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Design of Low Volume Rural Roads with Unbound Granular Materials using Odemark's Method

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***Abstract*— A large section of rural roads are found to fail due to failure of soft subgrade in alluvial soil deposit in Eastern part of India. Failure of such subgrade can be limited by use of suitable layers of unbound granular sub base and base on the top of subgrade . Present paper deals with design of pavement of low volume roads by Mechanistic-Empirical design approach using unbound granular materials for optimization of construction cost. Improvement of sub-grade and sub-base in road pavement is possible by use of suitable mix of alluvial soil with suitable admixtures. Pavement design approach in present paper is based on limiting the vertical compressive stress at the interface of granular unbound base and granular sub base layer in a three layer pavement structure. The formulation adopted in present work is based on the AASHO road test and relates to a decrease of Present Serviceability Index(PSI) by 2.0-2.5. Odemark's[9] approach has been used in this paper to transform the multilayered system to a semi infinite half space for use of Boussinesq's equation for determination of stress and strains to find out the required pavement thickness. The results thus obtained using present formulation have been compared with relevant international findings and may be used with better degree of reliability for design of low volume rural road with unbound granular materials.**

Index Terms*— Mechanistic-Empirical; Odemark's; Boussinesq's; Unbound granular base, sub base, subgrade, road pavement.

I. Introduction

India has emerged as one of the fastest growing economy in world in last decade. Presently, emphasis has been laid in its economic policy, to create better employment opportunity of direct and direct employment by enhancing its road network in order to reduce the gap of surface connectivity. India being one of the largest country in the world with huge population, has adopted the plan of extensive rural road connectivity named as Pradhan Mantri Gram Sarak Yojna (PMGSY) with every village in the country by all weathered road. The length of such rural road network is more than two third of India's total road length. However, most of the rural road section in India presently may be considered as low volume road which may further be upgraded to suitable level of road such as Other District road (ODR) or Major District Road (MDR) based on the actual traffic attracted in a given route during the design life of such roads. Therefore, at present low volume rural road (LVR) constitutes an integral component of the total road network in India. In this backdrop, new construction and upgradation of such roads would require suitable design and construction approach with alternative materials for optimization of huge project cost. In this context, present paper deals with determination of pavement thickness with unbound granular materials for low volumes rural roads based on AASHO[1] recommendation using odemark's[10] approach.

II. RURAL ROADS: APPLICATION OF ALTERNATE CONSTRUCTION MATERIALS

In order to achieve the path of sustainability in road construction, application of waste material and locally available resources has gained importance in recent times. Presently in India, annual solid production has reached 960 million ton generated as byproduct during industrial, mining, municipal, agricultural and other process. Out of this total waste nearly 30% consists of inorganic waste of industrial and mining sector, Blast furnace slag, construction and demolition material and mill tailing etc which may be used as granular base or sub-base material. Whereas Fly ash, Rice husk ash, Cement kiln dust, marble dust etc may be used for soil stabilization or as filler in Bituminous mix. Use of alternative materials in base and subbase including waste materials primarily reduces the cost significantly in pavement construction with unbound granular base and sub-base. Keeping this in view, application of alternative materials including waste in low volume rural road construction can be made with suitable design approach. The other way to reduce the cost of pavement is to improve the subgrade strength. It has been

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a common experience in India that most frequently the pavement fails due to failure of soft sub-grade, especially in alluvial soil deposit. Therefore, improvement of sub-grade by appropriate blending of Rice husk ash, Flyash, Lime with alluvial soft clay can be made to get a compacted sub-grade of adequate California Bearing Ratio (CBR) even under soaked condition. So, use of waste materials in soil stabilization in preparing compacted sub-grade layer or to use in granular base and sub-base would be a better alternative for construction and up-gradation of India's longest length of low volume rural road network.

III. DESIGN APPROACH

In the present paper, the pavement has been considered as three layer system as shown in Figure -1. The top layer consists of compacted unbound granular base of the thickness $h_1$with elastic modulus (E_1). The intermediate layer is a granular sub-base with thickness of h_2 and elastic modulus (E_2) resting on sub-grade soil with a modulus of (E_3). Various research works [3],[4],[7] have already been done for design of Flexible pavements which recommends the vertical compressive strain on the top of sub-grade or radial tensile strain at the bottom of bituminous layer as design criteria. Moreover, stress based or deflection based design criteria[3] have also been evolved. Each of these methods recommends to limit the stress, strain or deflection in different layer interface to determine the required thickness and modulus of constituent layers for a specified design load repetitions. Indian experience with gravel roads or roads with different unbound materials are limited.

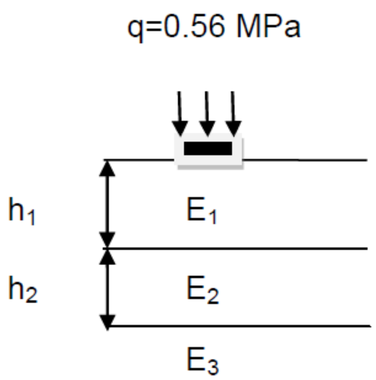

Figure 1.Typical Structure of Three layered flexible pavement.

Design approach in this paper includes the parameters like material properties traffic and environment factor for formulation of a model based on pavement response in terms of roughness. In present case, Danish criteria9 which are based on the vertical compressive stress at the top of , unbound layers has been considered in the analysis and presented below.

σ_z perm = 0.164 (N/ 10^6 x R)$^{(-1/3.26)}$ X (E /160)$^{\alpha}$ MPa, -- --- (1.0)

where, α= 1.16 if E < 160 MPa, else α= 1.0, N is the number of standard axle load repetitions, R is the regional factor of 2.75 has been used in this paper and E is the Modulus of material in MPa.

Odemark's approach:

Permissible vertical stress at the top of sub-base layer which acts at the interface of granular base and sub-base has been considered as failure criteria for analysis in the present work. To find out the vertical stress on the top of granular sub-base, Odemark's[10] method has been used to transform the multilayer system to semi infinite elastic half space for use of Boussinesq's approach.

Odemark's method assumes that the stress or strain below a layer depend on the stiffness of that layer only. If the thickness, modulus and poisons ratio of layers are changed but the stiffness remain unchanged the stress and strains below the layer should also remain unchanged. The transformation of layers can be done in the following manner as shown in Fig 2.0 by Odemark's approach.

The two layer system with modulus of E_1 of thickness h_1 with Poisson ratio ν_1 as top layer resting on bottom layer with modulus of E_2 and Poisson ration of ν_2. Transformation of such two layered system can be done with a concept of equivalent thickness (he) with a homogeneous modulus (E_2) and with a Poisson ratio of ν_2, which can be expressed as

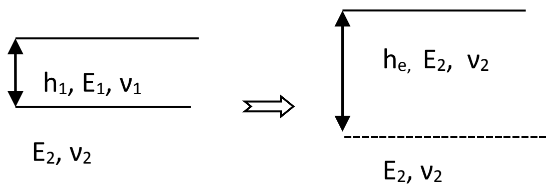

Figure 2. Transformation of a layered system by Odemark's Approach.

$$h_e = h_1 \sqrt[3]{\frac{E_1}{E_2}\left(\frac{1-\nu_2^2}{1-\nu_1^2}\right)} \quad \text{........................(2)}$$

Where he is termed as equivalent thickness. Considering ν_2 = ν_1 i.e. poisons ratio of layers are approximately same for constituent granular layers the following relationship can be obtained. It is evident from such transformation that the two layers with modulus E_1 and E_2 can be transformed in to a system with an uniform modulus E_2 with equivalent thickness of h_e.

$$he = \sqrt[3]{\frac{E_1}{E_2}} \quad \text{................................(3)}$$

Design input parameters

For determination of thickness of pavement the diameter of the loaded area has been combined as 300mm which carries an uniformly distributed load of 5.6 kg/cm^2 which acts the top surface of the pavement and has been shown in Figure 1.

The minimum elastic modulus (E_1) of unbound granular base layer has been recommended[5] as 100% CBR . However, according to IRC:37-2012[7] the elastic modulus of granular sub-base layer may be expressed as

$$(E_2) = 0.2\,(h_2)^{0.45}\,E_3 \quad \text{in MPa} \qquad \text{.....................................(4)}$$

Where h_2 = Thickness of granular sub-base (mm). Unbound Granular Subbase thickness of 100mm and 150 mm have been considered in the present analysis.

$$E_3 = 10\ \text{CBR} \quad \text{in (MPa) for CBR} \leq 5\% \qquad \text{.......................(5)}$$

$$= 17.6\,(\text{CBR})^{0.64} \text{ in MPa if CBR} > 5\% \qquad \text{………… (6)}$$

Where (E_3) is the Resilient Modulus of sub-grade.

The vertical stress σ_z acting at a depth he from pavement surface may be determined using Boussinesq's[10] theory and may be expressed as

$$\sigma_z = q.\left[1-\left(\frac{h_e}{\sqrt{a^2+h_e{}^2}}\right)^3\right] \qquad \text{……………................... (7)}$$

Where q = surface stress intensity and a = radius of contact between tyre and pavement.

Therefore, solving equation (1) and (7), and using back calculation technique, the thickness of pavement can be obtained for different axle load, environmental factor, sub-base thickness and sub-grade strength. Result of analysis using present approach for design of flexible pavement with unbound granular base and sub-base have been presented in Table-1.0 to Table 2.0.

IV. RESULTS AND DISCUSSIONS

The Elastic modulus (E_1) of first layer has been considered as 100% CBR i.e 335 MPa. The elastic modulus (E_2) of granular sub-base layer has been determined for various sub-grade strength and thickness of sub-base layer as described in previous section. In the present study, variation of sub-grade CBR from 2-10% has been considered and two different unbound granular sub-base thicknesses of 100mm and 150mm have been considered for determination of pavement thickness. Rural roads with cumulative ESAL repetitions more than 1,00,000 with unbound granular bases which comprise conventional Water Bound Macadam (WBM), Wet Mix Macadam (WMM) or Crusher run Macadam Base (CRMB) are used in India. For Rural roads for cumulative axle load repetitions less than 1,00,000 ESAL, Gravel road is recommended except for a very poor subgrade. In this backdrop, design load as ESAL repetitions from 20000 to 1MSa has been considered in the present study. The result obtained using present approach has been compared with the results obtained from other relevant findings.

Table 1.0 and Table 2.0 also show the comparison of pavement thickness determined by present analytical approach with the result of IRC:SP:72-2007 [5], the design guideline in India for design of low volume rural road with gravel or aggregate surface and flexible pavements as paved road. The pavement design presented in this manual for both gravel and flexible pavements are performance based on low volume road design as brought out in AASHTO[2] guide for design of pavement structures. The serviceability rating as per PMGSY[9] operation manual has been adopted in the guide line with a terminal serviceability index of 2.0. It is relevant to mention that the equation (1) which has been used in the present analysis is also based on AASHO road test and relates to decrease of pavement serviceability index to 2-2.5 as terminal value. In this backdrop, comparison of result using present approach and IRC:SP:72–2007 may be considered significant and meaningful. It is evident from the data presented in the table that, the thickness obtained using present approach is reasonably close up to 450000 ESAL repetitions. The thickness for higher loads, the required pavement thickness becomes less in present approach with respect to of IRC: SP:72-2007. It is relevant to note that increase in sub-base thickness of 50mm may result decrease of total pavement thickness of 25mm. which clearly shows the saving in cost of construction in this type of road with unbound granular materials. However, maximum thickness of granular sub-base having CBR between 20 -30% may be considered as 150mm for low volume roads, the thickness of sub base beyond this limit does not make any effective change in total pavement thickness.

The thickness of pavement thus obtained has also been compared with Kentucky's [11] design curves for flexible pavement in Figure (3). In Kentucky's approach, conversion of wheel load from 5000 lb to 9000 lb, an equivalent load factor of 16 was used to transform the effect of 8200 kg axle load. Figure 3 also compares results obtained from IRC:37-2001[7], the design guideline of flexible pavement in India based on Mechanistic – Empirical strain based design approach and also stress based design analysis from the findings of Biswas [3]. Results presented in Figure 3. can be classified as blending of results obtained from Mechanistic, Empirical and Mechanistic-Empirical approach. Comparison of results shows that the finding of present study is in good agreement with other studies in different ranges of soil subgrade strength.

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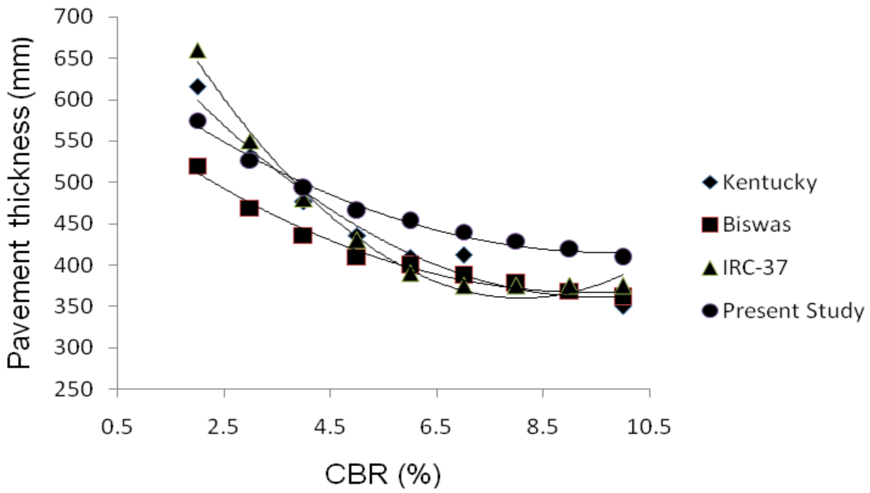

Figure 3. Comparison of pavement thickness obtained from different approaches

CONCLUSION

It can be concluded from such comparative study that Odemark's, method can effectively be used for determination of pavement thickness with unbound granular base and sub-base using terminal serviceability concept, based on pavement response. It is evident that use of appropriate thickness and strength of unbound granular sub base may reduce the thickness and cost of pavement in low volume road . This observation is more effective for pavements resting on soft subgarde with design CBR value up to 4%. It is also evident from this study, that the pavement thickness on soft soil using present approach is reasonably less than comparable design approaches and can be considered as economic design. Moreover, the optimum thickness of granular sub base may be considered as 150mm, beyond which change in pavement thickness is not significant.

Table 1.Comparison of pavement thickness obtained from Present study and IRC: SP-72-2007 considering 100 mm Granular sub base.

Pavement Thickness (mm) CBR Value and SP-72-2007							
CBR 2%	SP-72	CBR 3-4%	SP-72	CBR 5-6%	SP-72	CBR 7-9%	SP-72
288	300	231	200	172	175	115	150
329	325	274	275	221	250	181	175
373	375	318	325	268	275	234	225
417	425	361	375	312	300	280	275
456	475	398	425	349	325	318	300
503	550	443	475	394	375	364	325
554	650	491	650	441	425	410	375

Table 2.Comparison of pavement thickness obtained from Present study and IRC: SP-72-2007 considering 150 mm Granular sub base.

Pavement Thickness (mm) CBR Value and As per SP-72-2007							
CBR 2%	SP-72	CBR 3-4%	SP-72	CBR 5-6%	SP-72	CBR 7-9%	SP-72
271	300	208	200	132	175	NA	150
312	325	252	275	191	250	134	175
356	375	297	325	242	275	200	225
399	425	340	375	288	300	251	275
437	475	377	425	325	325	291	300
484	550	422	475	371	375	338	325
533	650	469	650	417	425	385	375

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