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Effect of soil stabilization on design of conventional and perpetual pavement in India

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Professional paper

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The present study compares conventional pavement and perpetual pavement in the case of ground-granulated blast-slag-stabilized black cotton soil. Ground-granulated blast slag (GGBS) can be used for pavement over weak subgrade. We added slag to soil in proportions of 10 %, 20 %, 30 %, and 40 %. After determining the engineering properties of the soil and GGBS, modified Proctor compaction and California bearing ratio tests were performed. After determining these values, six combinations for conventional pavements and perpetual pavements with treated and non-treated subgrades were designed using a mechanistic-empirical methodology. The pavements were designed using IITPAVE software. The relevance of perpetual pavements was justified based on life-cycle cost assessment and carbon dioxide emissions for a duration of 50 years. The present study concludes that for the implementation of perpetual pavements in a developing country such as India, there is a need for further study in the domain of soil stabilization as well as usage of high-stiffness base materials considering the rising cost of bitumen.

Key words:

soil stabilization, perpetual pavement, life cycle cost, carbon dioxide emission

Stručni rad

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Učinak stabilizacije tla na projektiranje konvencionalnih i trajnih kolnika u Indiji

Ovo istraživanje uspoređuje konvencionalni kolnik i trajni kolnik u slučaju tla - smonice stabilizirane s mljevenom granuliranom zgurom iz visoke peći. Mljevena granulirana zgura iz visoke peći (GGBS) može se koristiti pri izgradnji kolnika na tlima male nosivosti. Zgura je dodavana tlu u omjerima od 10 %, 20 %, 30 % i 40 %. Nakon utvrđivanja svojstava mješavina tla i GGBS-e, provedena su ispitivanja optimalnog udjela vlage i maksimalne suhe prostorne mase modificiranim Proctorovim pokusom te kalifornijskog indeksa nosivosti. Nakon utvrđivanja ovih vrijednosti, mehaničko-empirijskom metodologijom projektirano je šest konvencionalnih i šest trajnih kolnika s nestabiliziranom posteljicom i posteljicom stabiliziranom GGBS-om. Kolnici su projektirani pomoću IITPAVE softvera. Relevantnost trajnih kolnika opravdana je na temelju procjene troškova životnog ciklusa i emisije ugljičnog dioksida za životni vijek kolnika od 50 godina. Rezultati provedenog istraživanja pokazuju da za implementaciju trajnih kolnika u zemlji u razvoju kao što je Indija, postoji potreba za dodatnim proučavanjem u području stabilizacije tla kao i osnovnih materijala veće krutosti s obzirom na rastuće cijene bitumena.

Ključne riječi:

stabilizacija tla, trajni kolnik, trošak životnog ciklusa, emisija ugljičnog dioksida

1. Introduction

The number of vehicles in India is increasing each year. This imposes significant pressure on existing road networks. In India, major pavements are generally designed for 20 years. Hence, they require periodic maintenance and reconstruction. This results in traffic closures, temporary provisions for traffic flow, increased user delay costs, which adds to the overall cost, and causes inconvenience to people.

In a developing country such as India, long-lasting pavements are necessary because of the scarcity of resources and inadequate infrastructure funding. By only increasing the pavement thickness, the issue of bottom-up fatigue cracking is not addressed because if the strain in the pavement layers exceeds the endurance limit (EL), they fail prematurely. The EL value indicates the level of strain below which cumulative damage never occurs over an infinite number of cycles. If a pavement structure experiences less strain than its endurance limit when subjected to load repetitions, it can serve for a significantly longer period. A perpetual pavement is expected to serve for four to five decades, and it is also termed as a long-lasting pavement [1]. In the case of perpetual pavements, structural distress confined to the top of the pavement layer can only be alleviated with periodic maintenance [2]. There is a considerable reduction in the requirement of pavement construction materials owing to reduced maintenance activity. This is because the renewal of only the surface layer is required and the base structure remains in place. Perpetual pavements are designed by considering the EL of the strain values for pavement layers [3]. Perpetual pavements have been successful in countries such as the United States over the past few decades [4]. In Asia, China has also achieved similar success by adopting flexible perpetual pavements. In the case of India, official guidelines regarding perpetual pavements were not available until the Indian Roads Congress (IRC 37:2018) published guidelines with primary information regarding perpetual pavements.

Black cotton soil is expansive in nature and in India, over 20 % area is covered with black cotton soil [5]. It shows tremendous volume change owing to changes in the moisture content, and hence, it creates difficulty in flexible pavement construction. Any weakness in the subgrade soil affects all the overlying layers of the flexible pavement. Hence, to improve the properties of such soil, materials such as fly ash, lime, brick kiln dust, and bagasse ash can be used. Soil stabilization with cement may not be favorable considering the higher cost and environmental issues related to cement production. Among the various available materials, considerable improvement in the properties of soft soil has been observed when it is stabilized with ground-granulated blast slag (GGBS) [6]. Several studies have been conducted to investigate the effect of GGBS in various soils. The addition of GGBS has been found to be useful for improving the strength of lime-stabilized kaolinitic clays [7]. In the United Kingdom, the combination of red gypsum and GGBS has yielded satisfactory results in improving soil quality [8]. Many steel factories in the western Maharashtra region produce GGBS as a waste product, and its disposal has become a serious issue. Therefore, in this study, the bearing strength of black cotton soil is improved by using GGBS. Subsequently, a comparison is made among six combinations of conventional and perpetual pavements with treated and non-treated subgrades on the basis of pavement thickness, life cycle cost, and carbon dioxide (CO_2) emissions. In the present study, traffic of 150 million standard axles (msa) is assumed for designing pavement combinations by adopting the IRC 37 guidelines.

Objectives and scope of the investigation

- Determine the engineering properties of soil and GGBS.
- Design six conventional and six perpetual pavements using IRC 37:2018 guidelines.
- Perform life cycle cost comparison among all twelve pavement combinations.
- Evaluate and compare total CO_2 emissions caused by all twelve pavement combinations.
- Identify preferred pavement combinations cost-wise as well as by considering environmental aspects.

2. Materials

The following materials were used in this study.

2.1. Black cotton soil

The main characteristic of black cotton soil is its high clay content. In this study, black cotton soil was collected from Pune city, India. The construction or maintenance of pavements in these types of soils is very costly, time-consuming, and difficult because of the change in volumetric behavior with changes in climatic conditions [5]. The soil was excavated from beneath ground level at a depth of 50 cm. An Indian standard sieve of 425 μm was used to sieve the dried soil sample.

Table 1. Tests performed

Test	Indian code specification
Hydrometer analysis	IS: 2720 (Part IV) 1985
Sieve analysis	IS: 2720 (Part IV)-1985
Grain size distribution	IS: 2720 (Part IV)-1975
Atterberg's limits	IS: 2720(PART-V)-1985
Swelling pressure test	IS: 2720 (Part XI)-Constant pressure method
CBR test	IS: 2720 (Part XVI)-1987
Soil compaction test	IS: 2720 (Part VII)-1980 Light compaction method
Direct shear test	IS: 2720 (Part XIII)-1986

Table 2. Properties of the soil

Composition [%]			**Specific gravity**	**Liquid limit** [%]	**Plasticity index**	**Liquid limit** [%]	**OMC** [%]	**MDD** [kN/m^3]
Sand	**Silt and clay**	**Gravel**						
8.1	91.4	0.5	2.65	71	28.90	43.50	21.5	15.70

Table 3. Properties of GGBS

Specific gravity	**MDD** [kN/m^3]	**OMC** [%]	**Plasticity Index**
2.80	16.8	21.9	Non-Plastic

Table 4. Details of Atterberg limits and plasticity index

Soil + GGBS	**Plastic limit** [%]	**Shrinkage limit** [%]	**Plasticity index** [%]	**Liquid limit** [%]
Only soil	43.50	10.510	28.90	71.0
90 % + 10 %	38.10	9.725	30.00	68.8
80 % + 20 %	34.50	9.435	29.85	64.4
70 % + 30 %	34.45	9.154	24.31	57.8
60 % + 40 %	34.10	8.120	19.95	54.3

Table 5. Details of swelling pressure, cohesion and internal friction

BC soil + GGBS	**Swelling pressure** [kN/m^2]	**Cohesion** [kN/m^2]	**Angle of friction** [°]
Only soil	292	18.7433	19.60
90 % + 10 %	203	16.6818	20.75
80 % + 20 %	121	14.6905	21.85
70 % + 30 %	73	8.8268	23.37
60 % + 40 %	43	4.9105	23.94

Table 6. MDD and OMC values with varying GGBS dosages in soil

Percentage GGBS [%]	**MDD** [g/cm^3]	**OMC** [%]
0	1.600	21.5
10	1.670	19.5
20	1.730	18.6
30	1.700	17.1
40	1.680	16.9

2.2. GGBS

The GGBS used in this study was obtained from JSW Steel Limited, Dolvi, in Raigad district of Maharashtra. As GGBS is considered as a waste material, it can be used as a construction material. In this study, the soil was mixed with varying dosages of GGBS, and the engineering properties of the mixtures were determined. The tests that were performed are presented in Table 1. These tests were performed with 10 %, 20 %, 30 %, and 40 % GGBS content in black cotton soil.

2.3. Analysis of test results

Tables 2 and 3 list the properties of the soil and GGBS, respectively. The Atterberg limits and plasticity indices of the mixtures are listed in Table 4. The swelling pressure test results shown in Table 5 suggest that the swelling potential reduces with increasing GGBS content. The soil stability is improved as the swelling potential decreases. Increased GGBS content results in a large amount of calcium ions accumulating in the layer surrounding the surface of soil grains, thereby reducing the moisture and swelling of the soil. Improvement in the strength of the soil can be observed because pozzolanic compounds not only bring soil particles closer but also decrease the potential to swell. From Table 5, it is evident that increased GGBS content in the soil decreases the cohesion value and increases the angle of friction. This means that because of stabilization with GGBS, the soil becomes more resistant to shear stresses and less cohesive. It can be concluded that black cotton soil with GGBS addition shows improved shear strength. The compaction test results in Table 6

Table 7. CBR with different percentage of GGBS

Soli + percentage GGBS	CBR sample number			Mean CBR [%]	Standard deviation	Permissible variation in CBR [%]	Maximum variation in CBR [%]
	1	2	3				
0	7.40	6.67	6.87	6.98	0.38	+/- 1	0.73
10	8.34	8.48	8.32	8.38	0.09	+/- 2	0.16
20	9.18	10.10	10.54	9.94	0.69	+/- 2	0.60
30	8.85	8.92	8.78	8.85	0.07	+/- 2	0.14
40	8.50	8.42	8.13	8.35	0.19	+/- 2	0.37

show that the optimum moisture content (OMC) decreases with increased content of GGBS up to 20 %. Similarly, the maximum dry density (MDD) increases up to 20 % GGBS content and decreases beyond. Such a decrease in the MDD value is a result of coarser GGBS particles offering high frictional resistance to compaction owing to their surface texture and size. This also results in a decrease in the water-holding capacity; and hence, the OMC also decreases. The details of MDD and OMC in the stabilized mixtures are presented in Table 6.

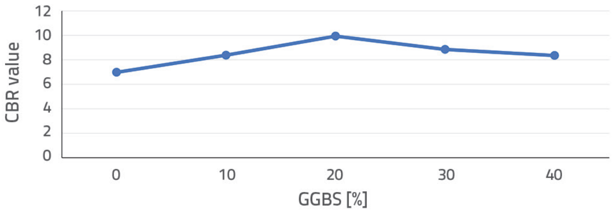

Figure 1. Relationship between % GGBS in soil and CBR value

The addition of GGBS up to 20 % leads to improvement in the CBR, as presented in Figure 1. The CBR increases from 6.98 % to 9.94 % with the addition of 20 % GGBS content. The CBR value decreases beyond 20 % GGBS content. The details of the CBR test readings are presented in Table 7. The design CBR was considered as 9.94 % for pavement design with treated subgrade with 20 % GGBS content.

3. Design criteria for perpetual pavement

The vertical compressive strain at the top of the subgrade and horizontal tensile strain at the bottom of the bituminous layer are considered as critical strains [9]. Previous studies have adopted a maximum limit of 70 microstrains(μ) for horizontal tensile strain and 200 microstrains(μ) for vertical compressive strain [2-4,10]. According to IRC 37:2018, 200μ and 80μ strain values have been proposed for the rutting and fatigue endurance limits, respectively, as the average annual temperature of pavements in a major part of India is close to 35 °C. The material properties, which were considered according to the IRC 37 guidelines, are presented in Table 8.

3.1. Pavement combination

The following combinations are proposed for pavement design in accordance with IRC 37 guidelines.

1. Conventional pavement
   - Bituminous course (BC), i.e., bituminous concrete + dense bituminous macadam (DBM) with a granular base, i.e., wet mix macadam (WMM) and granular sub-base (GSB) (Combination A).
   - BC with GSB (Combination B)
   - BC with sub-base treated with cement (CTSB) and WMM (Combination C)
2. Conventional pavement with GGBS
   - Combination A with treated subgrade (Combination D)
   - Combination B with treated subgrade (Combination E)
   - Combination C with treated subgrade (Combination F)
3. Perpetual pavement
   - BC with WMM and GSB (Combination G)
   - BC with GSB (Combination H)
   - BC with CTSB and WMM (Combination I)

Table 8. Material properties according to guidelines in IRC 37:2018

Material type	Poisson's coefficient	Elastic/Resilient modulus [MPa]
Granular base over sub-base treated with cement	0.35	350
Subgrade	0.35	$17.6 \times (CBR)^{0.64}$
Unbound granular layers	0.35	$0.2 \times M_{RS} \times (h)^{0.45}$
Sub-base treated with cement	0.25	600
Bituminous layer with viscosity grade VG40 binder	0.35	3000
M_{RS} - the modulus of resilience of subgrade soil in MPa, h - the thickness of the granular layer in mm		

4. Perpetual pavement with GGBS
    - Combination G with treated subgrade (Combination J)
    - Combination H with treated subgrade (Combination K)
    - Combination I with treated subgrade (Combination L)

3.2. Fatigue criterion

According to the IRC 37 guidelines, the equivalent number of standard axle load repetitions withstood by a pavement without rutting failure with a reliability level of 90 % is determined using equation 1. For the present study, the percent volume of air voids in the mix used in the bituminous layer is considered as 3.5 %, and the percent volume of effective bitumen in the mix used in the bottom bituminous layer is considered as 11.5 %, in accordance with IRC 37 guidelines.

$$N_f = \left(\frac{1}{\varepsilon_t}\right)^{3.89} \times 2.52 \times 10^{-7} \qquad (1)$$

Where ε_t is the maximum horizontal tensile strain and N_f is the fatigue life of the bituminous layer in “msa”.
According to Eq. (1), the allowable tensile strain at the bottom of the bituminous layer for a conventional pavement of 150 “msa” is 159.19μ.

3.3. Rutting criterion

The equivalent number of standard axle load repetitions withstood by a pavement until rut depth of at least 20 mm, in accordance with IRC 37 guidelines, for 90 % reliability levels is determined using equation (2).

$$N_R = \left(\frac{1}{\varepsilon_v}\right)^{4.5337} \times 1.41 \times 10^{-8} \qquad (2)$$

Where, ε_v is the vertical compressive strain at the top of the subgrade and N_R is the subgrade rutting life in “msa”.
According to equation (2), the allowable vertical compressive strain at the bottom of the subgrade for a conventional pavement of 150 “msa” is 292μ.
A pavement thickness greater than that allowed by the limiting value of EL does not provide any protection against structural damage. In fact, provision for greater thickness than that obtained by adopting EL may result in overdesign and extra cost. Therefore, as reported in Table 9 and shown in Figure 2, the design of the perpetual pavement was carried out using IITPAVE software until the EL of the strain values was closest to 200μ for rutting and 80μ for fatigue, whichever occurred first. In accordance with the basic concept of perpetual pavement of providing sufficient stiffness in the upper layer through thick bituminous layers, the minimum permissible thickness of the sub-base and base, according to the IRC specifications, was considered for all the pavement sections shown in Figure 3. Standard axle load of 80 KN with single dual wheel assembly and contact radius of 15.5 cm with a tire pressure of 0.56 MPa was considered in accordance with IRC 37 recommendations. It is evident that the bituminous layer thickness is significantly greater in perpetual pavements compared to conventional pavements with treated and untreated subgrade. This is because of the requirement of thicker upper layers in perpetual pavements to resist structural distresses at the top. These results are in accordance with previous studies on perpetual pavement [11]. In the present study, according to the guidelines in IRC 37, the linear elastic layered theory is used according to which all layers except the subgrade are assumed to be infinite in horizontal extent but finite in thickness, and the subgrade is considered to be semi-infinite.

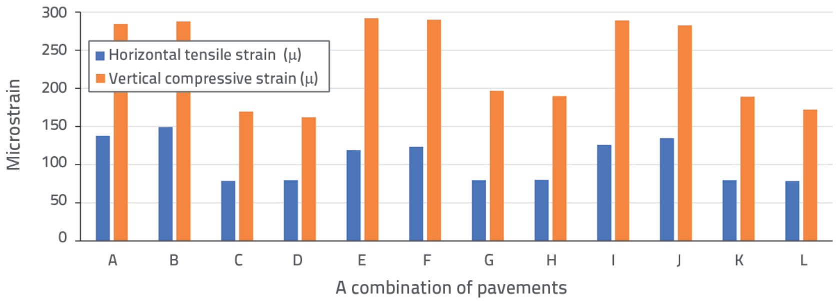

Figure 2. Strain values for different pavement sections

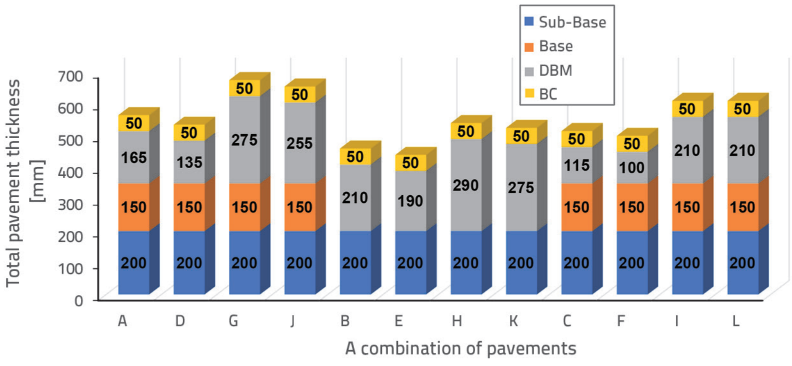

Figure 3. Pavement thickness according to pavement combination

Table 9. Thickness of pavement combinations

Pavement type	Combination	Layer thickness [mm]				Total thickness [mm]	Vertical compressive strain [μ]	Horizontal tensile strain [μ]
BC with GSB and WMM								
		GSB	WMM	DBM	BC			
Conventional	A	200	150	165	50	565	284.30	137.80
Conventional with GGBS	D	200	150	135	50	535	287.70	149.20
Perpetual	G	200	150	275	50	675	169.50	78.62
Perpetual with GGBS	J	200	150	255	50	655	162.10	79.57
BC with GSB								
		GSB		DBM	BC			
Conventional	B	200		210	50	460	292.00	119.10
Conventional with GGBS	E	200		190	50	440	290.00	123.40
Perpetual	H	200		290	50	540	197.10	79.57
Perpetual with GGBS	K	200		275	50	525	189.80	80.00
BC s CTSB and WMM								
		CTSB	WMM	DBM	BC			
Conventional	C	200	150	115	50	515	289	126
Conventional with GGBS	F	200	150	100	50	500	282.6	134.7
Perpetual	I	200	150	210	50	610	189.20	79.57
Perpetual with GGBS	L	200	150	210	50	610	172.20	78.55

4. Life cycle cost calculation

The life cycle cost comparison for a road of 14 m width and 1000 m length for all the mentioned pavement combinations was carried out using the schedule of rates for the year 2021, as shown in Table 10, for the state government of Maharashtra, India [12].

Table 10. Schedule of rates for the year 2021 in the state of Maharashtra, India

Material	Rate [US $/m^3]	MoRT&H specification clause number
CTSB	25.70	404
WMM	24.03	406
GSB	23.83	401
BC	98.78	509
DBM	92.55	507

We considered the recommended specifications of the Indian Ministry of Road Transport and Highways (MoRT&H) for material and work execution. In the present study, the net present value (NPV) method was used for long-term cost calculations with a 5 % discount rate and 10 % inflation rate [13].

The MoRT&H guidelines recommend a 25 mm BC layer overlay every five years as a part of routine maintenance [14]. In this study, parameters such as the initial construction cost, cost of periodic maintenance in the form of overlay, and life cycle cost considering five decades of service were considered. The costs of periodic maintenance considering these parameters are listed in Table 11.

Table 11. Maintenance cost (thousands of US $) for overlay of 25 mm BC

Year	Cost per m^3	Inflation cost	NPV
5.	34.36	43.85	27.23
10.	34.36	55.97	21.58
15.	34.36	71.43	17.10
20.	34.36	91.16	13.55
25.	34.36	116.35	10.74
30.	34.36	148.49	8.51
35	34.36	189.52	6.74
40.	34.36	241.88	5.34
45.	34.36	308.71	4.24
50.	Reconstruction		
		Total:	115.03

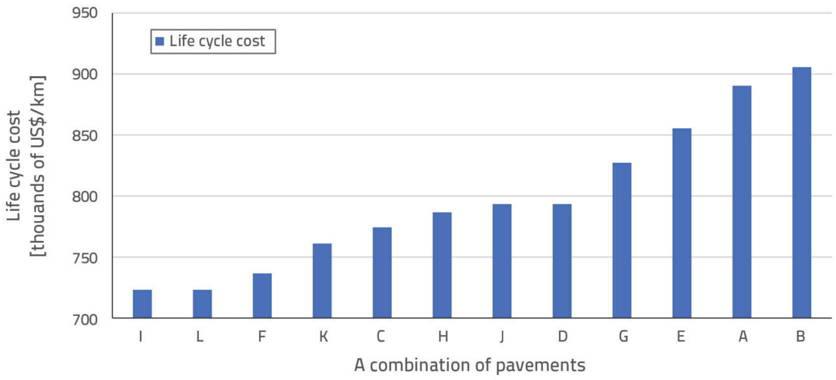

Figure 4. LCCA for pavement combinations in increasing order

While calculating the future cost of pavement construction, inflation in prices for half tenure of the design period was assumed. This consideration was based on information received from academics and engineers related to the road construction industry as well as from literature. The cost of reconstruction after every 20 years was also considered in the NPV calculation of the life cycle cost of conventional pavement with and without GGBS-treated subgrade. The calculation for the overall life-cycle cost is presented in Table 12. The life cycle cost for every pavement combination, in ascending order, is shown in Figure 4.

In the case of BC with WMM and GSB, the use of GGBS reduces the overall thickness of the pavement in the case of conventional and perpetual designs by 30 mm and 20 mm, respectively. From life cycle cost analysis (LCCA), a cost saving of 8.44 % is observed when GGBS is used in conventional pavement design. Similarly, savings of 7.06 % and 12.22 % are observed in the perpetual pavement with treated and untreated subgrades, respectively. In the case of BC with GSB, the use of GGBS reduces the overall thickness of the pavement in the case of conventional and perpetual designs by 20 mm and 15 mm, respectively. LCCA in this case shows that a cost saving of 5.86 % is observed when GGBS is used in conventional pavement design. Similarly, savings of 15.11 % and 18.97 % can be achieved in the perpetual pavement with treated and untreated subgrades. However, in the case of BC with CTSB and WMM, the use of GGBS reduces the overall thickness of the pavement in the case of conventional pavement design by 15 mm. In the case of perpetual pavement, no change in thickness is observed, irrespective of the use of treated subgrade. From LCCA, a cost saving of 5.11 % is achieved if GGBS is used in conventional pavement design. Similarly, savings of 7.06 % and 12.22 % can be achieved in the perpetual pavement with treated and untreated subgrades, respectively.

5. Carbon dioxide emission

The concept of embodied CO_2 for any material indicates the total carbon dioxide released during the production of that material. The energy used to extract, transport, and manufacture raw materials, as well as dismantle and dispose the product at the end of its lifetime, are taken into consideration to determine the embodied CO_2. Table 13 shows the embodied CO_2 for different materials based on the study of the Auroville Earth Institute and from the inventory of carbon and energy [15, 16].

Table 12. LCCA (thousands of US $) per kilometer

Pavement TYPE	Combination	Initial construction cost	Cost of maintenance	NPV	Total cost after 50 years	Saving in cost [%]
BC with GSB and WMM						
Conventional	A	400.13	115.03	375.24	890.40	-
Conventional with GGBS	D	361.24	115.03	338.76	815.03	8.46
Perpetual	G	542.66	115.03	169.58	827.27	7.09
Perpetual with GGBS	J	516.82	115.03	161.51	793.36	10.89
BC with GSB						
Conventional	B	408.08	115.03	382.50	905.61	-
Conventional with GGBS	E	382.10	115.03	358.28	855.41	5.54
Perpetual	H	511.71	115.03	159.89	786.63	13.13
Perpetual with GGBS	K	492.19	115.03	153.84	761.06	15.96
BC with CTSB and WMM						
Conventional	C	340.24	115.03	318.98	774.25	-
Conventional with GGBS	F	320.73	115.03	300.81	736.57	4.86
Perpetual	I	463.26	115.03	144.82	723.11	6.64
Perpetual with GGBS	L	463.26	115.03	144.82	723.11	6.64

Table 14 reports generalized proportions of various materials used in different layers of flexible pavement based on IRC SP:89, MoRT&H specifications, and IRC SP:53 [14,17,18].

Table 13. Embodied CO_2 (kg/kg material)

Material	Embodied CO_2
GGBS	0.07
Coarse aggregate	0.0216
Cement	0.83
Fine aggregate	0.002
Bitumen	0.48

Table 14. Generalized properties of pavement layers

Properties	Pavement layers				
	CTSB	DBM	GSB	BC	WMM
Cement (% maseni)	2	-	-	-	-
Bitumen (% maseni)	-	4.5	-	5.5	-
Aggregates (% maseni)	98	95.5	100	94.5	100
Density [kg/m^3]	2300	2300	2300	2400	2300
Coarse aggregates [%]	80	60	80	55	70
Fine aggregates [%]	20	40	20	45	30
Embodied CO_2 for 1/m^3	78.03	79.90	40.66	92.34	36.15

The embodied CO_2 for different layers of flexible pavement is also shown in Table 14 and the initial calculated CO_2 emission is shown in Table 15. An example for the calculation of the embodied CO_2 for a layer is discussed as follows.

Embodied CO_2 for 1 m^3 of pavement layer (kg) = 1 m^3 × density × (fine aggregates by mass % × embodied CO_2 of fine aggregates) + (coarse aggregates by mass (%) × embodied CO_2 of coarse aggregate) + (bitumen by mass (%) × embodied CO_2 of bitumen)], Sample calculation for embodied CO_2 for 1 m^3 layer of BC is as follows:

1 × 2400 × [(0.945 × 0.45 × 0.002) + (0.945 × 0.55 × 0.0216) + (0.055 × 0.48)] = 92.34 Kg

Sample calculation for initial CO_2 emission for combination A: [(92.34 × 0.050) + (79.90 × 0.1650) + (36.15 × 0.150) + (40.66 × 0.200)] × 14 × 1000 = 438.97 tons

The total CO_2 emissions due to reconstruction as well as maintenance activity are also considered in the calculations performed for a span of 50 years, as shown in Table 15. The total CO_2 emissions for all pavement combinations are shown in ascending order in Figure 5. The embodied CO_2 of GGBS per cubic meter of volume is approximately 120 kg according to the inventory of carbon and energy. Hence, the use of GGBS in soil stabilization compensates for some of the carbon footprint caused by slag production.

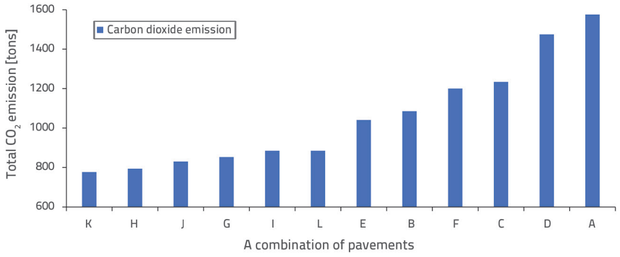

Figure 5. Total CO_2 emission for pavement combinations in increasing order

Table 15. CO_2 emissions for different pavement combinations (in tons)

Pavement type	Combination	Initial CO_2 emission	Total CO_2 emission (in 50 years)	Reduction in CO_2 emission [%]
BC with GSB and WMM				
Conventional	A	438.97	1575.46	
Conventional with GGBS	D	405.41	1474.79	6.82
Perpetual	G	562.01	852.89	84.72
Perpetual with GGBS	J	539.64	830.52	89.69
BC with GSB				
Conventional	B	413.39	1085.34	-
Conventional with GGBS	E	391.02	1040.59	4.30
Perpetual	H	502.88	793.75	36.73
Perpetual with GGBS	K	486.10	776.97	39.68
BC with CTSB and WMM				
Conventional	C	487.67	1233.90	-
Conventional with GGBS	F	470.89	1200.34	2.79
Perpetual	I	593.94	884.81	39.45
Perpetual with GGBS	L	593.94	884.81	39.45

6. Conclusion

- There is a considerable decrease in the thickness of bituminous layers in the case of pavements with treated subgrades. Although the pavement thicknesses proposed in this study are not absolute, they provide guidelines for comparing conventional and perpetual pavements. The theory of perpetual pavement suggests thicker bituminous layers to keep the strain levels below the limit. However, our study shows that providing a stable foundation, using treated subgrade and high-stiffness base materials are important factors considering the huge expenditure required for pavement construction in an oil importer country such as India. This can be related to the rising prices of crude oil worldwide.
- Cost comparison shows that BC with CTSB and WMM is the most cost-effective pavement option, whereas BC with GSB and BC with the GSB and WMM combination are the second and third choices, respectively, considering the overall cost.
- The cost calculations have been carried out with the present rate of materials. In the case of BC with GSB and WMM, the conventional pavement with GGBS is more economical than the conventional perpetual pavement without a treated subgrade. Thus, cost analysis in accordance with the current rates and correct anticipation of inflation is paramount.
- The overall analysis of CO_2 emissions shows a significant reduction in the total carbon footprint by adopting perpetual pavement over conventional pavement, considering a service period of 50 years. The analysis also shows that according to the carbon footprint, the order of preference in the selection of pavement among the combinations discussed in this study is BC with GSB, BC with GSB and WMM, and finally BC with CTSB and WMM.
- Although the initial construction cost of perpetual pavements is higher than that of conventional pavements, the benefits are notable in the long-term. A reduction in the maintenance schedule results in a decrease in natural resource consumption, energy savings, and pollution reduction. The benefits of perpetual pavement design show that perpetual pavements can be a part of sustainable development for emerging countries.

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