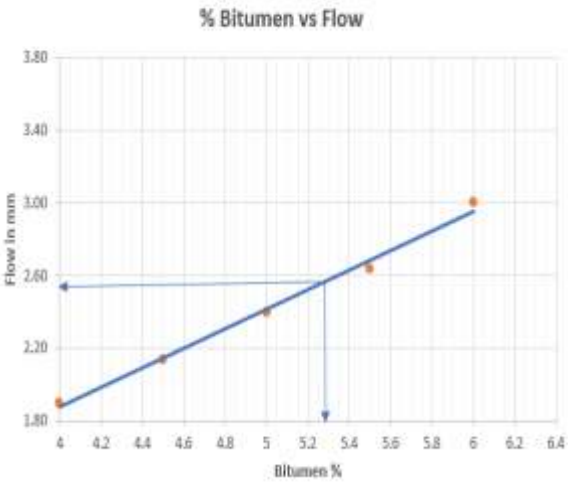
Graph: 1



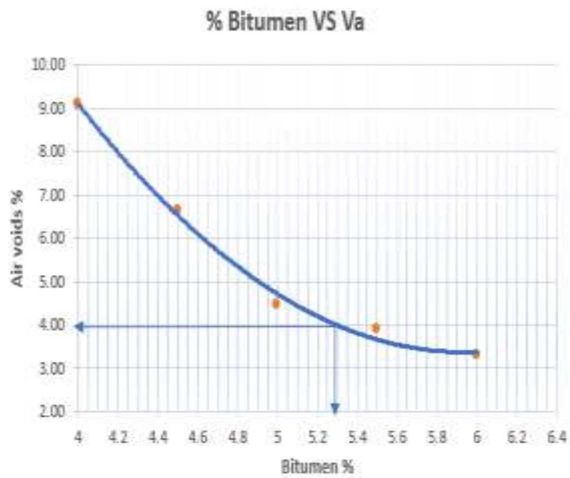
Graph: 2



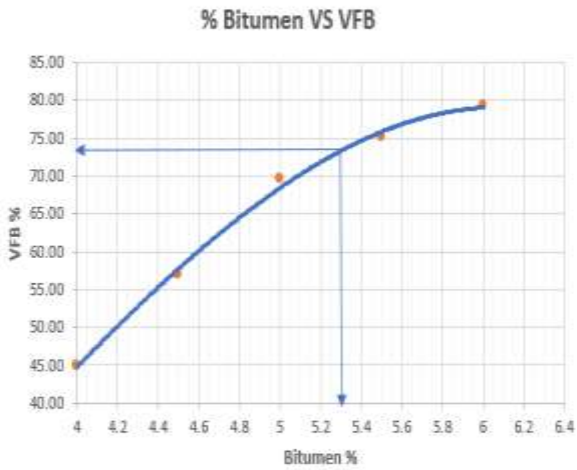
Graph: 3



Graph: 4



Graph: 5



Graph: 6

Based on the above graphs, ref to Clause. 5.1 of MS-2, Asphalt Institution it's recommended to choose the binder content at the median of the percent air voids limits, which is 4%. Hence, 4% air voids is achieved at a binder content of 5.3% (OBC). Casted the Moulds at 5.3% binder the results were shows in below table.

S. No	Binder Content (Pb) %	Wt. in Air (gm) (A)	Wt. in Water (gm) (B)	SSD Wt. (gm) (C)	Bulk Volume (cc) (D=B-C)	Bulk Sp. gravity of Specimen (Gmb) (E=A/D)	Theoretical Max. Sp. gravity of Specimen (Gmm)	% Air Voids (Pa)	VMA %	VFB %	Proving Ring Reading	Corrected Marshall Stability (KN)	Flow (mm)
1	5.30	1257	762.5	1258	495.5	2.537	2.65	4.3	15.2	71.8	325.00	21.9	2.5
2	5.30	1254.5	761	1255.5	494.5	2.537		4.3	15.2	71.9	350.00	24.8	2.8
3	5.30	1257.5	763	1258	495	2.540		4.1	15.1	72.5	330.00	23.3	2.7
						2.538		**4.2**	**15.1**	**72.1**	**335.0**	**23.3**	**2.7**
1	5.30	1258.5	764	1259.5	495.5	2.540	2.65	4.2	15.1	72.4	340.0	22.9	3.3
2	5.30	1263	765.5	1263.5	498	2.536		4.3	15.2	71.7	345.0	23.3	2.9
3	5.30	1260.5	764	1261	497	2.536		4.3	15.2	71.7	360.0	24.3	3.1
						2.537		**4.2**	**15.2**	**72.0**	**348.3**	**23.5**	**3.1**
Specifications as per MoRTH 5th revision, Table 500-11								**3-5**	**Min 12**	**65-75**		**Min 12**	**2-4**

TABLE 3-3: TEST RESULTS OF OBC TRAIL MIXES

IV. FLEXIBLE PAVEMENT

Flexible pavements are common for low to medium volume roads and high-volume interstate highways, airfield runways, taxiways, and aprons. As wheel loads increase, understanding subgrade and aggregate behavior becomes crucial. Stresses transmit through granular layers, distributing loads over a wider area, decreasing stress with depth. Flexible pavement design utilizes layered systems to exploit stress distribution. Rutting from heavy traffic and environmental conditions is a common issue. These pavements lack flexural strength and flex under loads.

DESIGN OPTIONS AND THEIR CRITICAL LOCATIONS

Design Option I: Conventional Design as per IRC: 37-2018, shows that the fatigue in the bottom of the bituminous layer and rutting in the top of the subgrade are the chances for the pavement failures for the conventional design.

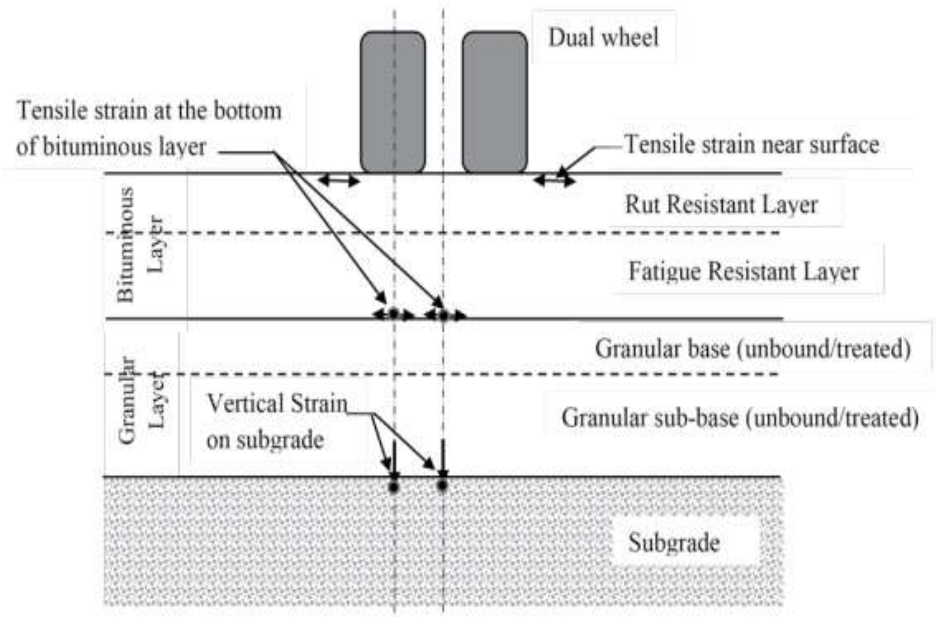


FIGURE 4-1: Pavement section with Bituminous Layer(s), Granular Sub-base & Base Layers, Subgrade Layer showing the locations of Critical strains

Design Option II: Modified Design as per IRC: 37-2018, shows fatigue in the bottom of the bituminous layer, fatigue in the bottom of the CTB layer and rutting in the top of the subgrade are the chances of the failures for the modified design.

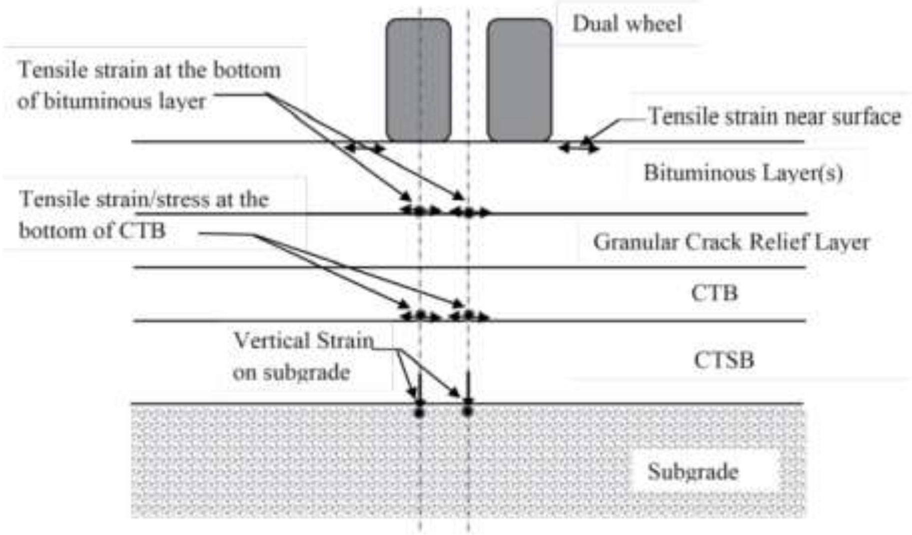


FIGURE 4-2: Pavement section with Bituminous Layer(s), Granular Crack Relief Layers, CTB and CTSB showing the locations of Critical Strains/Stresses

Section	From (Km)	To (Km)	Direction	CONVENTIONAL FLEXIBLE PAVEMENT ESTIMATED THICKNESS				
				LAYERS				
				BC	DBM	WMM	GSB	SUBGRADE
HS-1	725+000	785+000	Pune to Satara (LHS)	50	115	250	200	500
			Satara to Pune (RHS)	50	110	250	200	500
HS-2	785+000	865+300	Pune to Satara (LHS)	50	120	250	200	500
			Satara to Pune (RHS)	50	110	250	200	500

TABLE 4-1: ESTIMATED THICKNESS OF CONVENTIONAL DESIGN

Section	From (Km)	To (Km)	Direction	CTB& CTSB FLEXIBLE PAVEMENT ESTIMATED THICKNESS					
				LAYERS					
				BC	DBM	AIL	CTB	CTSB	SUBGRADE
HS-1	725+000	785+000	Pune to Satara (LHS)	40	60	100	140	200	500
			Satara to Pune (RHS)	40	60	100	130	200	500
HS-2	785+000	865+300	Pune to Satara (LHS)	40	60	100	100	200	500
			Satara to Pune (RHS)	40	60	100	110	200	500

TABLE 4-2: ESTIMATED THICKNESS OF CTB&CTSB LAYERS DESIGN

V. DESIGN OF RIGID PAVEMENT

Rigid pavement is a type of concrete pavement that is designed to provide durability, has a long lifespan, and has the ability to withstand heavy loads. It is commonly used for high-traffic roads, airports, and industrial areas, where the pavement needs to be able to handle a lot of wear and tear. The pavement structure deflects minimally under loading because of the high modulus of elasticity of its surface course. The rigid pavement consists of the various layers as shown in the figure.

Rigid Pavements: - Rigid pavements are composed of a cement concrete surface course and concealed base and sub base courses. The surface course is the rigid layer and provides the majority of strength. Rigid pavements have high flexural strength than flexible pavements due to which they can transmit the wheel load stresses over a wider area. Initial cost of these pavements is high as compared to flexible pavements but their maintenance cost is low. These pavements have a service life of 30 years and more.

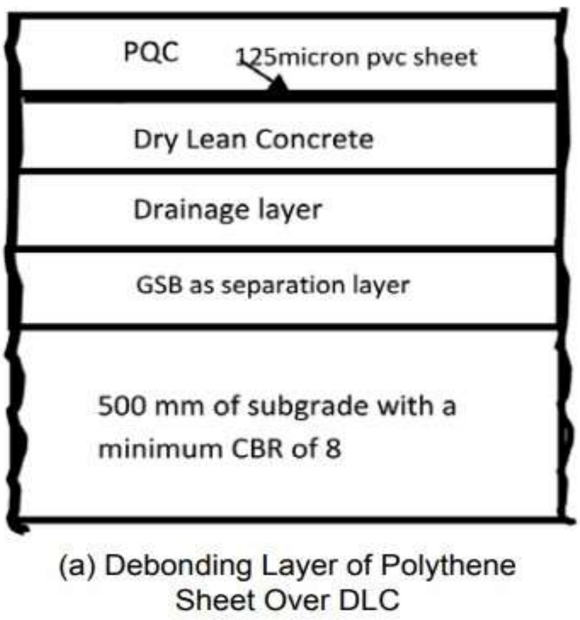


FIGURE 5-1: RIGID PAVEMENT LAYERS

SECTIONS	HS-1	HS-2
Layer Type	Thickness (mm)	
Pavement Quality Concrete (PQC) M 45 Grade	260+10	260+10
Dry Lean Concrete (DLC) M 10 Grade	150	150
Granular Sub-Base (GSB)	150	150
Subgrade CBR's (8% and 10%)	500	500

* PQC of 10mm additional thickness as per IRC: 58-2015 for inducing rough surface. (grinding)

TABLE 5-1: ESTIMATED THICKNESS OF RIGID PAVEMENT

Description	HS-1		HS-2	
	Dowel Bars	Tie Bars	Dowel Bars	Tie Bars
Bar Dia (mm)	32	12	30	12
Length (mm)	450	640	450	640
C/C Spacing (mm)	300	650	300	610
Dowel Bars: Mild Steel Bars & Tie Bars: Deformed Bars				

TABLE 5-2: RECOMMENDED JOINTS

VI. RESULT & CONCLUSIONS

COST COMPARISON

The initial cost of the rigid pavement is more compare to the flexible pavement and maintenance cost over the entire period in rigid pavement is less compare to the flexible pavement. While comparing the cost between conventional flexible pavement and modified layer it's observed that, pavement with modified layers is relatively less due to provision of less BC thickness.

Section	From (Km)	To (Km)	Direction	COST COMPARISION (IN CRORES RUPEES)		
				FLEXIBLE CONVENTIONAL	FLEXIBLE CTB&CTSB	RIGID
HS-1	725+000	785+000	Pune to Satara (LHS)	6.81	6.09	8.19
			Satara to Pune (RHS)	6.81	6.01	
HS-2	785+000	865+300	Pune to Satara (LHS)	6.89	5.78	8.19
			Satara to Pune (RHS)	6.81	5.75	

TABLE 5-3: COST COMPARISION OF THE FLEXIBLE & RIGID PAVEMENTS

Following conclusions are drawn from the project study of "Design and Cost Comparative Study of a Typical Six-Lane Expressway with Flexible and Rigid Pavements Options". The project is majorly divided into 4 sections viz., mix design of flexible pavement, pavement design of flexible pavement, design of rigid pavement and cost comparison. The conclusions from each section are briefed as below.

CONCLUSIONS

MARSHAL MIX DESIGN

- Bituminous concrete -II mix design was carried out as per the MS-2.
- Based on the aggregate gradation the blending proportions of the mix is taken as 31%: 20%:49%. (14mm down,7mm down and dust).
- The 4% air voids are achieved at 5.3% binder content; hence 5.3% binder content is adopted as OBC.
- At 5.3% binder content the average stability, VMA, VFB & Flow achieves as 23.3KN, 15.1%, 72.1% and 2.9mm respectively.

FLEXIBLE PAVEMENT DESIGN

- Pavement design is carried out as per IRC:37-2018.
- As specified in IRC: SP:87-2019, a minimum growth rates of 5% considered for design purposes.
- IRC 37:2018 is used for determining the pavement composition from the given design catalogue. This pavement designs are considered as flexible pavement with conventional and CTB & CTSB layers. However, the design catalogue is made for VG30 grade bitumen with elastic modulus 3000 MPa.
- IIT-Pave software is used to design the pavement for subgrade CBR's 8% and 10%, with Elastic moduli value of bitumen is considered as 3000MPa.
- For, same design traffic, while comparing the crust thickness of modified design with conventional design there was 50mm to 60mm bitumen layer thickness is reduced.

RIGID PAVEMENT DESIGN

- Referring to the relevant standards and specifications, the design for a typical rigid pavement for 6-lane national highway project.
- Axle load spectrum analysis is carried out with the collected axle load survey data for the needful rigid pavement design.
- With the obtained traffic axle load spectrum and selected pavement materials the Rigid pavement thickness is designed.
- There after the joints (dowel bars and tie bars) are design for the construction of rigid pavement in the section-1 and section-2 the details are;

For section 1:

- Mild steel dowel bar of 32 mm diameter and 450 mm length has to be placed at 300 mm spacing. The first dowel has to be placed at 150 mm from the pavement edge.
- Deformed tie bar of 12 mm diameter and 640 mm length has to be placed at 650mm spacing.

For section-2:

- Mild steel dowel bar of 32 mm diameter and 450 mm length has to be placed at 300 mm spacing. The first dowel has to be placed at 150 mm from the pavement edge.
- Deformed tie bar of 12 mm diameter and 640 mm length has to be placed at 650mm spacing.

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