Current Perpetual Pavement efforts in India - A case study and design with comparison of different pavement layer options in Perpetual Pavement

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Abstract: The construction of perpetual pavement has just recently started in India, and the design limitations of tensile strain at the base of the asphalt and compressive strain at the top of the subgrade are checked for 80 and 200 micro-strains, respectively. With SMA - 50 mm, DBM - 250 mm, WMM - 150 mm, GSB - 200 mm, and Subgrade - 500 mm pavement layers, the Delhi Vadodara Expressway Project (8 lanes divided carriageway) is constructed in the country's first perpetual pavement [11][12][13]. After this Expressway in India the upcoming / ongoing expressways are proposed to build with the perpetual pavement. These include the Bangalore-Chennai 4-lane Expressway, Varanasi Kolkata 4/6 lane Expressway and the Delhi-Amritsar-Katra 4-lane Expressway etc. [11][12]. It is obvious that using traditional pavement layers results in higher construction costs for India's proposed perpetual pavement crust. Hence, this study identifies the cost-effective alternative crust for perpetual pavement. In India, the road transportation has gradually increased over the years with improvement in connectivity between cities, towns, and villages in the country. Considering the financial impact on Nation the Ministry of Road Transport & Highways has published the circular vide MoRT&H (GOI) RW/NH-33044/18/2020-S&R(P&B) Dated: 14th Dec 2020 regarding cost effective new / alternative Material and Technology in highway construction to reduce construction cost.

However, this study identifies & design of the cost effective, less environment effects than current efforts & less time duration for Construction of Perpetual Pavements for upcoming Expressway / Highway in India.

Keywords - CBR, construction cost, current implementation, Environment effects, Expressway, Perpetual pavement.

I. INTRODUCTION

An asphalt pavement that is intended to survive for more than 50 years without having extensive structural repair or reconstruction is known as a perpetual pavement. Instead, it just needs periodic surface replacement to address problems that are limited to the top of the pavement.

In India, conventional pavement is intended to last for 15-20 years, but it is typically discovered that rehabilitation is needed after 5-7 years or sooner, and early failure happens after construction due to the use of subpar materials, overloading, permitting vehicles before all pavement layers have been completed, and a lack of sufficient quality control throughout the building of the pavement layers. According to Indian codal provisions, the corresponding limiting strains may be considered as 80 and 200 micro strains, respectively, given the climatic conditions present in India's plains, where the average annual pavement temperature may be near to 35^0C. In order to keep the horizontal tensile strain and vertical compressive strain within the previously indicated limiting strain values corresponding to endurance conditions, long-life pavement design entails choosing an appropriate pavement layer mix. Only the surface course of the long-lasting pavement's many layers has to be developed and built in such a way that it may occasionally be replaced [1].

Particularly in nations like India, perpetual pavements stand out as an affordable and environmentally friendly way to meet the growing demands on transportation infrastructure. Both in developed and underdeveloped nations, perpetual pavements have potential advantages. However, in order to fully realize their benefits in a variety of settings and geographical areas, more investigation, fieldwork, and thoughtful application are required. In

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addition to being a viable solution for meeting the changing needs of transportation networks, perpetual pavements have the potential to become a global standard for responsibly constructed pavements in terms of both cost and environmental impact. [16]

Further research is necessary to fully understand the environmental advantages of implementing Perpetual Pavement structures, as well as the effects of other variables like climate and the type of construction material used. [17]

As India becomes more modernized, more vehicle are being driven, which puts more strain on the nation's roads in the form of fatigue cracking and surface and structural rutting. This also raises the cost of maintenance and uses more resources. Once the 20-year design life of a pavement is reached, it must undergo structural rehabilitation and reconstruction; this necessitates significant rerouting and traffic closures, which raises the cost of the rehabilitation. This condition has been found to be improved by perpetual pavements, which can sustain pavement performance for almost 50 years without the need for extensive structural rehabilitation. There is a significant material savings because only the surface is replaced and the base structure remains intact, which lowers the cost of future formations and constructions. Even though perpetual pavements require more money up front to build than conventional pavements, the investment will pay off in the long run. Thus, the advantages of perpetual design with different highlights highlight the relationship between sustainable roads and perpetual designs. [18]

Perpetual flexible pavement performs better than rigid pavement for high traffic volume, long-life roads in terms of both environmental sustainability and life-cycle cost. Bitumen, one of the most recycled materials, is also used as a binding component in perpetual flexible pavement. Because of this, it is a better option than cement, which is essentially non-recyclable. Between perpetual flexible pavement and rigid pavement, a thorough life cycle analysis that takes into account all other factors, including user and social cost factors, can be carried out. Additionally, we ought to search for substitute pavement that has the same precise characteristics but is less costly and produces lower environmental impact. [19]

This paper is helpful to present discussion pertaining to identifies & design of the cost effective, less environment effects than current efforts & less time duration for Construction of Perpetual Pavements for upcoming Expressway / Highway in India.

II. LITERATURE REVIEW

1. A report on Perpetual Pavement: Way Forward from Design to Quality Construction (nbmcw.com) Atasi Das, Assistant Vice President, G R Infraprojects - Delhi Vadodara Expressway (8 Lane Divided Carriageway) [12]

This study presents the Perpetual Pavement idea and its practical use in the construction of expressways in India while taking into account the special layers, materials, and thicknesses that are pertinent to Indian circumstances and are in accordance with the regulations of the Indian Road Congress.

For mix design of asphalt mix, layer thickness, grading, and performance testing for perpetual pavement, there are no established guidelines. It has been determined that the maximum size of aggregate to be utilized is 25 mm, and 26.5 mm for Indian grading consideration, based on previous work done abroad. In India, aggregates with a size of 37.5 mm are used for DBM 1, however using bigger aggregate sizes has the drawback of trapping water in the mixture, which produces vapour in the summer heat and fractures or segregates aggregates from bitumen, causing pavement discomfort. It is advised that DBM Grade 1 be avoided in perpetual pavement as a result. The usage of stone matrix asphalt (SMA) was chosen to resist both rutting and durability issues for the renewable surface layer in order to accomplish the target of a 20-year surface life. SMA is a very rut-resistant bituminous course that has been successfully employed by many nations across the world as both a binder (intermediate) course and a wearing course, particularly for heavy traffic loads. SMA was developed in Germany in the middle of the 1960s. For efficient weight transfer, it is a gap-graded bituminous mix with stone-on-stone contact.

2. Guidelines for the Design of Flexible Pavements IRC:37-2018 (Fourth Revision) (Published by Indian Road Congress) [1]

According to IRC:37-2018, a pavement is referred to as long-life or perpetual if its lifespan is fifty years or longer. Pavements with design traffic of 300 msa or more may be created as long-life pavements in the Indian environment. According to Asphalt Institute, MS-4, 7th edition [39], the bituminous layer would never break if the tensile strain brought on by traffic in the layer is less than 70 micro strain (considered to be the endurance limit of the material). Similar to this, there won't be any rutting in the subgrade if the vertical subgrade strain is less than 200 micro strain. The comparable limiting strains for the climate on the Indian plains, where the average annual pavement temperature may be near to 350C, may be taken as 80 and 200 micro strains, respectively. In order to maintain the horizontal tensile strain and vertical compressive strain within the previously indicated limiting strain values corresponding to endurance condition, long-life pavement design entails choosing an appropriate pavement layer mix. Only the surface course of the long-lasting pavement's many layers has to be developed and built in such a way that it may occasionally

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be replaced.

3. A Synthesis on Perpetual Pavement by Dr. David Newcomb of the National Asphalt Pavement Association for the Asphalt Pavement Alliance (APA) [8]

This document was prepared for the Asphalt Pavement Alliance (APA), a coalition of the National Asphalt Pavement Association (NAPA), Asphalt Institute (AI), and State Asphalt Pavement Associations (SAPA).

The effectiveness of well-built, thick asphalt pavements has developed the idea of the perpetual pavement. Deep-strength and full-depth asphalt sections have been demonstrated to restrict distresses to the upper pavement layers, while being meant to function similarly to more traditional flexible pavements. This lowers the expense of rehabilitation and the inconvenience to users by allowing for routine removal of the surface layer and replacement with an HMA overlay. Recycling the pavement material that has been removed from the surface helps to preserve natural resources. There is a limit beyond which increasing HMA thicknesses yield very little return on investment, hence a different design strategy is required. Mechanistic approaches provide a way to determine the ideal pavement structure that won't need to be rebuilt for a certain material combination by calculating the stresses in pavement constructions. Distinct mixing characteristics need the development of different design criteria. In Illinois, California, and the United Kingdom, work on this has already started.

A method for designing pavements with a long lifespan has been proposed by the Transport Research Laboratory in the UK. The creation of national policies and processes should come next, giving pavement engineers the resources, they need to properly plan and build perpetual pavements. Along with new or reconstructed pavements, these recommendations should cover the rehabilitation of rigid and flexible pavements.

4. Review on the importance of perpetual pavement in future pavement networks (Mithil Mazumder, Hyunhwan Kim, Soon-Jae Lee - Journal of Advanced Construction Materials, Vol. 19 (1), 2015) [9]

The significance of perpetual pavement in upcoming pavement networks is discussed in this research. Perpetual pavement is defined, along with its mechanistic-empirical design principles and distinctions from ordinary pavement. There are offered specific layer uses and distresses. Future research recommendations are made in order to get the best asphalt perpetual pavement design. Due of their sustainability, perpetual pavements are becoming increasingly well-liked and accepted. Although users of perpetual pavement benefit from increased safety and lower user delay costs owing to less maintenance operations, there are also issues with the design technique being changed, economic applicability, and material limitations. For a better grasp of how to apply the ideal asphalt perpetual pavement design, fruitful research is required. It is necessary to do more study and construct a numerical model that replicates the deterioration of perpetual pavement based on wheel movement, freeze-thaw cycles, stochastic approaches, and partial or complete debonding.

In order to build high modulus asphalt pavement with a reduced overall thickness and lower material consumption, study is required to determine the best mix design. Based on the actual traffic section, it is necessary to invest in updating the fatigue endurance limit by creating a correlation between the laboratory fatigue endurance limit and field observed strain. Additionally, research is required to determine the causes, modes of failure, and optimum methods of compaction for top-down cracking. Understanding pavement layer bonding is crucial from an execution aspect since structural layers strengthen over time rather than deteriorate. Additionally, it is necessary to research how to transform the current pavement into the best permanent pavement.

It has been proven that perpetual pavement is more cost-effective than standard pavement when user delay costs are taken into account. Therefore, life cycle cost analyses may be done on several types of everlasting pavement. Perpetual pavement's high initial construction costs are primarily due to how much asphalt it consumes. So, a cost-effective strategy would involve utilizing less asphalt to produce it while still guaranteeing its definition. A sustainable optimum everlasting pavement design is unavoidable for future roadway networks because to the rising cost of aggregates and other pavement materials.

III. Perpetual Pavement Design & Comparison

- **Design of Perpetual Pavement**

The design of identified perpetual pavement options are presented below using the IRC:37-2018 [1], IRC:SP:59-2019 [3] & IRC:58-2015 [4]. For the Fatigue damage analysis of CTB layer the design traffic (with escalation) & Axle load spectrums are used as given in Appendix-VII of IRC:58-2015 [4]. Based on the Indian Road Congress (IRC) standards the alternative perpetual pavement options are designed & comparison of the same is provided. The following options of perpetual pavement were designed for 15% effective CBR & compared with the as built / ongoing Perpetual pavement (Option A) in India. The application of prime coat & tack coat is considered as per MoRT&H 5th Revision [7] [15].

Option A: bituminous surface course with granular base and sub-base (SMA + DBM + WMM + GSB + Subgrade)

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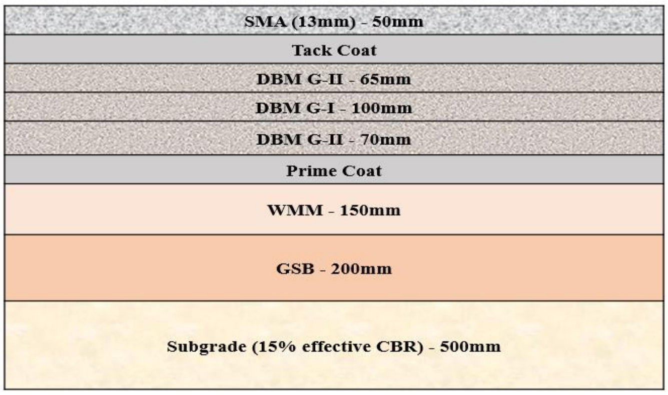

Fig -1: Option A

In the Varanasi Kolkata 4/6 lane Expressway, the perpetual pavement is proposed with pavement configuration SMA - 50 mm, DBM - 235 mm, WMM - 150 mm, GSB - 200 mm & Subgrade - 500 mm [11] [13].

Option B: bituminous surface course with CTSB, CTB and granular crack relief layer (SMA + DBM + AIL + CTB + CTSB + Subgrade)

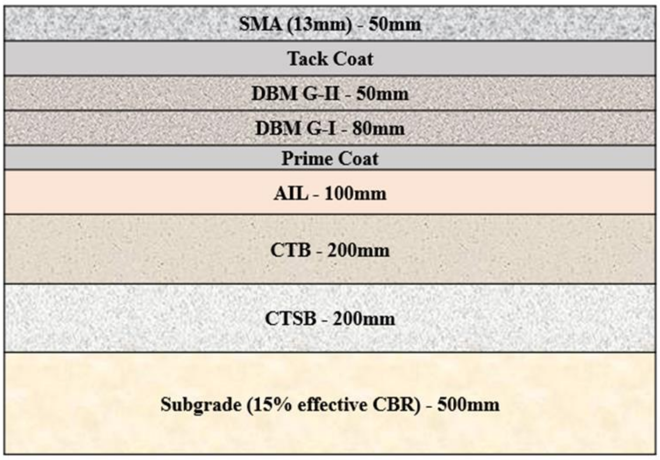

Fig -2: Option B

Option C: bituminous surface course with CTSB, CTB and SAMI (SMA + DBM + SAMI + CTB + CTSB + Subgrade)

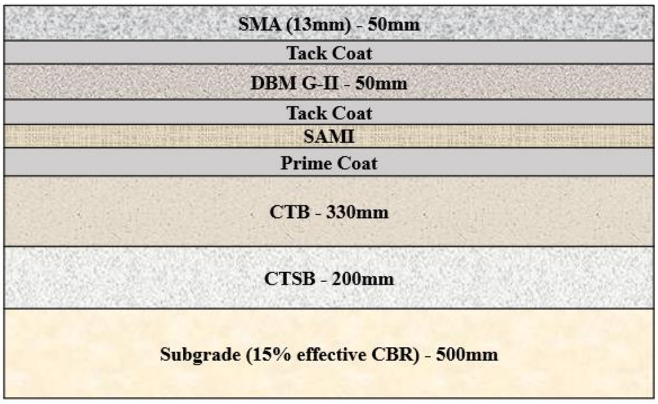

Fig -3: Option C

Option D: bituminous surface course with CTSB and emulsion / foam bitumen stabilised RAP / virgin aggregate (SMA + DBM + RAP + CTSB + Subgrade)

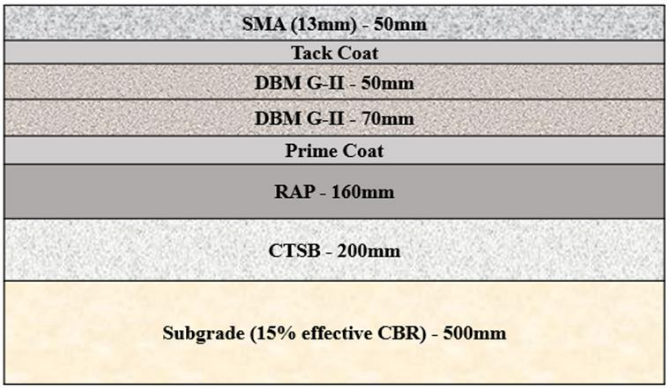

Fig -4: Option D

Option E: bituminous surface course with GSB, CTB and granular crack relief layer (SMA + DBM + AIL + CTB + GSB + Subgrade)

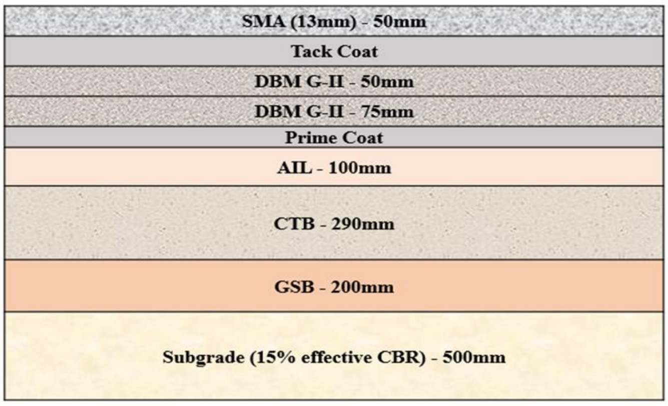

Fig -5: Option E

Option F: bituminous surface course with CTSB and granular base course (SMA + DBM + WMM + CTSB + Subgrade)

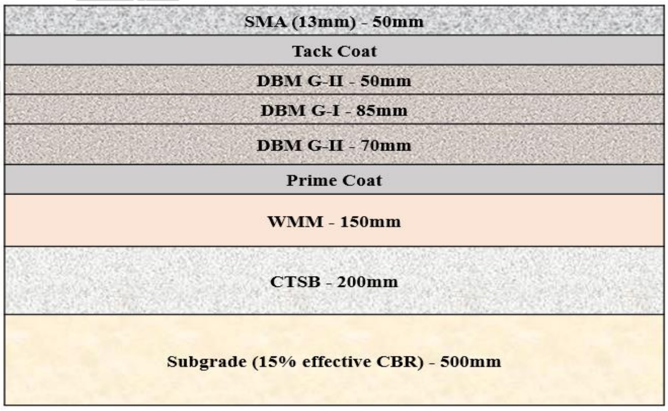

Fig -6: Option F

Option G: bituminous surface course with geogrid reinforced granular base and geogrid reinforced sub-base [MIF-1.8] (SMA + DBM + Geogrid reinforced WMM + Geogrid reinforced GSB + Subgrade)

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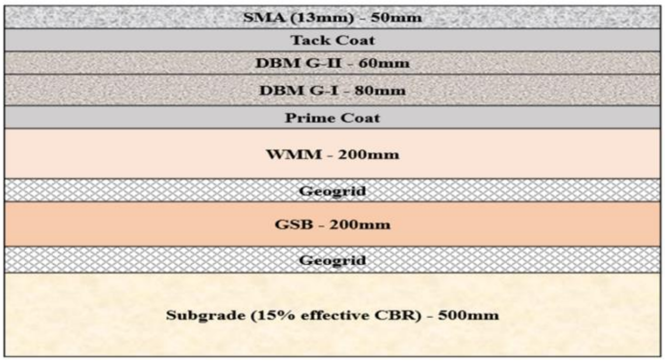

Fig -7: Option G

Option H: Rigid Pavement with bonded option (PQC + DLC + GSB + Subgrade)

This option is considered for the comparison only.

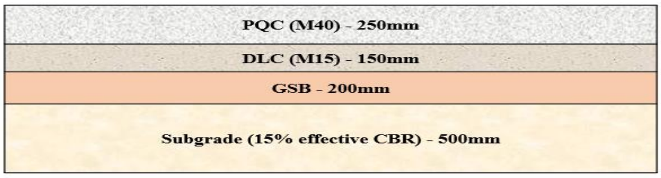

Fig -8: Option H

* SMA - Stone Matrix Asphalt [2], DBM - Dense Bituminous Macadam [5], WMM - Wet Mix Macadam, GSB - Granular Sub base, AIL - Aggregate Interlayer, CTB - Cement Treated Base, CTSB - Cement Treated Sub base, SAMI - Stress Absorbing Membrane Interlayer, RAP - Reclaimed Asphalt Pavement, Geogrid Reinforced WMM - Geogrid Reinforced Wet Mix Macadam, Geogrid Reinforced GSB - Geogrid Reinforced Granular Sub base, PQC - Pavement Quality Concrete, DLC - Dry Lean Concrete [7]

- **Comparison of Perpetual Pavement options**

The figure below shows the typical cross section of Eight lane divided carriageway (RHS) [12][6] used for the cost analysis of each option of perpetual pavement. The fig. shows only for the RHS carriageway, since the LHS carriageway same as that of the RHS carriageway.

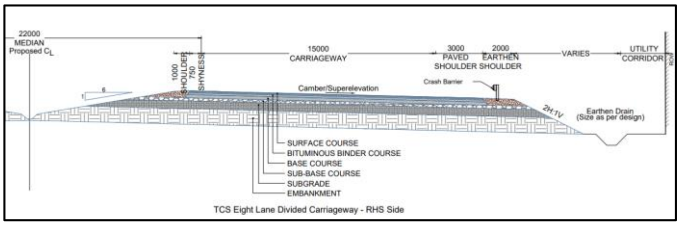

Fig -9: Typical Cross Section

For the designed crust, the cost comparison has carried out with details as follows. Unit rates of different items are calculated as per the MoRT&H Standard Data Book 2019. Government of Bihar, Road Construction Department Schedule of Rates - 2023 (Effective from 01.04.2023) [14] is used for the Rate Analysis. For rate analysis the location of Varanasi Kolkata expressway in Bihar is considered which is currently under bidding / awarded by NHAI [11][13]. Aggregate lead - Sahibganj Quarry (Quarry to Sahibgaj Railway station by road + Sahibganj to Son Nagar Railway station by rail + Son Nagar Railway station to Project Road location by road) : lead by Road - 80km & lead by rail - 382 km. Rates for Large Project were adopted for the rate analysis. The estimated below rates are exclusive of GST & Labour Cess.

Table -1: Summary of unit rates

Sr. No.	Item Description	MoRT&H Specification [7]	Unit	Rates (Rs)
1.	Tack Coat	503	Sqm	17.30
2.	Prime Coat	502	Sqm	57.81
3.	SMA (PMB 70-10)	515	Cum	14,863.12
4.	DBM (VG-40) Grade-I	505	Cum	11,662.94
5.	DBM (VG-40) Grade-II	505	Cum	12,168.82
6.	WMM	406	Cum	4,571.29
7.	AIL	406	Cum	4,571.29
8.	SAMI	517	Sqm	91.51
9.	Geogrid	703	Sqm	150.00
10.	RAP	519	Cum	9,323.74
11.	CTB	403	Cum	5,297.31
12.	GSB	401	Cum	4,155.18
13.	CTSB	403	Cum	4,851.80
14.	PQC	602	Cum	8,208.16
15.	DLC	601	Cum	5,076.94
16.	Subgrade	305	Cum	226.60

The cost comparison of designed perpetual pavement options is presented below chart.

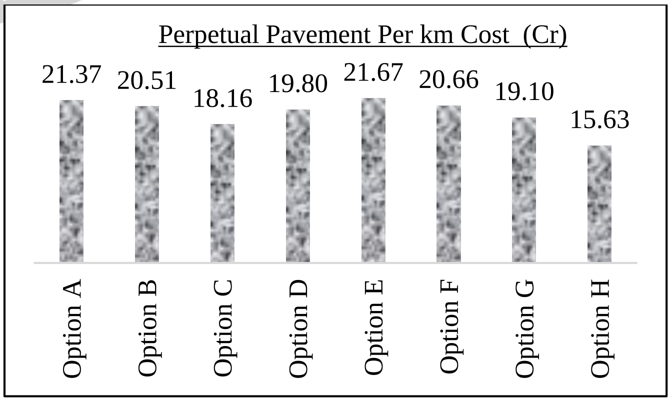

Fig -10: Chart - Cost Comparison

The comparison of overall impact of the perpetual pavement options are presented in Table & figure below. The comparison is made in numbering system. Number 1 to 8 are used to define the lower to higher impact of the perpetual pavement option.

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Table -2: Comparison of overall impact of Perpetual pavement options

Sr. No.	Description	Option A	Option B	Option C	Option D	Option E	Option F	Option G	Option H
1	Total Thickness	6	7	5	1	8	4	2	3
2	Req Natural Resources	6	7	3	1	8	5	4	2
3	Per km Cost	7	5	2	4	8	6	3	1
4	Reconstruction	-	-	-	-	-	-	-	8
5	Riding Quality effect	-	-	-	-	-	-	-	8
6	Scarcity of Material	-	-	-	8	-	-	-	-
7	Water requirement	1	5	7	4	6	3	2	8
8	Curing Period	-	6	7	5	7	5	-	8
9	Time period for completion	1	5	7	4	6	3	2	8
10	Construction difficulties	8	1	6	4	5	7	3	1
11	Emission of GHG	2	7	8	3	6	5	1	4
12	**Average**	**2.8**	**3.9**	**4.1**	**3.1**	**4.9**	**3.5**	**1.5**	**5.1**

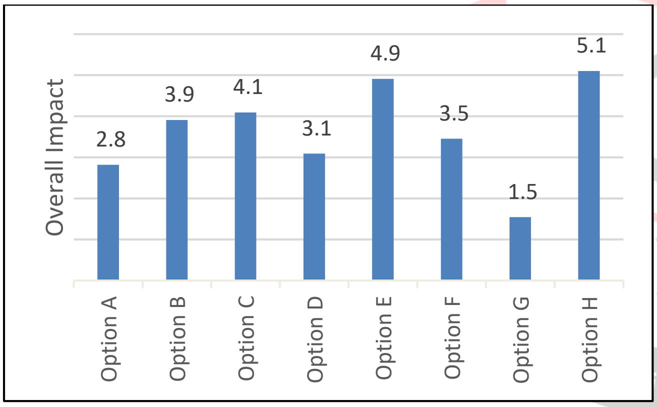

Fig -11: Comparison of overall impact of Perpetual pavement options

Note: The overall impact of the perpetual pavement option may differ based on the availability of material & required construction equipment's at location, CBR of subgrade, performance of pavement material, material rates, axle load of vehicles etc. prima phase of selecting perpetual pavement for designing and tendering can be done easily & suitability can be checked & implemented accordingly.

IV. CONCLUSION

In this study the design & comparison of the Perpetual pavement configurations with its impact on total thickness of pavement, required natural resources for construction, per km cost of construction, requirement of reconstruction during design life, riding quality effect of pavement, scarcity of material for construction, requirement of water during construction, time period for completion of construction, construction difficulties of pavement configuration, emission of GHG of pavement configuration has been done.

Based on this study, the cost effective, less environment effects than current efforts & less time required for construction the option of Perpetual Pavement combination is SMA (Stone Matrix Asphalt) - 50 mm, DBM (Dense Bituminous Macadam) - 140 mm, Geogrid reinforced WMM (Wet Mix Macadam) - 200 mm, Geogrid reinforced GSB (Granular Subbase) - 200 mm with Modulus Improvement factor (MIF) for Geogrid - 1.8 & Subgrade - 500 mm for 15% effective CBR.

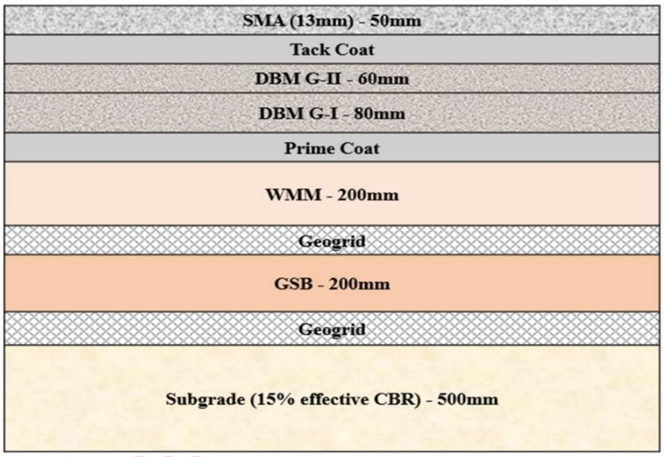

Fig -12: Selected Flexible Perpetual Pavement Option

Hence, the Perpetual Pavement with the above configuration is the cost effective, less environment effects & less time required for construction than current efforts taken for Perpetual pavement in India.

Note: The final selection of the Perpetual Pavement is done based on the design, cost comparison & less environmental effects. However, the performance of the selected pavement layers needs to be verified in the trial basis on the field.

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