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Review on Design of Perpetual Pavement for Expressways: Case Study of Bengaluru-Chennai Expressway

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ABSTRACT: India is seventh largest country by area and has the second largest road network in the world with length of 6.21 million km. USA is the third largest country by area and has the largest road network in the world with a length of 6.58 million km. Aiming for fast pace of development of road network to achieve connectivity between economic hubs and safe roads, the Government of India have taken initiative to build 800km of Expressways under Bharatmala Pariyojana. Apart from this the several State Governments are building Expressways. Conventional Pavement has design life of 15 years. New construction technology has evolved for a long life Pavement also known as “Perpetual Pavement”. The Perpetual pavement is a long life pavement designed for more than 30 years and can have a design life of up to 50 years without major structural rehabilitation and/or reconstruction activities and needing only periodic surface renewal in response to distresses confined to the top of the pavement. The Perpetual pavement concept was derived on a principle that thickly designed asphalt pavements with the appropriate material combinations, if properly constructed, will structurally outlive their design lives while simultaneously sustaining high traffic volumes/loads. The design philosophy is such that the pavement structure must have enough structural strength to resist structural distresses such as fatigue cracking, permanent deformation, and/or rutting; and be durable enough to resist damage due to traffic forces and environmental effects. This study discusses the use of Perpetual Pavement Design for Expressways in India using Indian Design Codes.

KEYWORDS: Perpetual Pavement Design, Fatigue Life, Rut Resistant, Pavement Material

I. INTRODUCTION

The primary reasons to build Expressways are to cater for high volume of traffic and achieve fast connectivity to economic hubs. This results in longer driving hours for drivers on high speed with limited stoppages. Due to this Expressways require highest safety measures and comfort conditions for drivers. One of the basic requirements for roads is to have minimum maintenance so that the traffic disruptions are limited. To achieve this the basic requirements are as follows:

- a. Adequately designed pavement from structural strength considerations, and
- b. Enhanced safety requirements, compatible with high traffic speeds and volumes;
- c. Adequate driving comfort for long distance high speed travel;
- d. Provision of the needed safety and comfort levels on a sustained basis without any dislocation, disturbance or inconvenience to the traffic.

Safety and comfort of user's aspects are related more to the surface characteristics. While the structural aspects are generally covered in IRC design standards coupled with MORTH policy.

Traffic Safety depends on a number of factors including pavement surface characteristics, the vehicles and the drivers, safe vehicle pavement interaction at high speeds. Adequacy of geometric design for the traffic speeds and volumes, special attention is needed to the aspect of skid resistance and hydro-planning.

Driving Comfort considerations call for increasingly more even surface with increase in speed. These properties of the pavement are related to its surface texture and surface drainage characteristics. More stringent norms for surface stability and hardness needs to be adopted for Expressways compared to other highways. The choice of construction

material, construction methodology and quality control techniques must be compatible to achieve the surface evenness levels needed level for Expressways.

The three main characteristics expected of an Expressway pavement surface from the users' point of view are:

- i. Good riding quality (low roughness value);
- ii. Skid-resistance i.e. good pavement - tyre friction including under wet weather situation;
- iii. Absence or limitation of rutting on wheel tracks.

A pavement having a life of fifty years or longer is generally termed as a long-life pavement or Perpetual pavement. IRC 37 2018 suggests that In India the Average Annual Pavement Temperature is close to 35°C and considering the endurance limit of the material, if the tensile strain caused by the traffic in the bituminous layer is less than 70 microstrain the bituminous layer will never crack. Similarly, if the vertical subgrade strain is less than 200 microstrain, there will be practically very little rutting in the subgrade. The design codes suggests that pavements with design traffic of 300msa or more may be designed as long-life pavements. Thus, long-life pavement design involves selecting a suitable pavement layer combination which can keep the horizontal tensile strain and vertical compressive strain limited to the afore-mentioned limiting strain values corresponding to endurance condition. Different layers of the long life pavement have to be designed and constructed in such a way that only the surface course would need replacement from time to time.

Pavement Performance Requirements are as follows:

- i) The pavement structure shall be capable of giving the specified performance over the entire operation period.
- ii) The flexible pavement surface shall satisfy the following standards:
 - a) Surface Finish: As per requirements of Clauses 902 and 903 of MORTH Specifications.
 - b) Roughness: In each lane measured by calibrated Bump Integrator: Not more than 1800 mm/km for each lane in a km length.
 - c) Rutting: In wheel path measured by 3 m Straight Edge: Nil
 - d) Cracking or any other distress: Nil
 - e) Surface macro-texture depth for satisfactory skid resistance: Not less than 1.00 mm (measured by sand patch test).
- iii) The new rigid pavement shall satisfy the following following standards:
 - a) Surface Finish: As per requirements of Clauses 902 and 903 of MORTH Specifications.
 - b) Roughness: In each lane measured by calibrated Bump Integrator: Not more than 1800 mm/km for each lane in a km length.
 - c) Cracking distress, texture as specified in IRC: 15 and IRC: SP: 83.

Designing a pavement that satisfies the performance criteria requires higher capital cost, and maintaining the pavement to the satisfactory performance criteria requires maintenance at periodic interval. Which in turn requires high maintenance cost at frequent intervals. With the large road network in India this maintenance cost could be astronomical for conventional pavement.

Also, the increasing cost of construction materials along with the heavy axle load & environmental conditions leads to premature failure of roads leads to construct more economical and long life pavements.

Perpetual pavements are engineered for a life for 30 years which provides high structural capacity, low user delay and rehabilitation, however it requires higher capital cost for construction and thus reduces the maintenance cost and benefits in long-term.

A case study of the Bengaluru Chennai Expressway was carried out to design the Perpetual Pavement using the data from the project and making an assessment for the various parameters used for design of pavement. A study was also carried out by varying the CBR% data to analyze the variation on the pavement design. It was noted that there is very slight change in the pavement design by varying the CBR% by > 8%. Further a study was carried out to work out the Life Cycle Cost of the Perpetual Pavement and compare it with the Life Cycle Cost of the Conventional Pavement.

II. STATE OF DEVELOPMENT

A comprehensive literature search was conducted and the concept of design of Perpetual Pavements, implications and future aspects were carried out and the findings from the previous research papers are included in this study. Recent developments in materials selection, mix design, and performance tests are said to offer the potential to construct pavement structures that will last over 50 years with periodic replacement of the pavement surface. A Perpetual Pavement structure will comprise of three-layered bituminous pavement system

- A rut-resistant, impermeable, wear-resistant and renewable top structural bituminous surface layer
- A rut-resistant and durable bituminous intermediate binder layer
- A fatigue-resistant and durable bottom bituminous base layer resting over a durable foundation (sub-base and sub-grade)

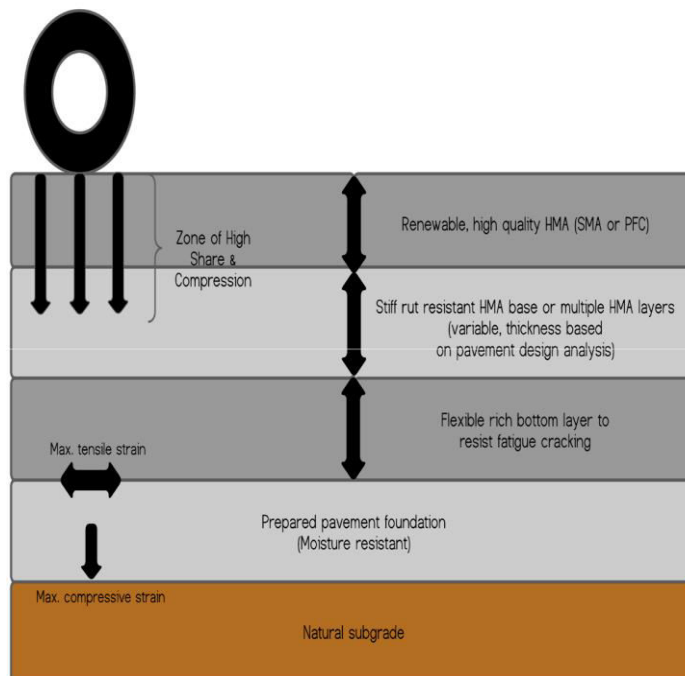


Fig.1 General Principal of Perpetual Design

I V S S Krishna Chaiatanya, Elegesan. R [1] The Perpetual Pavement design concept is based on the principles of thicker HMA pavement design using appropriate material combination to achieve long life. The design philosophy is based on requirement that the pavement must achieve enough strength to resist

- Structural distress such as bottom-up fatigue cracking, permanent deformation and rutting
- Resist damage due to traffic forces

Saurabh Kulkarni, Mahadeo Ranadive [2], The 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. The relevance of Perpetual pavements was justified based on life-cycle cost assessment and carbon dioxide emissions for a duration of 50 years.

IRC 37-2018 [3] Guidelines for the Design of Flexible Pavements, the pavements for very high density corridors (more than 300 MSA) and expressways shall preferably be designed as long-life pavements and proposes the vertical compressive strain 200μ and horizontal tensile strain 80μ for rutting and fatigue limits.

IRC:SP:99-2013 [4], Gives detailed requirement for design and construction of pavement for Expressways either flexible or rigid.

Guidelines for Expressways [5], Gives detailed requirement corresponding to enhanced safety, driving comfort, riding quality and maintenance requirements.

Chandan Basu, Atasi Das, Pavanaram Thirumalasetty, Tanmay Das [6], Aims at studying the potential Perpetual and non-conventional pavement types applicable for highways and compares with the conventional types in terms of the economics of construction. Hypothetical road with three scenarios of 2-lane, 4-lane and 6-lane highways were envisaged. But, realistic design parameters were adopted. The life cycle cost of conventional and Perpetual pavements are worked out using the current rates of construction.

K.Anusha, B.Krishna Naik [7] The study of Life Cycle Cost Analysis of Flexible, Rigid, Perpetual Pavements has brought out the pavement design and life cycle cost analysis in respect of conventional flexible pavement, Perpetual pavement, conventional rigid pavement. The pavement design for all these alternatives were been evolved in terms of initial design thickness for design life of the pavement and periodical rehabilitation required as overlay thickness for life cycle of 50 years. The cost analysis in terms of initial cost of construction of the pavement and rehabilitation cost of pavement over life cycle of the pavement.

Satyarth, Dr. Pradeep K. Gupta [8] This paper focuses the design of flexible pavement as per the guidelines of IRC:37-2012 with an appropriate and productive combination of maintenance and designed life. The paper aims at proposing a design of Perpetual Pavements with the use of IIT PAVE and IRC 37, 2012 for a stretch in Panchkula where there is dense traffic as high as 500 msa. The pavement is designed for calculated msa and with the obtained values of horizontal and vertical strains for the actual designed msa was calculated and checked for the fatigue and rutting type of failure when the pavement is designed for a design life of 40 years or more.

Manikanta Vangari, C.L Pravallika, G. Sai Reddy [9], The study focuses on the pavement performance, durability, maintenance requirements, hydrologic benefits, and environmental considerations of a full-depth composite recycled asphalt pavement in any climate. The findings were that the Perpetual Composite pavements mitigate various structural and functional problems that typical flexible or rigid pavements tend to present, such as hot-mix asphalt (HMA) fatigue cracking, subgrade rutting, Portland cement concrete (PCC) erosion, and PCC Loss of friction, among others. At the same time, though, composite systems are potentially more prone to other distresses, such as reflective cracking and rutting within the HMA layer. Premium HMA surfaces and/or reflective cracking mitigation Techniques may be required to mitigate these potential problems. Perpetual composite pavements are the pavements designed from bottom to top to resist structural failure, minimizing cracking and rutting with only periodic maintenance of the wearing course for a period of more than 50 years. The rigid pavement used under the asphalt pavement makes it stronger than the general asphalt pavement.

Shinde. S. S., Kore. S. B., Bavane. N. U., Kadam. S. R. [10], Perpetual Pavement is characterized by higher construction costs compared to conventional flexible pavement designs, they require less maintenance and less frequent rehabilitation over the 50 year lifecycle if designed and constructed properly. Pavement design can save on materials and energy used in maintenance over the pavement lifecycle and reduces the noise and emissions accompanied by maintenance activities. All these benefits lead to decrease in maintenance cost through the pavement lifetime and improve sustainability. Perpetual Pavements are a viable option for constructing structurally stable and long lasting roads with minimal maintenance and other overheads for Indian conditions

Mr. Vivek Shete, Dr. Gopal Mulgund [11], The aim of the Perpetual pavement design is to achieve long life for pavement. There are some additional factors like climate, which imposes the extra challenge. The study involves the evaluation of the Perpetual pavement design in the real time road networks and highways and its comparison with conventional pavement design. Considerations of the severe impact of the year-round environmental conditions that affect pavements in different countries were also studied.

Mithil Mazumder, Hyunhwan Kim, Soon-Jae Lee [12], This paper reviews the importance of Perpetual pavement in future pavement networks. Definition of Perpetual pavement including its mechanistic-empirical design principles and difference with conventional pavement are discussed. Specific layer purposes and distresses are provided. Recommendations are given for future research in order to obtain an optimum asphalt Perpetual pavement design.



IRC 9-2022 [13] Provides guidelines on the various methods for traffic data collection, its duration, frequency, location, compilation and safety aspects which determines the quality and type of vehicle classification to be adopted. It also explains the various automatic traffic count equipment's and methods to be selected based on various parameters.

IRC:64-1990 [14] Provides guidelines on the speed-flow relationships, level of service for various category roads, capacity and design service volumes for various category roads, equivalency factor for converting vehicles data to PCU for various road category. It also recommends the design service volume for multi-lane roads.

IRC:108-2015 [15] Provides guidelines for methodology for traffic analysis and forecast on highways and application of seasonal variation, growth factor/ rates and various methods of estimation of forecast.

IRC:SP:19-2020 [16] Provides guidelines for carrying out the different traffic surveys required for preparation of road project.

IRC:SP:89 (Part II) -2018 [17] Provides the design methodology for stabilized pavement. It gives the details of the requirements for the material and testing used for conventional stabilization and commercial chemical stabilization to be used in sub-base and base.

S.K. Bagui, Atasi Das [18], This paper reviews the materials to be used, aggregate grading, bitumen quality control adopted during execution and major causes of failure of Perpetual pavements.

Sang ICK Lee, Lubinda F. Walubita, Sheng Hu, Tom Scullion [19], This paper reviews a critical review of field performance is warranted with recommendations on how to make the PPs cost competitive with both conventional 20 years flexible pavements and rigid concrete pavements. Thus, this study was initiated with the following goals: • To synthesize case studies on in-service PPs with life cycle cost (LCC) comparison with conventional flexible and rigid pavements. • To recommend modification to the current PP design and enhance existing mechanistic empirical (M-E) design software by incorporating the developed Perpetual pavements design procedure. • To recommend the best practice for construction of Texas.

Robert Q. Kluttz, Raj Dongre, R. Buzz Powell, J. Richard Willis, David H. Timm [20], This paper reports on the final surface characterization and full forensic analysis of a highly modified asphalt pavement versus conventional Hot Mix Asphalt (HMA) at the National Center for Asphalt Technology (NCAT).

Rafiqul A. Tarefder, Damien Bateman [21], The main goal of this research was to provide guidance for future designs of Perpetual pavements in the state of New Mexico.

Saud A. Sultan, Zhongyin Gu [22], This paper reviews the use of cement stabilized RAP materials as base layer in new or rehabilitated Perpetual pavements in China 265 increases the service life, and structural capacity while reduces the cost of rehabilitation.

U.S. Department of Transportation, Federal Highway Administration [23], This paper reviews the Perpetual pavement for this project to reduce overall life-cycle costs and to increase the sustainability of the pavement. This design limits future rehabilitation activities to the surface course and minimizes the impacts to traffic by limiting long-term work zones and costly reconstruction alternatives in the future.

Gholam Ali Shafabakhsh, Mehdi Koohmish [24], The main aim of this research was to evaluate and compare Perpetual pavements with conventional flexible pavements and to study the possibility of their use instead of conventional flexible pavements for high-traffic-volume rural routes and various climatic conditions prevailing in some cities in Iran.

Saurabh Kuklarni, Mahadeo Ranadive [25], This study focuses on comparing the outputs obtained through the use of some of these software with the help of a data suitable to Indian scenario. The study further focuses on the process of selection of a particular design and analysis software according to the region and also highlights the problems associated in using such software in context with Indian Conditions.

Mark Buchner, David Newcomb, Jim Huddleston [26], This paper reviews design and construction of full depth Perpetual pavements.



Aleksander Szwed, Inez Kamieska [27], This paper reviews a two-step method for stiffness distribution design with application to Perpetual pavements is proposed. In the first step resultant stiffness of asphalt concrete layers is estimated using nomograms obtained via solution of three-dimensional problem of a layered half-space. As controlling parameter vertical strain in the soil base is used. In the second step simplified model of composite beam is applied to predict distribution of stiffness within the asphalt layers.

S Gireesh Kumar, J Satya, Kratagya Mittal, Sridhar Raju [28], The present studies to aims at designing a high modulus Dense Bituminous Macadam (DBM) mixture for Perpetual pavements using Industrial Grade (IG) bitumen in combination with Viscosity Grade (VG30) bitumen.

III. CONCLUSION

Perpetual Pavements are becoming more accepted and popular due to its sustainability. Users of Perpetual pavement enjoying benefits of improving safety and low user delay cost due to less maintenance activities, there are also concerns, including modification to the design procedure, economic application and material restriction.

Perpetual Pavement provides long-term solution to ever increasing traffic volumes with sporadic overloading observed on Indian roads and therefore, it should be adopted in India on proposed Expressways. Perpetual Pavement design can save on materials and energy used in maintenance over the pavement lifecycle and reduces the noise and emissions accompanied by maintenance activities. All these benefits lead to decrease in maintenance cost through the pavement lifetime and improve sustainability. Perpetual Pavements are a viable option for constructing structurally stable and long lasting roads with minimal maintenance and other overheads for Indian conditions.

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