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TECHNICAL PAPER

STAGE CONSTRUCTION OF FLEXIBLE PAVEMENT – AN ECONOMICAL APPROACH

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ABSTRACT

India is a developing country with limited resources to upgrade as well as develop the connectivity to large number of habitations. The flexible pavements are designed by the procedure laid down in IRC:37-2018 "Guidelines for the Design of Flexible Pavements" and accordingly the pavements are being designed for 15 to 20 years design period. The subsequent renewal coats are laid at prescribed interval usually 4 to 5 years or as per pavement condition as prevalent in MoRTH and State PWDs. This paper emphasizes the concept of Stage Construction using renewal cycle period as design period utilizing the strength of existing high resilient modulus wearing course of BC in crust composition resulting in saving in initial cost and crust thickness considerably as well as reduction in carbon footprint.

1. INTRODUCTION

India has one of the largest road networks across the world, spanning over a total of 5.89 million km. This road network transports around 65 per cent of all goods in the country and 90 per cent of India's total passenger traffic uses road network to commute. Road transportation has gradually increased over the years with the improvement in connectivity between cities, towns and villages in the country. Huge investments have been made in the road sector with total investment increasing more than three times from Rs 51,914 crore (US$ 7.43 billion) in 2014-15 to Rs 158,839 crore (US$ 22.73 billion) in 2018-19 (1). The development of roads is taken up by State as well as Union Govt. in India for various categories of roads but considering the vast population and requirement of huge network of road still required to be taken up along with maintenance of existing structure based on an economical as well as durability concept is to be adopted in India.

2. PAVEMENT DESIGN

The basics of pavement design involve designing pavements for satisfactory functional and structural performance of the pavement during its intended service life period. Roughness caused by variation in surface profile, cracking of layers bound by bituminous or cementitious materials, rutting (permanent or plastic deformation) of unbound/ unmodified or partially modified subgrade, granular layers and bituminous layers are the primary indicators of the functional and structural performance of pavements.

For the satisfactory performance of bituminous pavements and to ensure that the magnitudes of distress are within acceptable levels during the service life period, the guidelines of IRC:37-2018(2) recommends that the pavement sections be selected in such a way that they satisfy the limiting stresses and strains prescribed by the performance models adopted in the guidelines for subgrade rutting, bottom-up cracking of bituminous layer and fatigue cracking of cement treated bases.

2.1 Design Life and Stage Construction in Pavement Design

Pavements are typically designed for a specified "Design Life". Design Life (or "Design Period") is the time from original construction to a terminal condition for a pavement structure. A terminal condition refers to a state where the pavement needs reconstruction. Structural design is carried out so that the pavement structure is sufficient to withstand the traffic loading encountered over the pavement's design life. It is recognized that intermittent maintenance and rehabilitation efforts may be needed to preserve a pavement's surface quality and ensure that the structure lasts through the design life.

It is recommended in IRC:37-2018 that a design period of 20 years may be adopted for the structural design of pavements for National Highways, State Highways and Urban Roads while for other categories of roads, a design period of 15 years is recommended.

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Stage construction of pavement may be adopted in projects where the growth of traffic is uncertain or future traffic volumes are expected to increase substantially due to future developments. Stage construction may also be adopted in projects for which subsequent maintenance is mandated on 'performance basis'. For projects in which stage construction is adopted, the base and sub-base layers shall be designed for the full design period. Stage construction is not allowed for pavements with cement treated bases and sub bases.

The stage construction of bituminous layer(s) of the pavement is also provided in IRC:37-2018 with the provision that it should be designed for more traffic than estimated for the initial (first) stage design period (or traffic) so that the pavement will have at least 40 % life remaining after stage-1 period (traffic). As per codal provisions the pavement life consumed increases linearly with traffic, and accordingly the design traffic for stage-1 shall be taken as 1.67 times the design traffic estimated for stage-1 period. The requirement of the second stage pavement shall be determined after evaluation of the structural condition of the pavement by Falling Weight Deflectometer (FWD) method as per IRC:115-2014 or by Benkelman Beam Deflection (BBD) method as per IRC:81-1997.

2.2 Use of Stage Construction

In India the pavement is designed for design life as prescribed in IRC:37-2018 for various categories of roads and subsequent renewal layer is provided on pavement after due renewal cycle of 4 years for NH/MDR/City roads and 5 years to 8 years for other categories of roads. Ministry of Road Transport and Highways, Government of India vide its Circular No. RW/NH-33044/10/2002-S&R(P&B) dated 21.8.2018 has issued certain guidelines based on the mode of periodic renewal.[3] Similarly various State PWDs have also issued guidelines in this regard [4] states the category wise renewal cycle duration. In this article, the concept of stage construction with due renewal cycle is studied and considering the renewal coat of BC as a Structural (part of crust composition) as well as functional layer, with subsequently reduced Resilient Modulus after stage design life.

In normal practice of road construction in India, the periodic renewals are being traditionally taken up by Government Departments, NHAI and state PWDs and accordingly since renewal coat may not be avoided at prescribed interval, it would be wiser to utilize it fully as a new wearing course having high resilient modulus hence using its strength as part of the crust composition. Accordingly designing the road for a longer period with renewal coats at prescribed intervals may not be a good option in comparison to designing the pavement for a shorter duration taking the modified reduced strength of previous wearing course into consideration.

2.3 Pavement Design using Renewal Cycle as Design Life

As per existing practice a flexible pavement is designed for a design life of 15/20 years as per IRC:37-2018. Methodology envisages current traffic to be projected to a period of 15 years on a given growth rate and provide the resultant crust. As there is a practice of providing a renewal coat of wearing course every 4-5 years, which is not counted while designing the pavement initially for 15/20 years, the practice leads to an over safe design causing unnecessary burden on the exchequer. Alternatively stage construction may be followed for enhanced design period for each stage traffic as 1.67 times the standard design traffic for stage-I. In this paper it is being highlighted that while designing a flexible pavement for 15 years it will be judicious to consider the subsequent renewal Bituminous Layers (BC) as part of crust with appropriate reduction in Resilient Modulus of designed MR of old BC, to save the cost.

Earlier when SDBC/Pre Mix Seal coat was being used as a wearing coat, it was not treated as a structural layer due to very low Resilient Modulus. Since BC is considered as part of the crust it becomes imperative to take into account the subsequent addition of crust while designing the pavement.

This paper is basically based on the following concepts:

i. The renewal layer of Bituminous Concrete having Resilient Modulus of 2000/3000 MPa may be adopted as a structural layer imparting strength to the crust in addition to a functional layer as wearing coat. The concept of authors is to provide the minimum required crust at the beginning with full granular crust (At par with full design life) and to utilize the bituminous layers to function as a structural layer, as elaborated above. Bituminous Concrete has quite high resilient modulus of 2000/3000 MPa based on viscosity grade of bitumen and traffic condition, the authors have conceptually suggested utilizing its higher strength to be used as a structural layer as well as functional layer.

ii. The Resilient modulus of the topmost bituminous layer is reduced during the design life due to repetitive exposure to traffic load and at the end of design life may reach up to 40% of the initial Resilient Modulus.

The concept of authors is that bituminous layer having Resilient Modulus of 2000 MPa shall be reduced to minimum 800 MPa and shall work as a WMM layer treated with 1% cement and 3.5% Emulsion having

Resilient Modulus of 800 MPa. Similarly bituminous layer having Resilient Modulus of 3000 MPa will be reduced to minimum 1200 MPa at the end of design life due to exposure to repetitive loading.

3 STUDY OF PAVEMENT DESIGN USING RENEWAL CYCLE:

In this paper various combinations of pavement design of full term and stage construction of pavements of MDR with new construction of pavement are taken up for comparison. These cases are discussed below:

3.1 Case -1

Category- State Highway
Construction- New construction with Conventional and stabilized aggregate CVPD- 4000, VDF- 5.0
Pavement width- 4 lane dual carriageway

The pavement was designed using IIT Pave with design period of 20 years with the provision of GSB and Emulsion treated aggregate ETA (WMM+1% cement +3.50% emulsion). Since the renewal coat of BC is provided after every 4 years as per MORTH and State PWDs circulars/guidelines, the pavement was redesigned for renewal cycle of 4, 8, 12, 16 and 20 years for extended design life of 6 years, 10 years, 14 years, 18 years and 22 years respectively. Following observations are found after designing the pavement by IIT Pave:

i. The crust composition of GSB, ETA, DBM and BC with total initial crust of 510 mm was found. After the provision of minimum 40mm BC at every 4 years, crust becomes 670 mm after 20 years design life.

ii. The pavement was designed for renewal cycle at 4 years for initial design life of 6 years with the same granular crust composition with total/initial crust thickness of 450 mm. The strains were found within the allowable limits. Subsequently the strains were checked after each renewal cycle of 8,12,16 years with design life of 10,14,18 and 22 years respectively with enhanced crust of renewal coat and consideration of old bituminous layer assuming modified Resilient Modulus of 40% of initial Resilient Modulus of bituminous layer. The strains were found well within the allowable limits. It is also observed that horizontal tangential strains (epT) and horizontal radial strains (epR) are significantly less leading to minimum cracking and rutting during its design life and providing a better ride quality.

iii. There was considerable saving in initial cost in the form of 60 mm DBM costing around Rs 95 Lacs/km and also the flexibility option of assessing and redesigning the pavement stagewise without much problem.

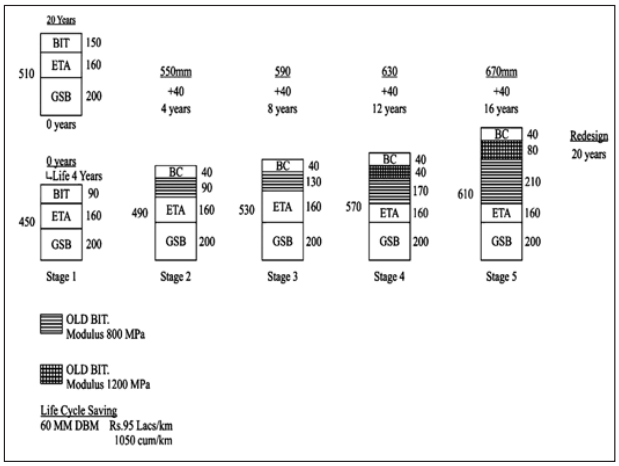
iv. The use of stabilized material leads to saving of aggregates and carbon footprint. In the state of Uttar Pradesh PWD has executed scores of projects using the stabilized layers of pavement

case1- New construction of 4 lane dual carriageway with Emulsion treated aggregates layer(ETA)* on SH

CVPD- 4000 *ETA-WMM+ 1% cement+3.50% Emulsion

PAVEMENT STATUS	Status at the end of (yrs)	Renewal cycle planned (yrs)	Design life (yrs)	MSA	CRUST COMPOSITION/Resilient Modulus in Mpa	TOTAL CRUST IN MM	allowable tensile strain	designed tensile strain	allowable vertical compressive strain	Designed vertical compressive strain
New construction design life 20 yrs		every 4 years	20	99.8	200mm GSB(350) + 160mm ETA*(800)+110mm DBM(3000)+ 40mm BC(3000)	510	$149.13x10^{-6}$	$95.42x10^{-6}$	$319.14x10^{-6}$	$318.50x10^{-6}$
Renewal coat after 4,8,12 and 16 years					40 mm BC(3000) in four renewals	670				
Stage construction-1	0	4	6	18.97	200mm GSB(350) + 160mm ETA*(800)+50mm DBM(2000)+ 40mm BC (2000)	450	$206.47x10^{-6}$	$85.87x10^{-6}$	$460.28x10^{-6}$	$452.7x10^{-6}$
Stage construction-2	4	8	10	37.96	200mm GSB(350) + 160mmETA(800) +90mm old bituminous layer(at par with ETA modulus800)+ 40mm BC (3000)	490	$191.20x10^{-6}$	$51.83x10^{-6}$	$394.98x10^{-6}$	$391.60x10^{-6}$
Stage construction-3	8	12	14	59.15	200mm GSB(350) +250mmETA(800) + +40mm exising bit layer(1200)+40mm BC (3000)	530	$170.60x10^{-6}$	$36.75x10^{-6}$	$358.17x10^{-6}$	$334.70x10^{-6}$
Stage construction-4	12	16	18	84.91	200mm GSB(350) + 250mmETA(800) + +80mm exising bit layer(1200)+40mm BC(3000)	570	$155.46x10^{-6}$	$21.93x10^{-6}$	$330.72x10^{-6}$	$289.20x10^{-6}$
Stage construction-5	16	20	22	116.2	200mm GSB(350) + 250mmETA(800) +120mm exising bit layer(1200)+40mm BC(3000)	610	$143.41x10^{-6}$	$22.69x10^{-6}$	$308.60x10^{-6}$	$252.20x10^{-6}$

Note- Resilient Modulus value is mentioned alongwith each pavement layer such as BC with VG-40 bitumen havong Resilient modulus is shown as BC(3000)



leading to huge saving in aggregate consumption having huge cost impact and reduction of Carbon Footprint. Based on the case study of two State Highway upgradation projects, it was observed that around 25-30% savings in aggregates resulted in 51400 ton of carbon emission[5].

3.2 Case -2

Category- State Highway

Construction- New construction with conventional material

CVPD- 4000, VDF- 5.0

Pavement width- 4 lane dual carriageway

The pavement was designed using IIT Pave with design period of 20 years with the provision of GSB and WMM. Since the renewal coat of BC is provided after every 4 years as per MORTH and State PWDs circulars/ guidelines, the pavement was redesigned for renewal cycle of 4, 8, 12 ,16 and 20 years for extended design life of 6 years, 10 years, 14 years,18 years and 22 years respectively . Vertical compressive strains and horizontal tensile strains were checked by IITPAVE and following observations are found:

i. The crust composition of GSB, WMM, DBM and BC with total initial crust of 570 mm was found. After the provision of minimum 30 BC at every 4 years, crust becomes 690 mm after 20 years design life.

ii. The pavement was designed for renewal cycle at 4 years as first stage for initial design life of 6 years with the same granular crust composition with total/initial crust thickness of 530 mm.The strains were found within the allowable limits. Subsequently the strains were checked after each renewal cycle of 8,12,16 and 20 years with design life of 10,14,18 and 22 years with enhanced crust of renewal coat and consideration of old bituminous layer assuming modified Resilient Modulus of 40% of initial Resilient Modulus of bituminous layer. The strains were found well within the allowable limits. It is also observed that horizontal tangential strain(epT) and horizontal radial strains (epR) are significantly less leading to minimum cracking and rutting during its design life and providing a better ride quality.

case2- New construction of 4 lane dual carriageway with conventional aggregates on SH

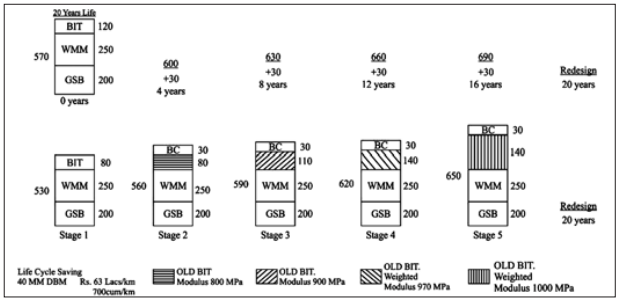
CVPD- 4000

PAVEMENT STATUS	Status at the end of (yrs)	Renewal cycle planned (yrs)	Design life (yrs)	MSA	CRUST COMPOSITION/Resilient Modulus in mpa	TOTAL CRUST IN MM	allowable tensile strain	designed tensile strain	allowable vertical compressive strain	Designed vertical compressive strain
New construction design life 20 yrs		every 4 years	20	99.8	200mm GSB(350) + 250mm WMM(450)+90mm DBM(3000)+ 30mm BC(3000)	570	$149.13x10^{-6}$	$147.1x10^{-6}$	$319.14x10^{-6}$	$316.60x10^{-6}$
Renewal coat after 4,8,12 and 16 years					30 mm BC in four renewals	690				
Stage construction-1	0	4	6	18.97	200mm GSB(350) + 250mm WMM(450)+50mm DBM(2000)+ 30mm BC(2000)	530	$206.47x10^{-6}$	$189.0x10^{-6}$	$460.28x10^{-6}$	$396.80x10^{-6}$
Stage construction-2	4	8	10	37.96	200mm GSB(350) + 250mm WMM(450)+80mm old bituminous layer(800)+ 30mm BC (3000)	560	$191.20x10^{-6}$	$24.69x10^{-6}$	$394.98x10^{-6}$	$357.00x10^{-6}$
Stage construction-3	8	12	14	59.15	200mm GSB(350) +250mm WMM(450) +110mm old bituminous layer(900*)+ 30mm BC(3000)	590	$170.60x10^{-6}$	$7.45x10^{-6}$	$358.17x10^{-6}$	$316.20x10^{-6}$
Stage construction-4	12	16	18	84.91	200mm GSB(350) + 250mm WMM (450) +140mm old bituminous layer(970)+ 30mm BC(3000)	620	$155.46x10^{-6}$	$7.54x10^{-6}$	$330.72x10^{-6}$	$286.20x10^{-6}$
Stage construction-5	16	20	22	116.2	200mm GSB(350) + 250mm WMM (450)+170mm old bituminous layer(1000)+ 30mm BC(3000)	650	$143.41x10^{-6}$	$6.76x10^{-6}$	$308.60x10^{-6}$	$258.60x10^{-6}$

* weighted resilient modulus=(80*800+30*1200)/110=909 say 900Mpa

iii. There was considerable saving in initial cost in the form of 40 mm DBM costing around Rs 63 Lacs/km and also the flexibility option of assessing and redesigning the pavement stagewise without much problem.

iv. For the same data as in Case-1 above, where the base course of ETA is used the total crust thickness for 20 years design life comes out to be 510 mm while in conventional approach in this case, where the base course of WMM is used, the total crust thickness for the same life is 570 mm. This shows the impact of using the technique of stabilized pavement layers.



3.3 Case -3

Category- MDR

CVPD - 1500 , Pavement width- 2 lane single carriageway

The pavement was designed using IIT Pave with design period of 15 years with the provision of GSB and Emulsion treated aggregate ETA (WMM + 1% cement + 3.50% emulsion). Since the renewal coat of BC is provided after every 4 years as per MORTH and State PWDs circulars/ guidelines, the pavement was redesigned for renewal cycle of 4, 8, 12 and 16 years for extended design life of 6 years, 10 years, 14 years and 16 years respectively. Vertical compressive strains and horizontal tangential and radial strains were checked by IITPAVE and following observations are found:

i. The crust composition of GSB, ETA, DBM and BC with total initial crust of 460 mm was found. After the provision of minimum 40 mm BC at every 4 years, crust becomes 580 mm after design life.

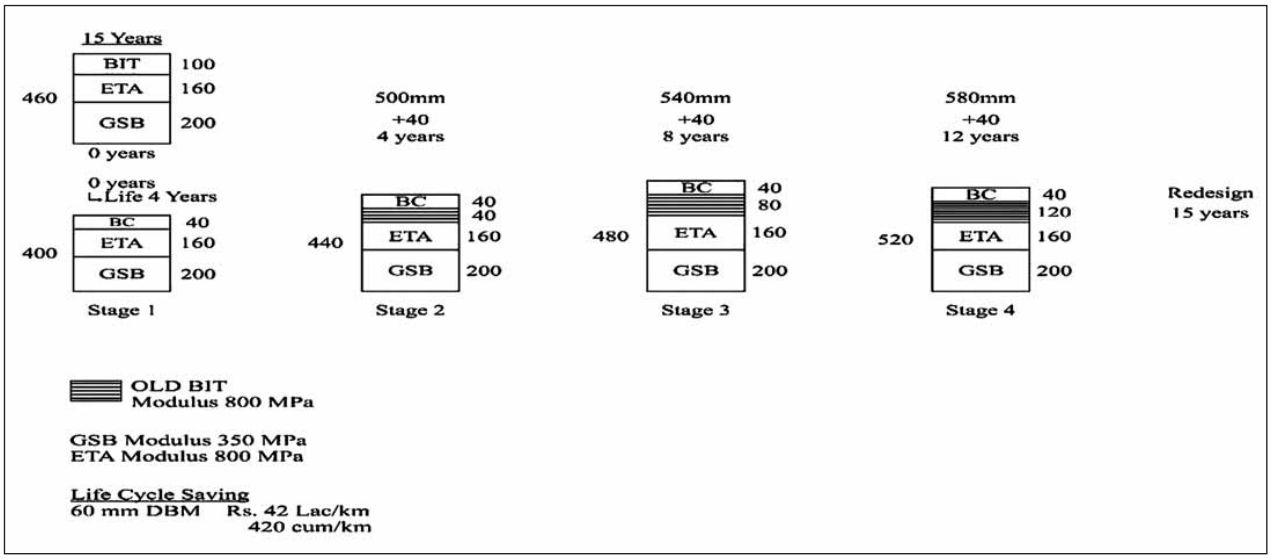
ii. The pavement was designed for renewal cycle at 4 years for initial design life of 6 years as first stage with the same granular crust composition with total/initial crust thickness of 400mm. The strains were found within the allowable limits. Subsequently the strains were checked after each renewal cycle of 8,12,16 years with design life of 10,14, and 16 years with enhanced crust of renewal coat and consideration of old bituminous layer assuming modified Resilient Modulus of 40% of initial Resilient Modulus of bituminous layer. The strains were found well within the allowable limits. It is also observed that horizontal tangential strains (epT) and horizontal radial strains (epR) are significantly less leading to minimum cracking and rutting during its design life and providing a better ride quality.

iii. There was considerable saving in initial cost in the form of 60 mm DBM costing around Rs 42 Lacs/ km and also the flexibility option of assessing and redesigning the pavement stagewise without much problem.

Case 3- New Construction of 2 Lane single carriageway with Emulsion treated aggregates layer(ETA)* on Major District Road

CVPD- 1500

PAVEMENT STATUS	Status at the end of (yrs)	Renewal cycle planned (yrs)	Design life (yrs)	MSA	CRUST COMPOSITION	TOTAL CRUST IN MM	Allowable tensile strain	designed tensile strain	Allowable vertical compressive strain	Designed vertical compressive strain
New construction design life 15 yrs		every 4 years	20	31.01	200mm GSB(350) + 160mm ETA*(800)+60mm DBM(3000)+ 40mm BC(3000)	460	$201.41x10^{-6}$	$112.20x10^{-6}$	$413.00x10^{-6}$	$407.0x10^{-6}$
Renewal coat after 4,8 &12					40 mm BC(3000) in three renewals	580				
Stage construction-1	0	4	6	9.78	200mm GSB(350) + 160mm ETA*(800)+ 40mm BC (2000)	400	$327.79x10^{-6}$	$27.51x10^{-6}$	$676.48x10^{-6}$	$580.70x10^{-6}$
Stage construction-2	4	8	10	18.08	200mm GSB(350) + 160mmETA(800) +40mm old bituminous layer(at par with ETA modulus800)+ 40mm BC (2000)	440	$279.89x10^{-6}$	$30.17x10^{-6}$	$590.74x10^{-6}$	$492.40x10^{-6}$
Stage construction-3	8	12	14	28.17	200mm GSB(350) +160mmETA(800) +80mm exising bit layer(800)+40mm BC (3000)	480	$206.44x10^{-6}$	$51.10x10^{-6}$	$421.84x10^{-6}$	$406.20x10^{-6}$
Stage construction-4	12	16	16	34.00	200mm GSB(350) + 160mmETA(800) +80mm exising bit layer(800)+40mm existing bit layer(1200)+40mm BC(3000)	520	$196.70x10^{-6}$	$26.22x10^{-6}$	$404.70x10^{-6}$	$346.30x10^{-6}$



4. CONCLUSION:

By the above studies it is concluded that stage construction may be effectively applied in the design of flexible pavements using successive renewal cycles as design life. By adopting stage construction and using the strength of renewal coat of BC, we can not only utilize the successive renewal coats to the full extent but may also utilize the cost incurred on successive renewal coats which in case of full design period becomes redundant. By adopting the stage construction, we also get the opportunity to accommodate the actual traffic conditions vis-a vis the predicted one during a shorter span of time instead of 15 or 20 years. In a developing country like India, large variations are seen in traffic conditions, so stage construction will help in achieving better economical and more acceptable results.

Based on above study we may conclude that for a developing country like India where resources are scarce, stage construction may be adopted to achieve overall economy and reduction in Carbon Footprint.

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