FINANCIAL ANALYSIS OF RIGID AND FLEXIBLE PAVEMENT
MUMBAI-PUNE EXPRESSWAY

CE6030

CONSTRUCTION ECONOMICS AND FINANCE

Group – 5

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Index

Abstract

The Mumbai-Pune Expressway stands as a testament to modern infrastructure, connecting two major cities in India. Within the realm of transportation engineering, the choice between rigid and flexible pavements holds significant weight in terms of durability, maintenance costs, and overall financial implications. This abstract delves into the financial analysis of rigid and flexible pavements specifically concerning the Mumbai-Pune Expressway.

Flexible pavements, characterized by their layered structure of bitumen and aggregates, present a compelling option for highway construction. The inherent flexibility of these pavements allows for gradual strengthening and improvements as traffic volumes increase, aligning seamlessly with the evolving needs of the Mumbai-Pune Expressway. Additionally, the surfaces of flexible pavements can be milled and recycled, offering a sustainable approach to rehabilitation. From a financial perspective, the initial investment and maintenance costs associated with flexible pavements are comparatively lower than their rigid counterparts. This cost-effectiveness makes flexible pavements an attractive choice for large-scale projects like the Mumbai-Pune Expressway, where budget considerations play a crucial role.

On the other hand, rigid pavements, predominantly constructed using cement concrete, boast durability and an extended design period. Despite being more expensive upfront, rigid pavements require less maintenance over their lifespan. This attribute translates to long-term cost savings and a reduced need for frequent repairs or rehabilitation efforts. The Mumbai-Pune Expressway, as a critical transportation artery, benefits from the robustness of rigid pavements, ensuring smooth traffic flow and minimal disruptions.

The financial analysis of rigid and flexible pavements on the Mumbai-Pune Expressway underscores the importance of striking a balance between initial investment and long-term sustainability. While flexible pavements offer cost-effective solutions and adaptability to changing traffic patterns, rigid pavements provide durability and longevity, albeit at a higher initial cost. The decision-making process must weigh these factors carefully to optimize the financial performance and operational efficiency of the expressway.

The financial analysis presented in this abstract shed light on the intricate considerations involved in selecting pavement types for high-traffic corridors like the Mumbai-Pune Expressway. By evaluating the upfront costs, maintenance requirements, and lifespan of rigid and flexible pavements, stakeholders can make informed decisions that prioritize both financial prudence and infrastructure resilience.

Introduction

The economic part is carried out for the design pavement of a section by using the result obtain by design method and their corresponding component layer thickness. Concrete pavement a large number of advantages such as long life span negligible maintenance, user and environment friendly and lower cost. Keeping in this view the whole life cycle cost analysis for the black topping and white topping have been done. A highway pavement is a structure consisting of superimposed layers of processed materials above the natural soil sub-grade, whose primary function is to distribute the applied vehicle loads to the sub-grade. The pavement structure should be able to provide a surface of acceptable riding quality, adequate skid resistance, favourable light reflecting characteristics, and low noise pollution. The ultimate aim is to ensure that the transmitted stresses due to wheel load are sufficiently reduced, so that they will not exceed bearing capacity of the sub- grade. Two types of pavements are generally recognized as serving this purpose, namely flexible pavements and rigid pavements.

While doing the financial analysis, we are going to follow the steps mentioned below in the same order:

(i) Data collection
(ii) Design of Flexible Pavement
(iii) Design of Rigid Pavement
The purpose of designing the pavements is to determine the thickness of each layer, the quantity of material to be used, the quantity of excavation to be done, etc.
(iv) Cost estimation of:
  (a) Initial Cost using rate schedule
  (b) Operation and Maintenance Cost
(v) Preparation of Cash flow
  (a) Cost: Initial cost, Annual operating and maintenance cost, recurring cost
  (b) Revenue: Toll tax
(vi) Financial analysis
  (a) PW/AW
  (b) IROR
  (c) Payback period
(vii) Economic Analysis
  (a) B/C ratio
  (b) Social factors?
  (c) Environmental factors - CO_2 emission
(viii) Risk Analysis
  (a) Monte carlo simulation
  (b) Break Even analysis
(ix) Conclusion

Data Collection

- **Traffic data**

An accurate estimate of the traffic that is likely to use the project road is very important as it forms the basic input in planning, design, operation and financing. A thorough knowledge of the travel characteristics of the traffic likely to use the project road as well as other major roads in the influence area of the study corridor is, therefore, essential for future traffic estimation. To get the data of present traffic condition detailed survey needs to carried out, which is not possible. So traffic data is sourced from Daily traffic count from Khalapur toll plaza. The reason of choosing this toll plaza is being one of the busiest toll plazas on Mumbai-Pune expressway.

Traffic data	
Period	Feb, 2016
Toll Plaza	Khalapur
Direction	Mumbai to Pune
Remarks	Axle load survey for 10 days on Khalapur toll plaza
Source	Annexture 8 - Daily Tollable Toll Collection Traffic Count and Revenue Entry Details
Reference	https://msrdc.in/Site/Upload/GR/Khalapur%20YCEW%20Feb%202016.pdf

Date	Car	Bus	Truck	LCV	MAV	3 Axle
2/1/2016	7461	784	602	1362	435	385
2/4/2016	7683	726	639	1493	480	494
2/7/2016	10262	838	342	1027	399	275
2/10/2016	8160	770	617	1469	445	511
2/13/2016	11548	902	679	1577	473	520
2/16/2016	7580	758	649	1406	450	477
2/19/2016	10122	834	526	1428	422	414
2/22/2016	10011	1036	1042	2023	584	597
2/25/2016	7793	759	652	1467	465	479
2/28/2016	9911	884	382	1098	396	309
Average Traffic	9053	829	613	1435	455	446
% composition	70.6%	6.5%	4.8%	11.2%	3.5%	3.5%

- **Temperature**

The weather in Pune is typically tropical with average temperatures ranging between 20°C and 28°C degrees around the year. Pune will never cease to amaze you. For design consideration we can assume temperature to be 25°C.

- **Design Traffic**

Since traffic running on the pavement is of different vehicle, so we need to standardize it in order to design, for that we estimate the commercial vehicles per day (CVPD) in terms of million standard axles (MSA)

Computation of design Traffic in terms of cumulative number of standard axles to be carried by the pavement during design life. To calculate number of commercial vehicles per day (CVPD) in design life of 20 years, following formula has be used.

$$N = \frac{365 * A\,[(1+r)^n - 1] * VDF * LDF}{r}$$

Where;

N = The cumulative number of standard axles to be catered for in design in terms of million standard axles (MSA)

A = Initial traffic in the year of completion of construction duly modified as shown below.

LDF = Lane distribution factor

VDF = Vehicle damage factor

n = Design life in years

r = Annual growth rate of commercial vehicles {this can be taken as 7.5% if no data is available}

- **Calculation of VDF**

In order to do the design of flexible pavement, we need to estimate VDF (vehicle damage factor). We need to make following assumption regarding the Axle type of each vehicle.

Assumptions:

- Front axle is single axle with single wheel,
- Rear axle
    - for car is single axle with single wheel,
    - for bus is single axle with dual wheel,
    - for truck is tandem axle,
    - for LCV is single axle with single wheel,
    - for MAV is tridem axle,
    - for 3 Axle is tandem axle.

	Car		Bus		Truck		LCV		MAV		3 Axle	
Average weight (in kg)	1700		10000		18500		5000		45500		28000	
Axle type	Front axle	Rear axle	Front axle	Rear axle	Front axle	Rear axle	Front axle	Rear axle	Front axle	Rear axle	Front axle	Rear axle
Axle load distribution	850.00	850.00	3333.33	6666.67	3700.00	14800.00	2500.00	2500.00	18200.00	27300.00	7000.00	21000.00
VDF	0.00029	0.00029	0.06916	0.48225	0.10499	1.00000	0.02188	0.02188	61.46560	2.20627	1.34505	4.05350
Total VDF	0.00058		0.55141		1.10499		0.04377		63.67187		5.39855	
Count	9053		829		613		1435		455		446	
Weighted Average VDF	2.54											

Design of Flexible pavement

Design parameters:

VDF = 2.54 (as calculated earlier)

LDF = 60% (For three lane in each direction)

n (Design life) = 20 years
r (rate of traffic growth annually) = 7.5% (As per IRC-37-2001)
Effective CBR = 9 (assumed)
CVPD in one direction (A_0) = 3778 (sum of average daily traffic excluding car, since it is not considered as commercial vehicle)
m (Construction period) = 2 years
Mix design parameters of bituminous layer:
Air voids (V_a) = 3%
Effective bitumen content (V_{be})= 11.5%

Design process:

Step 1 -> Calculate the no of CVPD in the year of completion of construction

A = A_0*(1+r)^m

A = 3778 * (1+0.075)^2 = 4366

Calculate the no. of CVPD in the design life of 20 yearr

$$N = \frac{365 * A\,[(1+r)^n - 1] * VDF * LDF}{r}$$

N = (365 * 4366 * [(1+0.075)^20 – 1] * 2.54 * 0.60/0.075)*10^{-6}

N = 105.12 MSA

Step 2 -> Choose the layer combinations (from IRC:37 catalogues)

Layer	Thickness (in mm)
BC (Surface Layer)	40
Binder coarse	120
Base (WMM)	250
GSB	200
Subgrade	500

The reason for selecting higher binder thickness is higher traffic 50 MSA)

Step 3 -> Drawing system boundaries

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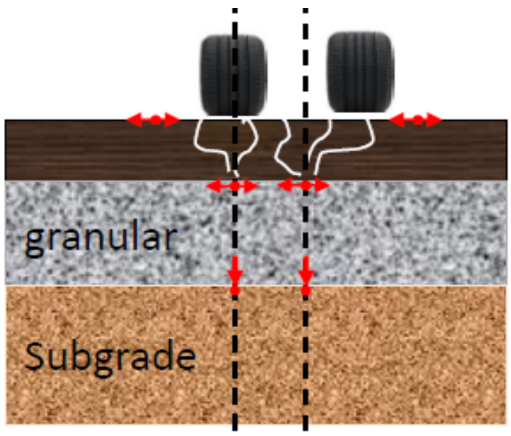


Layer	Thickness (in mm)
Bituminous layer	160
Granular layer	450
Subgrade layer	500

	M_R (in Mpa)	Poisson's ratio
Subgrade	71.82	0.35
Granular Layers	224.49	0.35
Bituminous Layers	2200.00	0.35

Step 5 -> Calculate the Allowable strain values

Calculate the Allowable vertical compressive strain values at top of subgrade for RUTTING Failure

For Expressway/NH/SH (>20 MSA) (for 90 % reliability)

$$N = 1.41 \times 10^{-8} \times \left(\frac{1}{\varepsilon_v}\right)^{4.5337}$$

This formula is used to calculate the ε_v (allowable vertical compressice strain

ε_v = (1.41 * 10^{-8} / 105.12)^(1/4.5337) = 3.155 * 10^{-4}

Calculate the allowable horizontal tensile strain values at bottom of bituminous layer for FATIGUE Failure

For Expressway/NH/SH/urban roads (for 90 % reliability)

$$N = 0.5161 \times C \times 10^{-4} \times \left(\frac{1}{\varepsilon_t}\right)^{3.89} \times \left(\frac{1}{M_R}\right)^{0.854}$$

$$C = 10^M \qquad M = 4.84\left[\frac{V_{be}}{V_a + V_{be}} - 0.69\right]$$

Air voids (V_a) = 3%

Effective bitumen content (V_{be})= 11.5%

From V_a and V_{be}; M is calculated as 0.499

; C = 10^M = 3.155

; ε_t = 1.699 * 10^{-4}

These strain values are compared with the actual strain values obtained using IITPave software.

So, allowable strains are:

- Horizontal = 1.699 * 10^{-4}
- Vertical = 3.155 * 10^{-4}

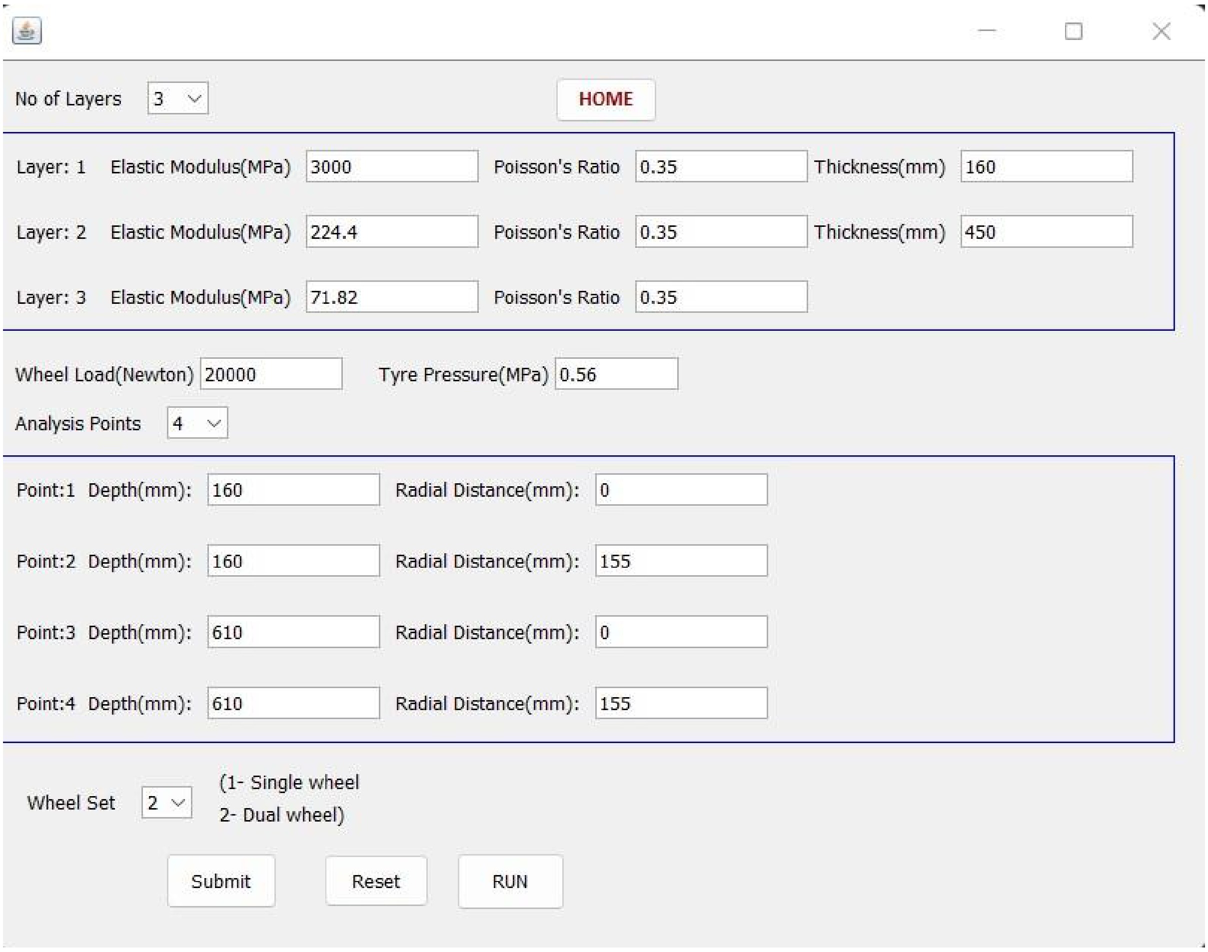
Step 6 -> Calculate the Actual strain values using IITPAVE Software

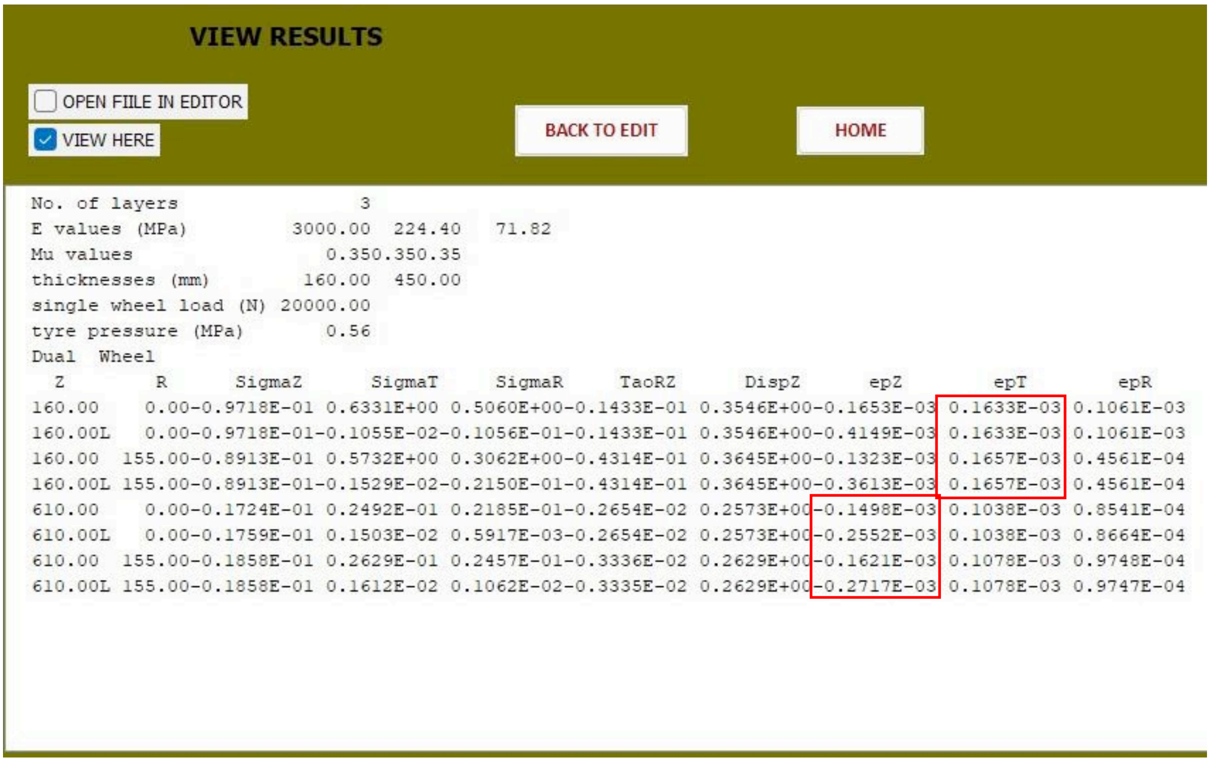
Results:

	Actual strain	Allowable strain	Remarks
Vertical strains	2.710E-04	3.155E-04	Pass
Horizontal strains	1.657E-04	1.699E-04	Pass

So, thickness assumed for each layer is safe for design.

See next page for IITPave results





Results from IITPave software

Design of Rigid pavement

Design parameters:

VDF = 2.54 (as calculated earlier)

LDF = 60% (For three lane in each direction)

n (Design life) = 30 years

r (rate of traffic growth annually) = 7.5% (As per IRC-37-2001)

Effective CBR = 9.0% (assumed)

CVPD in one direction (A_0) = 3778 (sum of average daily traffic excluding car, since it is not considered as commercial vehicle)

m (Construction period) = 2 years

Tyre Pressure (in MPa) = 0.8

E (in MPa) = 30000

Unit Weight (in KN) = 24 kN

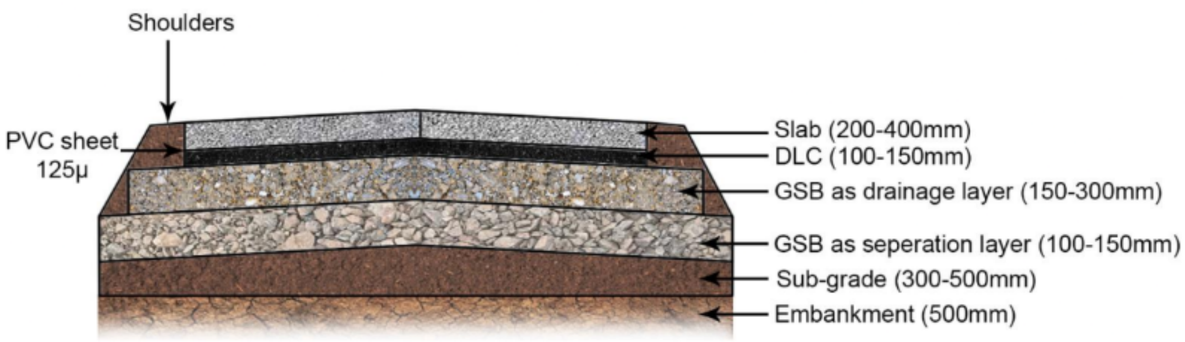
Poisson's Ratio = 0.35

Flexural Strength (@ 90days) = 4.95 MPa

Positive Temperature Diff. = 21°C

Negative Temperature Diff. = 15.5°C

Cross section of rigid pavement:



Cross section of typical Rigid pavement

Design Process:

According to the IRC 53 provision and the Software for calculating Thickness {sheet added in excel}

Axle Category	Proportion	Axle repetitions for BUC	Axle repetitions for TDC
Front Single	0.4	8073946	6661006
Rear Single	0.25	5046216	4163129
Tandem	0.2	4036973	3330503
Tridem	0.15	3027730	2497877
Total	1	20184866	16652514

First, we have number of axles at the end of life = Commercial Vehicle at end of Design Life (in Predominant Direction) * Average number of axles

Then considering the critical vehicles which is on the edge

Then calculating the number of vehicles in bottom-up cracking and top-down cracking by multiplying above number with the traffic in day/night

Then according to the above table dividing the number of axles for each type

Then check for each type of axle and finding their CFD

If the sum of all the CFD is less than 1 than the given thickness is OK or else we have to increase the thickness

Results:

Dowel Bar:

Diameter: 32mm

Length: 600mm

Spacing: 300mm

Thickness of DLC: 150mm

Slab Thickness: 310mm

Cost estimation

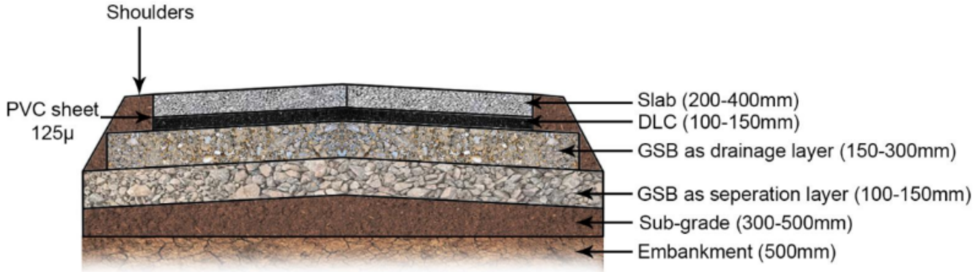
Under this head, we have estimated the cost of the following:

(i) Site Preparation
(ii) Excavation
(iii) Construction
(iv) Maintenance

The length of the rigid pavement has been estimated to be **94.5 km** and the width of the same has been estimated to be **31.5 m**.

1. Cost estimation for rigid pavement:

1.1. *Design of rigid pavement layers*



Cross section of typical Rigid pavement

Pavement quality concrete = 310mm

Polyvinyl chloride (PVC) sheet = 0.125mm

Dry lean concrete (DLC) = 150mm

Granular sub base as drainage layer = 250mm

Granular sub base as separation layer = 150mm

Subgrade = 500mm

Total depth of the of the pavement ***= 1360.125mm***

1.2. Steel bars

Providing dowel bars of length **1800mm** and diameter of **32mm.**

1.3. Site preparation cost

SSR Item No.	Description	Unit	Quantity	Rate	Total Cost
2.01	Cutting down trees including trunks and branches with girths above 30cm to 60cm and stacking the materials neatly with all lifts and lead of 1000m as directed and earth filling in the depression / pit if any.	Number	7088	462	3274656
2.07	Clearing grass and removal of rubbish up to a distance of 50 metres outside the periphery of the area .	Square metre	2976750	4	11907000

Total cost incurred for site preparation is = 3274656 + 11907000

= **15,181,656**

1.4. Excavation cost:

SSR Item No.	Description	Unit	Quantity	Rate	Total Cost
2.11	Excavation for roadway in earth, soil of all sorts, sand, gravel or soft murum including dressing section to the required grade, camber and side slopes and conveying the excavated materials with all lifts upto a lead of 50m. and spreading for embankment or stacking as directed	Cubic metre	4398.4	85	373863
2.27	Providing earth work in embankment with approved materials obtained from departmental In Rs. land upto lead of 50m. including all lifts, laying in layers of 20cm. to 30cm. thickness breaking clods, dressing to the required	Cubic metre	809750	172	139277072

	lines, curves, grades & section, watering and compaction with vibratory roller to achieve not less than 97 % of standard proctor density etc. complete. (Material obtained from departmental Land)				

Total cost incurred for excavation is = 373863 + 139277072

= **139,650,935**

1.5. <u>Construction cost:</u>

SSR Item No.	Description	Unit	Quantity	Rate	Total Cost
5.11	Providing and laying in-situ M40 Grade unreinforced plain cement concrete pavement with max 20% fly Ash (Fly-ash upto 20% by weight of Cement) over a prepared sub base with 43 grade cement , coarse and fine aggregate (VSI grade finely washed crushed sand) conforming to IS 383, using fine and coarse aggregates combined gradation as per Table 600-3 of MORTH Specification 2013, mixed in a batching and mixing plant/ non tilting mixer and Weigh batcher as per approved mix design, admixtures, transporting to site, spreading, laying with approved make paver,compacted and finished in a continuous operation, finishing to lines and grades as directed by Engineer-in-charge and curing by curing compound /by providing cement vata in cement Mortar 1:8 @0.6m X 0.6m centre to centre, admeasuring 80 mm at bottom and 40 mm at top with depth of 75mm and maintaining the same throughout curing period by any other method approved by Engineer-in-charge	Cubic Metre	922792.5	5981	5519221943
5.13	Construction of dry lean cement concrete Sub- base over a prepared sub-grade with coarse In Rs. and fine aggregate (VSI grade finely washed crushed sand) conforming to IS: 383, the size of coarse aggregate not exceeding 25 mm, , cement content not to be less than 150 Kilogram/ cum, optimum moisture content to be determined during trial length construction, concrete strength not to be less than 10 Mpa at 7 days, mixed in a batching plant/ Weigh batch mixer, transported to site with all leads and lifts, laid with a paver with electronic sensor /by suitable means as approved by Engineer-in-charge , compacting with vibratory roller, finishing, curing and including preparation of sub-grade surface if required etc. complete.	Cubic Metre	446512.5	3240	1446700500
5.19	Providing and laying 125 micron Low Density Polyethylene (LDPE) sheet confirming to IS 3395 :	Square Metre	2976750	21	62511750

	1997 below concrete pavement including all materials and labour complete				
5.14	Providing and fixing in position TMT FE 500, 32 mm dia dowel bars precoated with anticorrosive epoxy paint of required Dia. 60 cms. Long and at 30.00 cm. C/C and PVC pipe of 40 mm dia wherever directed including handling, straightening, necessary cutting supported by TMT FE 500, chairs with proper alignment by using properly designed assembly of Bulkheads lubricating half length with bituminous paint as directed etc. complete	Number	283.5	411	116518.5
5.17	Cutting transverse contraction joints 3 to 4 mm wide and depth 60mm. .in concrete slab using concrete cutting machine with diamond studded saw within 48 hours of casting of bay / slab etc. complete including subsequent widening of the groove 8 to 10 mm. wide at top having depth of 15 mm. as directed by Engineer incharge.	Running Metre	94500	71	6709500
5.16	Providing and fixing in position TMT FE 500, tie bars precoated with anticorrosive epoxy paint of 12 mm dia. 70 cms.long and at 30.00 cm. C/C and wherever directed including handling, straightening wrapping with paper of approved quality for half length, necessary cutting, handling, straightening , supported by assembly of TMT FE 500, chairs with proper alignment etc. complete.	Number	283.5	233	66055.5
2.35	Providing, laying and spreading soil on a prepared sub grade, pulverizing, mixing the spread soil in place with rotavator with 3 per cent slaked lime with minimum content of 70 per cent of CaO, grading with motor grader and compacting with the road roller at OMC to achieve atleast 98 per cent of the max dry density to form a layer of sub base.	Cubic Metre	1488375	532	791815500
3.04	Construction of granular sub-base by providing close graded material, spreading in uniform layers with motor grader / Paver on prepared surface, mixing by mix in place method with rotavator at OMC, and compacting with vibratory roller to achieve the desired density, complete as per clause 401 -- By Mix in Place Method and Grading - I Material	Cubic Metre	1190700	1542	1836059400

Total cost incurred in the construction of the pavement = 5519221943+ 1446700500 +62511750 + 116518.5 + 6709500 + 66055.5 +791815500 + 1836059400
= 9663201167

1.6. Maintenance cost

SSR Item No.	Description	Unit	Quantity	Rate	Total Cost
	Maintenance cost per km per lane per year	km	567	100000	56700000
	Major Maintenance (every 5 years)	km	567	200000	113400000

There is an annual maintenance cost of **5.67Cr** and a major maintenance cost of **11.34Cr** in every five years.

1.7. Result

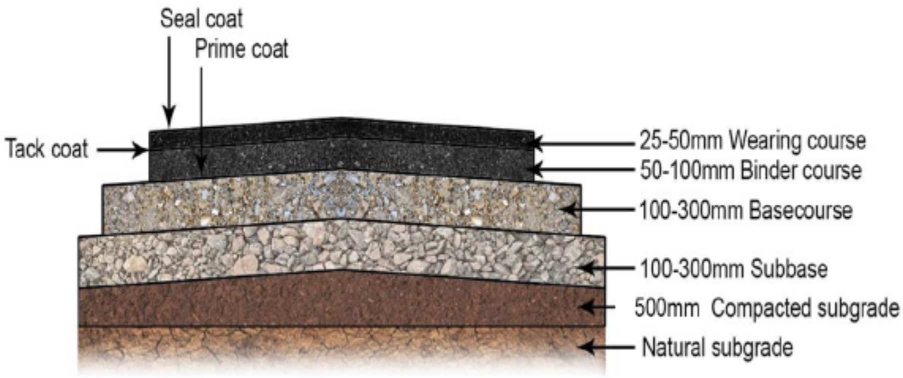
Net Initial cost of the rigid pavement = **981.8Cr**

Annual operation and maintenance cost = **5.67Cr**

Major Maintenance (every 5 years) = **11.34Cr**

2. Cost estimation for flexible pavement:

2.1. Design of flexible pavement



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Cross section of typical flexible pavement

Base (Wet Mix Macadam) = 250mm

Granular sub base = 200mm

Total depth of the flexible pavement = **610mm**

2.2. Site preparation cost

SSR Item No.	Description	Unit	Quantity	Rate	Total Cost
2.01	Cutting down trees including trunks and branches with girths above 30cm to 60cm and stacking the materials neatly with all lifts and lead of 1000m as directed and earth filling in the depression / pit if any.	Number	7088	462	3274656
2.07	Clearing grass and removal of rubbish up to a distance of 50 metres outside the periphery of the area .	Square metre	2976750	4	11907000

Total cost incurred for site preparation is = 3274656+11907000

= 15181656

2.3. Excavation cost

SSR Item No.	Description	Unit	Quantity	Rate	Total Cost
2.10	Excavation or roadway in earth, soil of all sorts, and, gravel or soft murum including dressing section to the required grade, camber and side slopes and conveying the excavated materials with all liftsup to a lead of 50m. and spreading for embankment or stacking as directed. By Manual Means. (with prior permission of S.E.)(assuming surface layer to be on top and rest all layer combine will level up to ground)	Cubic metre	1696747.5	272	461515320

Total cost incurred for excavation is **461515320**

2.4. Construction cost

SSR Item No.	Description	Unit	Quantity	Rate	Total Cost
3.23	Wet Mix Macadam -- Providing, laying, spreading, and compacting graded stone aggregate to wet mix macadam specification including premixing the material with water at OMC in mechanical mix plant, carriage of mixed material by tipper to site, laying in uniform layers with paver in sub-base/base course on well-prepared surface, and compacting with vibratory roller to achieve the desired density. Laying by Grader/Paver.	Cubic metre	744187.5	1748	1300839750
2.29a	Supplying hard murum/ kankar at the road site, including conveying and stacking complete.	Cubic metre	595350	321	191107350
2.31	Compacting the hard murum side widths including laying in layers on each side with vibratory roller including artificial watering etc. complete.	Square metre	2976750	16	47628000
3.01	Construction of granular sub-base by providing close graded Material, mixing in a mechanical mix plant at OMC, carriage of mixed Material to worksite, spreading in uniform layers with motor grader/Paver on prepared surface and compacting with vibratory roller to achieve the desired density, complete as per clause 401 -- Plant Mix Method and Grading - I Material.	Cubic metre	595350	1738	1034718300
3.29	Prime coat - Providing and applying primer coat with bitumen emulsion on prepared surface of granular base including cleaning of road surface and spraying primer at the rate of 0.60 kilogram/square metre using mechanical means.	Square metre	2976750	21	62511750

	Watering and compacting of embankment formed of materials obtained from the road cutting with a lead of 50 m, not less than 97% of standard Proctor density after laying them in layers of 20 cm to 30 cm with Power roller.	Cubic metre	1339537.5	59	79032712.5
3.3	Providing and applying tack coat on the prepared surface by heating in a boiler and spraying bitumen set footed in bitumen boiler on B.T. surface at 2.5 kilograms/10 square metres (VG-30 bulk bitumen rates are considered to arrive at rates).	Square metre	2976750	11	32744250
3.44	DENSE BITUMINOUS MACADAM: Providing and laying dense bituminous macadam using crushed aggregates of Grading 1, premixed with bituminous binder of specified grade of bitumen at 4.50 percent by weight of total mix and filler, transported to site with VTS, laid over a previously prepared surface, finished to the required grade, level, alignment, and rolling to achieve the desired density for 76-100 mm compacted thickness. USING Batch mix type hot mix plant with SCADA, Sensor Paver, Vibratory roller with Stone Dust filler. (VG-30 bulk bitumen rates are considered to arrive at rates)	Cubic metre	476280	6268	2985323040
4.01	Providing bituminous Type A liquid seal coat on bituminous surface including supplying all materials and bitumen of specified grade, preparing existing road surface, heating and applying bitumen at 0.98 kilogram/square metre by mechanical means, spreading chips and rolling by static roller having weight 8 to 10 MT, etc., complete. (VG-30 bulk bitumen rates are considered to arrive at rates)	Square metre	2976750	45	133953750

Total cost incurred in the construction of flexible pavement = 1300839750 + 191107350 + 47628000 + 1034718300 + 62511750 + 79032712.5 + 32744250 + 2985323040 + 133953750

= **5867858903**

= 586.78Cr

2.5. ***Maintenance cost***

SSR Item No.	Description	Unit	Quantity	Rate	Total Cost
	Assuming that the full road is not being maintained, we calculated an average cost of Rs. 1,50,000 per kilometer for maintenance of all six lanes.	km	567	150000	85050000
	Major maintenance every 3 years costing Rs. 4,00,000	km	567	400000	226800000

There is an annual maintenance cost of **8.505Cr** and a major maintenance cost of **22.68Cr** in every three years.

2.6. ***Result***

Total initial cost of the rigid pavement	= **634.455 Cr**
Annual operation and maintenance cost	= **8.505 Cr**
Major Maintenance (every 3 years)	= **22.68 Cr**

Cost Cashflow:

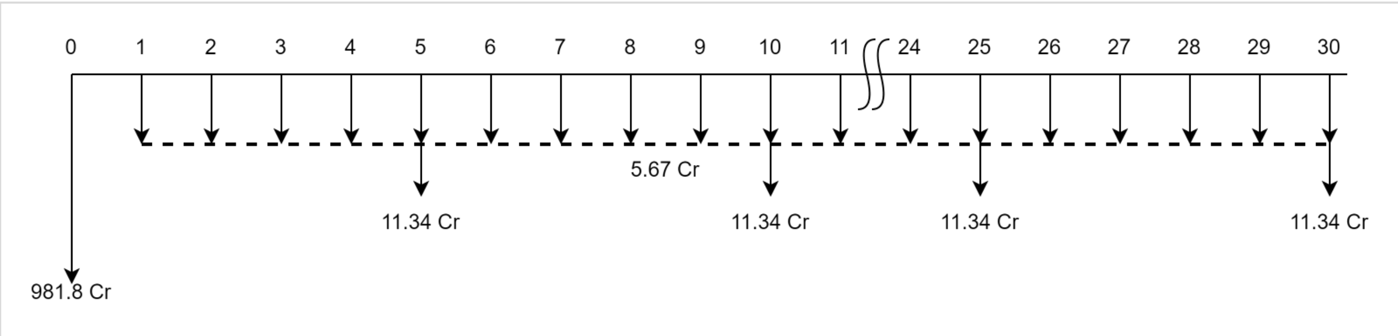
Rigid pavement:

Initial cost = 981.8 Cr

Annual operation and maintenance cost = 5.67 Cr

Major maintenance cost (every 5 years) = 11.34 Cr

Design Life = 30 years



Cashflow of rigid pavement

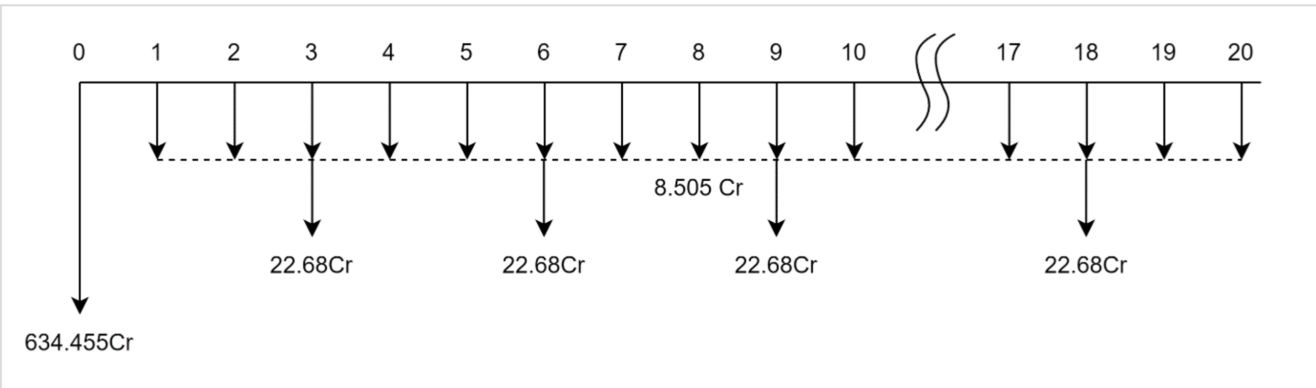
Flexible pavement:

Initial cost = 634.45 Cr

Annual operation and maintenance cost = 8.5 Cr

Major maintenance cost (every 5 years) = 22.68 Cr

Design Life = 20 years



Cashflow of flexible pavement

Revenue Cashflow:

Revenue is recognized in the form of toll tax obtained from the vehicle using the expressway.

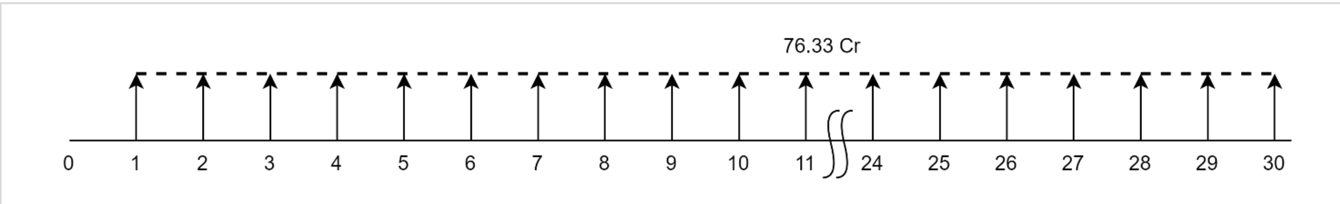
Average traffic per day data and toll tax rate of vehicles are taken from Annexture 8 - Daily Toll Collection Traffic Count and Revenue Entry Details

	No. of vehicles	Toll rates	Toll Revenue
Car	9053	100	905310
Bus	829	115	95347
Truck	613	215	131795
LCV	1435	295	423325
MAV	455	510	231999
3 Axle	446	680	303348

Daily toll revenue = 20,91,124 Lakh

Annual toll revenue = 76.33 Cr

Assuming vehicles using the expressway is independent of the pavement type, so revenue cashflow is independent of the pavement type; i.e. Rigid and Flexible pavement.



Cashflow of revenue

Financial Analysis:

1. Present worth analysis:

So, we have two alternatives to choose for the construction of Mumbai-Pune expressway;

Since we don't have discount rate, according to Law.resource.org guidelines on financial analysis of expressway (page 101) we can assume 12% is commonly used in India.

Alternative-1: Rigid Pavement

Rigid pavement	
Initial cost	981.8
Annual operating and maintenance cost	5.67
Major maintenance cost (every 3 years)	11.34
Annual Toll Tax Revenue	76.33
Design life	30

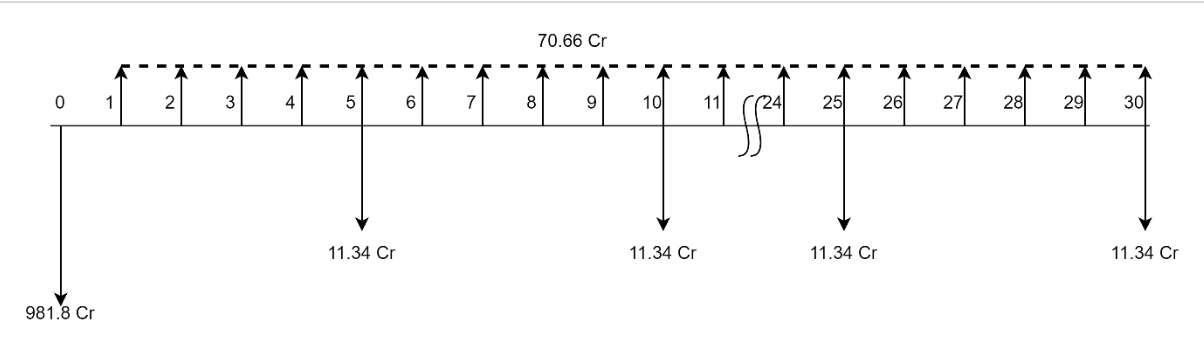
Alternative-2: Flexible Pavement

Flexible pavement	
Initial cost	634.4555879
Annual operating and maintenance cost	8.505
Major maintenance cost (every 3 years)	22.68
Annual Toll Tax Revenue	76.33
Design life	20

To conduct present worth analysis, life of two alternatives should be equal, but, if life of two alternatives is not equal, then we have to take LCM of life of all the alternatives and consider multiple cycles of them. For us, LCM (30, 20) = 60 years. So, we have to consider 2 cycles of rigid pavement and 3 cycles of flexible pavement for present worth analysis.

For Rigid pavement:

Let's calculate the net cash flow (Inflow – Outflow) for both the alternatives.



Net cashflow for Rigid pavement (i = 12%)

Present worth for 1 cycle (X) = -981.8 + 70.66 * (P/A, 12%, 30) – 11.34 * (A/F, 12%, 5)*(P/A, 12%, 30)

Using the uniform series present worth factor; $\frac{P}{A} = \frac{(1+i)^n - 1}{(1+i)^n * i}$a

Or we can also use the interest table.

X = -981.8 + 70.66 * 8.0552 – 11.34 * 0.1574 * 8.0552

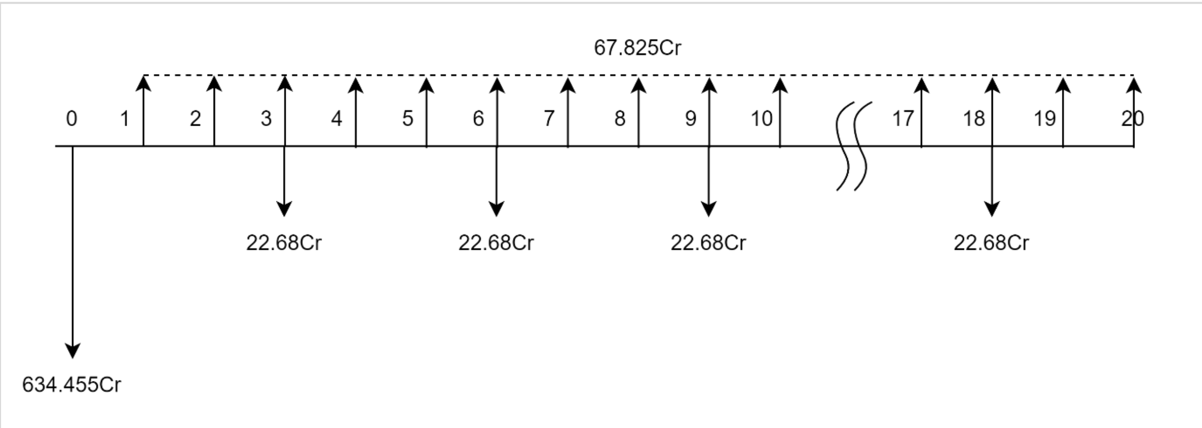
X = -426.99 ≈ -427 Cr

Present worth for 2 cycles = X + X*(P/F, 12%, 30)

= -427 – 427*0.0374

PW(rigid pavement) = -442.97 Cr

For Flexible pavement:



Net cashflow for Flexible pavement (i = 12%)

Present worth for 1 cycle (Y) = -634.455 + 67.825 * (P/A, 12%, 20) – 22.68 * (A/F, 12%, 3)*(P/A, 12%, 18)

Y = -634.455 + 67.825 * 7.4694 - 22.68 * 0.2963*7.2497

Y = --176.56 ≈ -176.6 Cr

Present worth for 3 cycles = Y + Y*(P/F, 12%, 20) + Y*(P/F, 12%, 40)

= -176.6 - 176.6*0.1037 -176.6*0.0107

PW(flexible pavement) = -196.80 Cr

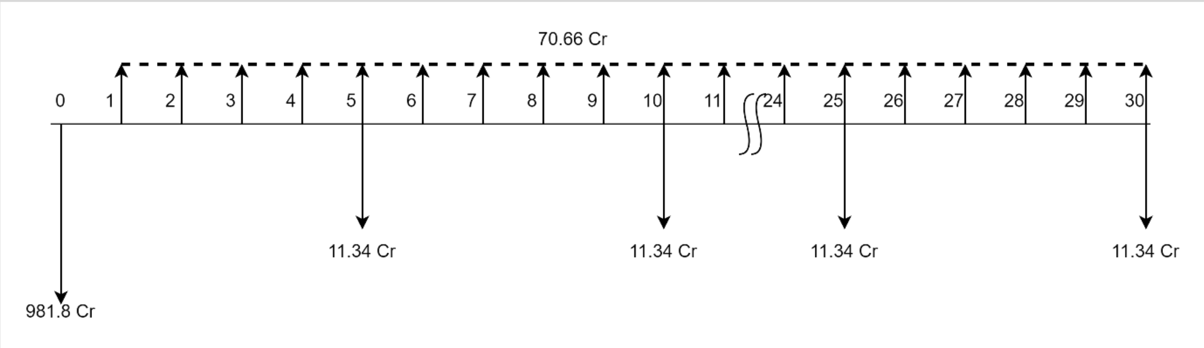
So, Present worth of flexible pavement is greater than rigid pavement. Since cost is taken as negative and revenue as positive.

Choose Flexible pavement.

2. Annual worth analysis:

To conduct the annual worth analysis, we will use the capital recovery factor and transform all the cash flow in terms of annuity.

For Rigid pavement:

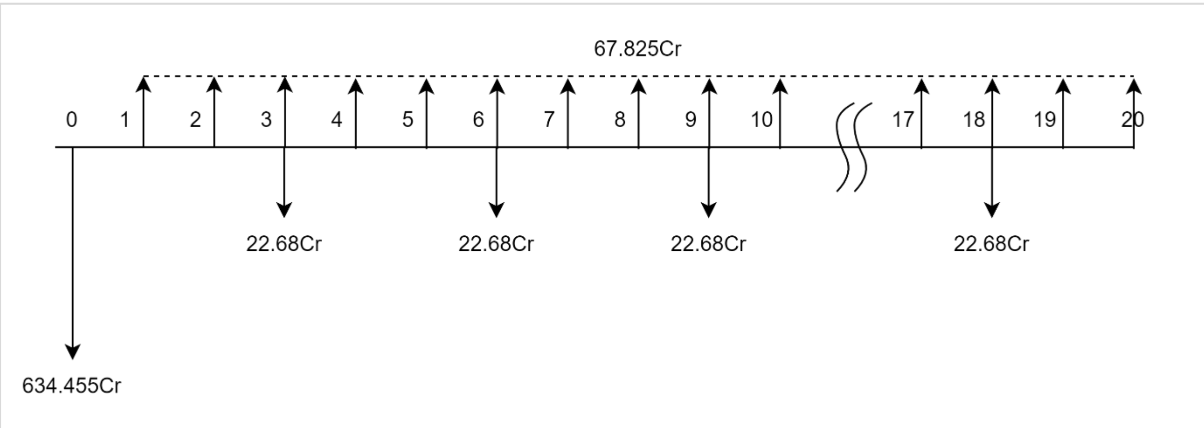


Annual worth (AW) = -981.8 * (A/P, 12%, 30) + 70.66 - 11.34*(A/F, 12%, 5)

= -981.8 * 0.1241 + 70.66 - 11.34*0.1574

= -52.97 Cr

For flexible pavement:



Annual worth (AW) = -634.455 * (A/P, 12%, 20) + 67.825 - 22.68 * (A/F, 12%, 3)*(P/A, 12%, 18) * (A/P, 12%, 20)

= -634.455 * 0.1339 + 67.825 - 22.68 * 0.2963 * 7.2497 * 0.1339

= -23.65 Cr

So, annual worth of flexible pavement is greater than rigid pavement or we can say that flexible pavement is more economical than rigid pavement.

Choose Flexible pavement.

3. IRR Analysis:

Internal Rate of Return (IRR) analysis evaluates the profitability of an investment by calculating the discount rate that makes the net present value (NPV) of cash flows equal to zero. It's widely used for comparing projects, as a higher IRR indicates a more attractive investment opportunity, assuming all other factors are constant.

IRR Analysis				
Flexible pavement			Rigid pavement	
Year	Cash Flow		Year	Cash Flow
0	-634.55		0	-981.8
1	67.82		1	70.66
2	67.82		2	70.66
3	45.14		3	70.66
4	67.82		4	70.66
5	67.82		5	59.32
6	45.14		6	70.66
7	67.82		7	70.66
8	67.82		8	70.66
9	45.14		9	70.66
10	67.82		10	59.32
11	67.82		11	70.66
12	45.14		12	70.66
13	67.82		13	70.66
14	67.82		14	70.66
15	45.14		15	59.32
16	67.82		16	70.66
17	67.82		17	70.66
18	45.14		18	70.66
19	67.82		19	70.66
20	-566.73		20	59.32
21	45.14		21	70.66
22	67.82		22	70.66
23	67.82		23	70.66
24	45.14		24	70.66
25	67.82		25	59.32
26	67.82		26	70.66
27	45.14		27	70.66
28	67.82		28	70.66
29	67.82		29	70.66
30	45.14		30	-922.48
31	67.82		31	70.66
32	67.82		32	70.66
33	45.14		33	70.66
34	67.82		34	70.66
35	67.82		35	59.32

36	45.14
37	67.82
38	67.82
39	45.14
40	-566.73
41	67.82
42	45.14
43	67.82
44	67.82
45	45.14
46	67.82
47	67.82
48	45.14
49	67.82
50	67.82
51	45.14
52	67.82
53	67.82
54	45.14
55	67.82
56	67.82
57	45.14
58	67.82
59	67.82
60	45.14
Internal Rate of Return (IRR)	7.19%

36	70.66
37	70.66
38	70.66
39	70.66
40	59.32
41	70.66
42	70.66
43	70.66
44	70.66
45	59.32
46	70.66
47	70.66
48	70.66
49	70.66
50	59.32
51	70.66
52	70.66
53	70.66
54	70.66
55	59.32
56	70.66
57	70.66
58	70.66
59	70.66
60	59.32
Internal Rate of Return (IRR)	5.64%

Although, the IRR of both the alternatives is less than the assumed MARR, since the calculated IRR of Flexible Pavement is greater than the calculated IRR of Rigid Pavement, **the Flexible Pavement alternative will be preferable based on IRR analysis**.

4. Payback Analysis:

In Payback Analysis, we calculate the time period within which our initial investment plus the annual costs is recovered without considering time value of money i.e., assuming interest rate to be zero. While calculating the payback period, we have assumed that the recurring cashflows will have some contribution towards the payback period i.e., suppose the first recurring cashflow which repeats in an interval of three years occurs at the end of year 3 and the payback period is 2. Then in the amount recovered, we will add two-third of the recurring cashflow amount instead of totally ignoring it and writing it off as zero. But suppose the last recurring cashflow occurs at the end of year 18 but the payback period is greater than 18. Then in this case we will consider only the recurring cashflows occurring till end of year 18 because there is no continuation of this cashflow beyond year 18.

Payback Period Analysis: -				
Flexible pavement			Rigid pavement	
Initial Cost (in Cr.)	634.55		Initial Cost (in Cr.)	981.8
Annual O&M Cost (in Cr.)	8.505		Annual O&M Cost (in Cr.)	5.67
Major maintenance cost (in Cr.)	22.68		Major maintenance cost (in Cr.)	11.34
Annual Revenue (in Cr.)	76.33		Annual Revenue (in Cr.)	76.33
Payback period (in years)	10.53		Payback period (in years)	14.36
NPW (for i = 0%)	0		NPW (for i = 0%)	0

It can be observed that the payback period of Flexible Pavement alternative is less than the Rigid Pavement alternative and hence according to payback period analysis, Flexible Pavement alternative will be preferable. But since, payback period analysis does not take time value of money into account and does not consider the cashflows occurring after the calculated payback period and also since the design life of both the alternatives is different, it will not be justified to use Payback Period Analysis.

Economic Analysis:

Decision to choose between the alternatives is necessarily relies more on financial analysis than economic analysis. However, is carried out to see the impact of alternatives on the nations GDP and overall welfare of the people of the region. That's why economic analysis is also carried out in government projects.

Rigid Pavement:

Production Impacts: High CO2 emissions from cement production, significant energy use.
Longevity: Generally longer lifespan, potentially fewer major rehabilitations.
Thermal Mass: Higher albedo (reflectivity), which can reduce urban heat island effect.
Recycling: Can be recycled into aggregate for new concrete or other applications.

Flexible Pavement:

Production Impacts: Lower CO2 emissions per ton compared to concrete, but petroleum-based materials have significant environmental impacts.
Maintenance Frequency: Typically requires more frequent maintenance and resurfacing, which increases life cycle impacts.
Temperature Sensitivity: Can soften and deform under high temperatures, affecting performance and requiring more maintenance.
Recycling: Asphalt is highly recyclable, often reused in new asphalt pavement, reducing raw material needs.

1. Calculating the Socio-Environmental Cost

This type of evaluation should focus only on projects where environmental impacts, both costs and benefits, are large, can be easily identified and where these can be quantified and valued. There are basically three major impacts that can occur. The first relates to human health and includes costs related to death or illness; the second relates to human welfare and includes damage to property, traffic congestion, changes in soil productivity or land use. The last relates to environmental resources and includes impacts on coastal waters, freshwater ecosystems, biodiversity, etc.

To quantify these costs on environment and society we calculate the CO_2 equivalent, CO_2 equivalent is the measure of CO_2 emitted in the process of producing and maintaining the alternative

Following assumptions/values has been taken to calculate the CO_2 equivalent of the rigid vs flexible pavement:

- Considered CO_2 emission due to tree cutting same in both cases
- Wet Volume = Dry Volume/1.54
- Volume of concrete used in rigid pavement = 1369305 m^3
- Assuming ratio of cement : sand : aggregate in concrete = 1:2:4
- Density of cement = 1440 Kg/m^3
- Density of steel = 8.05 Ton/m^3

- Density of bitumen = 1250 Kg/m^3
- Asphalt paver moves 12.5m in one go so it will move approximately 3 times for the width of road 31.5m

Using the estimates of CO_2 equivalent from [Ref 1]

Material type		Unit	Energy consumption (MJ)	CO2 equivalent (kg)
Asphalt	Petroleum asphalt	ton	4649.2	439.81
	Modified asphalt	ton	5412.22	323.04
Cement	P.I.52.5	ton	3621.271	1520.368
	P.O.42.5	ton	3180.845	1342.315
	P.S.32.5	ton	2302.316	988.967
Aggregate	Gravel	m3	46.5	3.87
	Stone chips	m3	55.361	14.4
	Sand	m3	61.088	15.9
Steel	Fe415	ton	-	1850
Calcium oxide	Stone chips	ton	4307.1	1193.213

Social cost of carbon = 90$/ Ton of CO_2 [Ref 2]

Flexible Pavement				
Construction Material				
Material	Unit	Quantity	CO2 quantity emitted (Ton)	Equivalent cost
Bitumen	ton	595350	261840.88	23565679.52
Aggregate (Gravel)	m3	1934887.5	7488.01	673921.3163
Total Cost due to CO2 emission	$24,239,600.83			

Rigid Pavement				
Construction Material				
Material	Unit	Quantity	CO2 quantity emitted	Equivalent cost
Cement	ton	281685.6	428265.8	38543919.51
Aggregate (Gravel)	m3	1973160	7636.1	687251.628
Aggregate (Sand)	m3	391230	6220.6	559850.13
Steel	ton	7.22	13.4	1202.689063
Total Cost due to CO2 emission	$39,792,223.95			

CO_2 emission in concrete is higher than flexible pavement

2. Calculating the Benefits generated

2.1. Increase in land price:

Due to construction of the expressway the land prices near the expressway hiked due to the development of the area nearby by petrol pumps, restaurants and repair shops

Assumptions in calculating land price [Ref 3]:

- Distance from road where the land price is hiked is till 3 miles perpendicular to the road, but the price increased will vary according to the distance from road so on an average it is taken as 1 mile, because after that it is not significant increase
- Land price hike due to road construction is from 0 to 35%, so on an average it is taken as 12% (hike depends on distance from road)
- Price of land before construction is considered to be as 100Rs/Sqft
- Proportion of land which can be developed is considered to be 40%, rest is dense forest, mountain ranges, river which is considered not to developed

Distance from road where land price is impacted	1	Miles
Distance on both sides	2	Miles
Range of increase in land price	12.00%	%
Price of land before road construction	100	Rs/Sqft
Length of road	94	Km
Plain land	40.00%	%
Dense forest and mountains	60.00%	%
Increase in price of overall land	**₹902,400,000.00**	

2.2. Increased tax collection:

Due to increase in the demand of land near the construction of expressway the government is able to collect the taxes in the name of property taxes

Assumptions in calculating tax revenue collected [Ref 4]:

- Property tax rate is considered to be 0.02%

Maharashtra property tax rate	0.02%	%
Area of land where price is hiking	120.32	Km2
Market value of land	₹121,222,400,000.00	Rs
Overall tax collection	**₹2,917,095,833.60**	

3. B/C Analysis

Conducting a benefit-cost analysis (BCA) for flexible and rigid pavement is essential for informed decision-making. It allows for a comprehensive evaluation of the total costs (initial construction, maintenance, and rehabilitation) against the benefits (longer lifespan, reduced maintenance frequency, and user comfort) over the pavement's lifecycle. BCA helps in comparing the economic efficiency of both pavement types, identifying the option that provides the highest net benefit. This analysis supports stakeholders in making cost-effective choices, ensuring optimal allocation of resources, and enhancing long-term infrastructure sustainability and performance. Additionally, it helps justify funding and investment decisions to policymakers and the public.

Considering all the cost and benefits incurred in the construction of rigid vs flexible pavement

Cost Benefit Analysis				
	Flexible Pavement		Rigid Pavement	
Cost of CO2 Emission(Rs)	₹2,019,158,749.24	At t = 0 years	₹3,314,692,255.38	At t = 0 years
Initial Cost	₹6,344,555,878.50	At t = 0 years	₹9,818,033,757.74	At t = 0 years
Annual O&M Cost	₹85,050,000.00	Every year	₹56,700,000.00	Every year
Major Maintenance	₹226,800,000.00	Every 3 years	₹113,400,000.00	Every 5 years
Cost Annual Value(Rs)	$1,299,201,859.75		₹1,846,351,600.83	
Land Value increase	₹902,400,000.00	At t = 0 years	₹902,400,000.00	At t = 0 years
Property Tax Collection	₹2,917,095,833.60	Every year	₹2,917,095,833.60	Every year
Toll Collected	₹763,260,077.50	Every year	₹763,260,077.50	Every year
Benefit Annual Value	₹3,801,168,122.21		₹3,792,383,147.67	
Overall tax collection	2.925771768		2.053987521	

Conclusion of B/C ratio analysis

B/C ratio of flexible is greater than the rigid pavement so, there is more benefit in flexible pavement compared to the concrete in relation to the costs

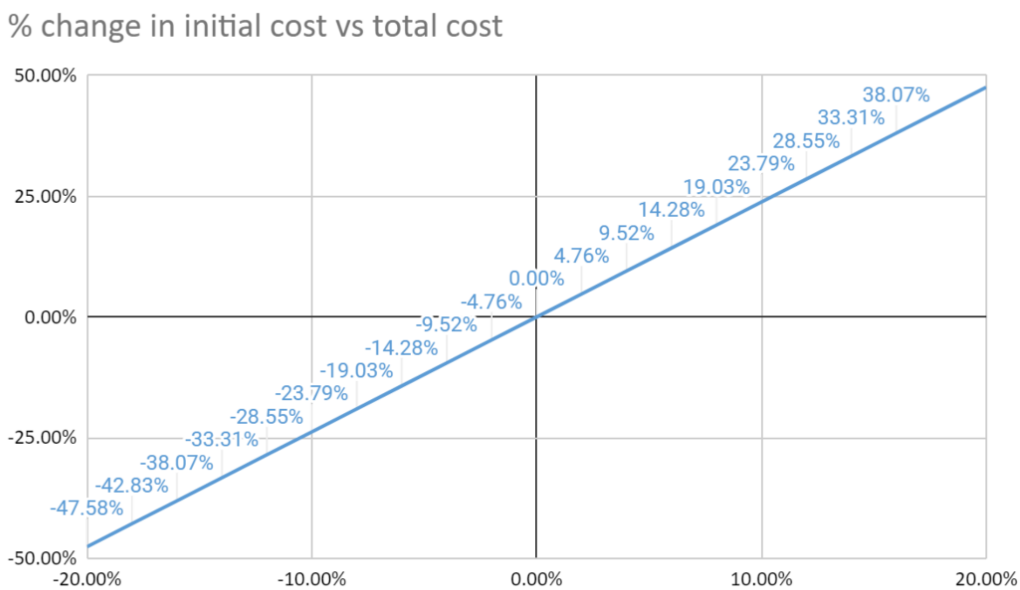
Risk Analysis:

Conducting risk analysis for flexible and rigid pavement analysis is crucial to account for uncertainties in factors like material performance, traffic loads, environmental conditions, and maintenance costs. It helps identify potential risks, assess their impacts, and develop strategies to mitigate them, ensuring more reliable and cost-effective pavement design and management.

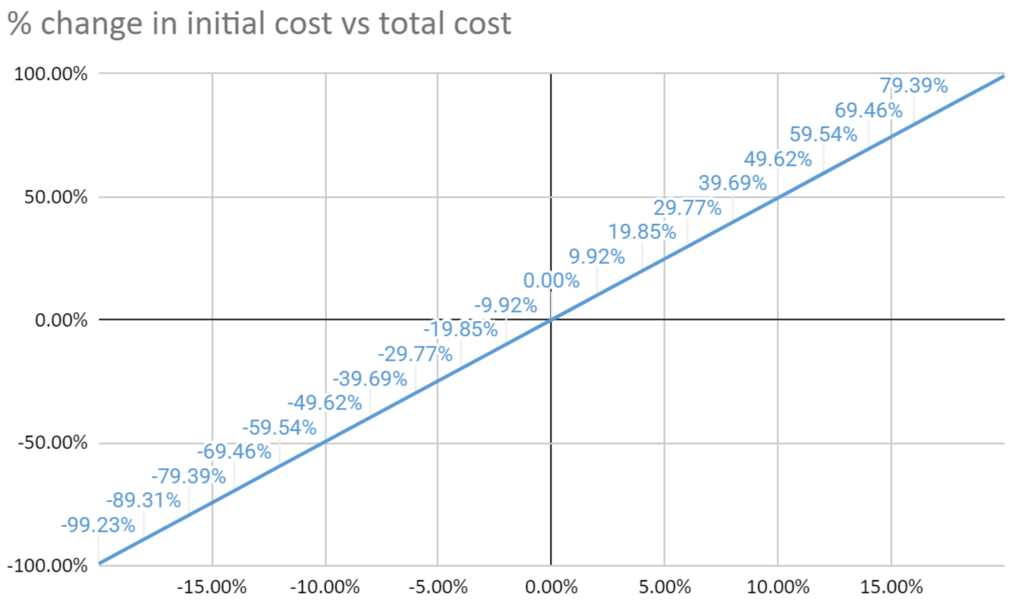
Sensitivity Analysis:

Conducting sensitivity analysis for flexible and rigid pavement is essential to understand how changes in key variables, such as material costs, traffic loads, and maintenance schedules, affect overall performance and costs. This analysis helps identify the most influential factors, allowing engineers to prioritize resources and make informed decisions. By evaluating how different scenarios impact the pavements' lifecycle costs and durability, sensitivity analysis aids in optimizing design choices, improving reliability, and ensuring cost-effectiveness. It also helps anticipate potential issues and adjust plans accordingly, leading to more resilient and sustainable pavement solutions.

Here we are trying to analyze how total cost change with the change in initial cost.



Rigid pavement



Flexible pavement

Breakeven analysis:

Since we have assumed the discount rate as 12% for our financial analysis, it may be possible that our choice will change if we change the discount rate. To determine that, we are conducting the breakeven analysis by keeping the MARR as variable.

AW $_{(flexible)}$ = -634.455 * (A/P, i, 20) + 67.825 - 22.68 * (A/F, i, 3)*(P/A, i, 18) * (A/P, i, 20)

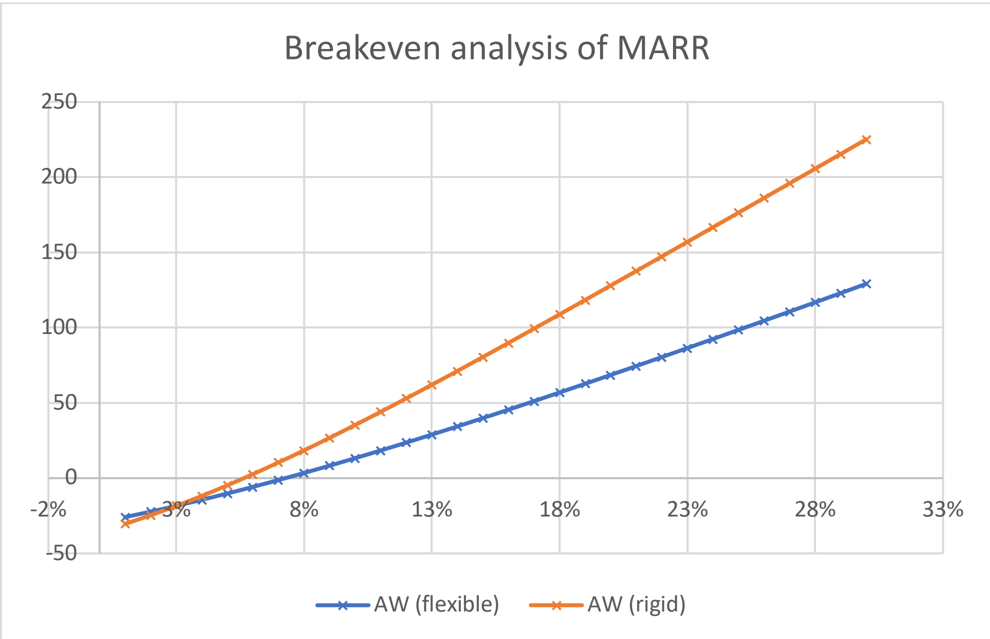
AW $_{(rigid)}$ = -981.8 * (A/P, i, 30) + 70.66 - 11.34*(A/F, i, 5)

Here by changing MARR (i) we will calculate different values of AW $_{(flexible)}$ and AW $_{(rigid)}$ and then plot these values to determine the MARR for which AW $_{(flexible)}$ and AW $_{(rigid)}$ are equal.

By using the goal seek function, MARR (i) turn out to be 3.01%. Data table can be used to calculate AW of both the alternatives at different MARR and calculating the difference, Breakeven will be where difference is zero.

Data table			
	AW (flexible)	AW (rigid)	Difference
MARR	-18.33	-18.33	0.00
1%	-25.86084026	-30.39001887	4.53
2%	-22.22513434	-24.63963785	2.41
3%	-18.3923427	-18.42935811	0.04
4%	-14.36892975	-11.78474495	-2.58
5%	-10.16243345	-4.736254577	-5.43
6%	-5.781265025	2.682368732	-8.46
7%	-1.234505316	10.43564369	-11.67
8%	3.468294578	18.48774254	-15.02
9%	8.31730167	26.80365051	-18.49

10%	13.30257353	35.35006162	-22.05
11%	18.41421122	44.09601034	-25.68
12%	23.64249071	53.01326159	-29.37
13%	28.97797189	62.07649567	-33.10
14%	34.41158558	71.26333072	-36.85
15%	39.93469964	80.5542252	-40.62
16%	45.53916591	89.93229855	-44.39
17%	51.21735016	99.38310249	-48.17
18%	56.96214731	108.8943682	-51.93
19%	62.7669844	118.4557485	-55.69
20%	68.62581349	128.0585674	-59.43
21%	74.53309669	137.6955866	-63.16
22%	80.48378529	147.360793	-66.88
23%	86.47329458	157.0492089	-70.58
24%	92.49747582	166.7567262	-74.26
25%	98.55258666	176.4799633	-77.93
26%	104.6352609	186.2161417	-81.58
27%	110.7424781	195.9629827	-85.22
28%	116.8715345	205.7186198	-88.85
29%	123.0200144	215.4815253	-92.46
30%	129.1857634	225.25045	-96.06



So, breakeven point is 3.01%; it means that if we consider MARR greater than the breakeven point (3.01%), then Flexible pavement is economical and if MARR is lesser than the breakeven point (3.01%), then Rigid pavement is economical.

Assumed MARR for financial analysis was taken as 12%, so Flexible pavement is more economical, hence better than rigid pavement.

Conclusion:

We started the analysis on the assumption that the rigid pavement even with higher initial cost will be more beneficial in financial as well as economical terms in the overall life cycle of the project. But we reached to a conclusion that on the basis of the data we collected and the assumptions we made, we found that the flexible pavement option was being more beneficial. Some of the reasons identified by us were:

1. The Cost of Carbon emission is too much for the concrete production and that made it 1.5 times that of the flexible pavement.
2. The difference in maintenance was more but was not able to impact the overall decision as the initial cost numbers very way higher than these.
3. The estimates were also not able to reach the actual budget of the project at which it was constructed, so there is a chance that we might have missed some aspects of the estimation and that made some change in the cash flows leading to change in decision
4. Toll tax revenues were also from the data of vehicles in 2016

In this project, we successfully designed both flexible and rigid pavements and conducted comprehensive financial analyses, including present worth analysis, breakeven analysis, and sensitivity analysis. By applying theoretical concepts from class and adapting them to real-world conditions, we developed robust pavement designs that balance performance and cost-effectiveness. Our financial analyses provided valuable insights into the long-term economic viability of each design option, considering fluctuating material prices and maintenance costs. Despite the challenges, we created a detailed cost model that ensures informed decision-making and sustainable pavement solutions. This project underscored the importance of integrating technical knowledge with practical financial considerations in engineering practice.

References:

Economic analysis

Ref 1:https://www.sciencedirect.com/science/article/pii/S0959652622004309

Ref 2:https://earth.org/social-cost-of-carbon/

Ref3:https://www.researchgate.net/publication/335505130_Modelling_the_Impacts_of_Road_Construction_on_Land_Values

Ref 4:https://www.nobroker.in/blog/property-tax-mumbai/#:~:text=The%20tax%20rate%20for%20residential,tax%20rate%20x%20capital%20value