ULTRATHIN WHITE TOPPING-A STRENGTHENING MEASURE FOR HEAVILY TRAFFICKED RURAL ROADS

Amit Gupta[1] and U. C. Sahoo[2]*

[1] Sr. Design Engineer, L&T Construction, India, Email: ag15@iitbbs.ac.in

[2] Assistant Professor, School of Infrastructure, IIT Bhubaneswar, India, Email: ucsahoo@iitbbs.ac.in

ABSTRACT

Rural roads in India are usually constructed as granular pavements with thin bituminous surfacing. This is adequate for most of the roads as they usually carry very low traffic volume. But in some cases, after development of certain rural road links, the traffic increases many fold as these links act as bye pass routes for nearby higher category roads and also due to establishment of new industries in the locality. Because of thin surfacing, these roads deteriorate very fast under the action of heavy traffic load and therefore an efficient strengthening measure for such roads is very much needed. White-topping, which is a PCC overlay on existing deteriorated bituminous surface has shown promising results in addressing both structural and functional distresses. Literature review suggests that minimum 75 mm of bituminous thickness is required (after milling), for the efficient functioning of ultrathin white topping (UTW), the thickness of which is less than 100 mm. Considering the thin bituminous surfacing of rural roads and need for white-topping to address frequent surface failures, a study has been taken up to assess the performance of UTW over 25 mm bituminous layer. UTW of thickness of 75 mm over 25 mm open graded premixed carpet (OGPC). OGPC was considered in this study. Concrete of grade M60 was developed using polymeric fibers for UTW. KENSLAB program was used to assess the performance of UTW with the properties obtained in the experimental investigations. The fatigue life of the OGPC-UTW pavement was also analyzed with and without bonding. The study recommends 75 mm of UTW of square panels with 600 mm joint spacing over 25 mm thickness of OGPC for low volume rural roads as a durable strengthening/rehabilitation measure.

Keywords*: Rural roads, ultrathin white-topping, strengthening, low volume road*

1. INTRODUCTION

About 80% of the total road network in India comes under rural roads category, which are mostly constructed as granular pavements with thin bituminous surfacing (i.e. OGPC) as per the guidelines of Indian Roads Congress (IRC: SP-20, 2002). It is adequate for most of the roads as they usually carry very low traffic volume. But in some cases, after development of the rural road links, the traffic increases many fold due to many inherent reasons. Because of thin surfacing, these roads deteriorate very fast under the action of heavy traffic load and deterioration of these roads can occur in various forms depending upon the loading and climatic factors. The major forms of failure of flexible pavements are permanent deformation along the wheel path (also known as rutting) and cracking of the thin surface. For rural roads with thin surfacing, rutting is considered as the major mode of failure. This occurs due to repeated application of the axle loads and is more prevalent in case, the pavement thickness is inadequate or due to poor subgrade condition. Also, ingress of water through the pores of bituminous mix is another factor leading to deterioration of low volume roads.

White-topping, which is usually a PCC overlay on existing deteriorated bituminous surface has shown promising results in addressing both structural and functional distresses. It is a relatively new technique although it has been in use since 1918 (Rasmussen and Rozycki, 2004). In case of white-topping, a sound bond between PCC overlay and bituminous pavement is ensured. Due to this bond, the two layers of pavement behave as a composite section and thus the total depth of pavement increases. Due to the composite action, the neutral axis shifts downwards while resisting curling of beam and much of PCC layer remains is compression and as it is well known that concrete is strong in compression and weak in tension, thus design for the slab will result in thinner PCC overlay. In case of no bonding the pavement layers behave independently and thus there are chances that most of PCC layer is in tension because there will be two different neutral axis for PCC layer and bituminous layer. If the thickness of PCC lies in between 50 mm and 100 mm then it is called as ultra-thin whitetopping whereas if thickness is more than 100 mm but less than 200 mm then it is called as thin whitetopping (ACPA, 1998). The concrete is usually a high strength fiber reinforced concrete. Research in India has started on the use of white-topping from last 10 years due to rapid demand of rehabilitation of the existing bituminous pavements (Jundhare et al., 2012).

The present study focuses on development of a concrete mix for UTW and performance assessment of UTW over existing thin bituminous surfacing layer for rural roads, through experimental and analytical investigations. The study mainly focuses on assessment of 75 mm of UTW over 25 mm thick OGPC.

2. WHITE TOPPING FOR RURAL ROADS

As white-topping thickness may vary from 50 mm to 200 mm, its use is limited to moderate to low traffic conditions. The greater thickness of whitetopping is generally used for larger number of load repetitions and with higher axle load. Fiber reinforced concrete sections of 50 mm and 90 mm thickness with 600 mm to 1800 mm joint spacing have been used as a rehabilitation measure for asphalt pavement in USA (IRC:SP:76, 2015). From a study carried out in Kentucky, Cole (1997) reported that UTW of 50 mm to 90 mm is sufficient for carrying traffic loads of low volume roads, residential streets and parking lots. He also reported that the bond between UTW and existing bituminous layer significantly reduces the stresses in concrete section. However, importance of bonding was first realised in Iowa (U.S.) where various combinations of surface treatment were compared and it was suggested that the milling along with cement & water grouting technique exhibits higher bond strength and can be used where high bonding is required. Bond strength of 0.69 MPa was found to be satisfactory (Grove et al., 1993). Saeed et al. (2001) conducted field studies on General Aviation Airport, Tennesse and concluded that 100 mm thickness of whitetopping with 1020 mm of joint spacing gives satisfactory performance.

Vandenbossche (2003) conducted field studies in Minnesota and reported that UTW can be successfully placed on as little as 75 mm of asphalt, if the quality of the asphalt is good. But in Brazil UTW has been successfully placed on a bituminous layer of thickness as little as 45 mm only (Pereira et al., 2006). In Indian perspective, as rural roads carry comparatively lower volume of traffic, they are constructed as granular pavements with thin bituminous surfacing. These pavements comprise of bitumen surfacing of about 25 mm laid over WBM layer (about 150 mm thick) and granular subbase (about 250 mm thick) over the compacted subgrade. No study was found which reports the performance of UTW over thin (less than 50 mm) surfacing layers. Therefore there is a need to assess the performance of UTW over 25 mm OGPC to find out the possibility of applying this for the low volume rural roads in India.

3. EXPERIMENTAL INVESTIGATIONS

3.1.Mix design of concrete for UTW

Importance of concrete mix for UTW was realized since the first few projects across the world. Since thickness of UTW is very less, considerably high strength of concrete is required. Fiber reinforced concrete of grade M60 was tried under this study. Fibers are incorporated to address the tendency of high strength concrete towards plastic shrinkage cracking. Fibers also increase the ductility and abrasion resistance (IRC:SP:76, 2015) of the concrete. Polypropylene fibers as shown in Fig. 1 were used in the concrete mix. IRC suggests the use fibers up to 0.3% by volume of concrete. Fibers used were obtained from Reliance Industries and of 10-70 micron diameter with the aspect ratio of 200-2000. The specific gravity of fibers were in range of 0.91-1.34 with the melting point above 160 ^{o}C. Use of supplementary cementitious materials (SCMs) like flyash, slag, silica fume etc. is recommended to achieve the desired properties of concrete. Fly ash was also used as supplementary cementitious material (SCMs) as IRC suggest its use up to 20 % by weight as the replacement of cement. Silica fume was used in the mix to gain higher strength. Dosage of silica fume as per IRC should be 3 to 10% by weight of cementitious material. Cubes and beams were casted for finding out the compressive and flexural strength of the concrete mix.

Fig. 1: Fibers used in the mix

The maximum size of aggregates used in the mix was 12.5 mm. Based on sieve analysis, proportions of each sizes of aggregates were fixed to follow the standard curve of DIN 1045 as shown in Fig. 2.

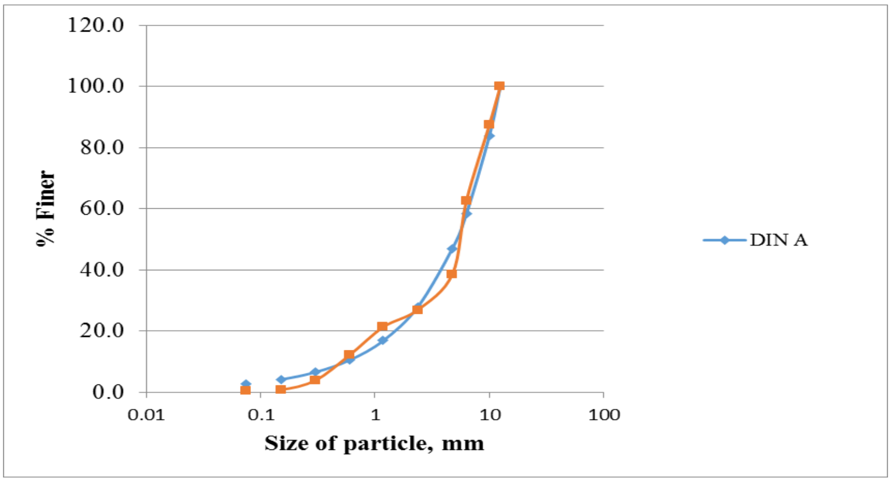


Fig. 2: Aggregate gradation adoptedfor concrete mix

High strength mixes generally require higher cement content (limited to 450 kg/m^3) and with lower water-cement ratio in range of 0.3-0.38. In this study, water-cement ratio of 0.28 was used for design of the M60 grade concrete. Chemical admixtures i.e. superplasticizer was used to increase the workability at low water cement ratio. A maximum dosage of the chemical admixture of 2% is recommended as higher dosage of chemical admixture retards setting of the mix. Concrete samples were prepared as per the procedure mentioned in the following section.

To prepare the mix, firstly the dry aggregates were poured in the mixer and mixed thoroughly for approximately 2 minutes. Then approximately 75 % of the total required water was mixed in the mixer and mixed for 3 minutes. Then mixer was stopped and the complete mix was mixed with the help of shovels. Fibers were then poured in the mix and the mix was rotated for 30 seconds more. Finally, the remaining 25% water mixed with the superplasticizer was added and the complete mix was mixed in the mixer for 2 minutes. The amount of superplasticizer required was adjusted on the basis of slump requirement on the field. Since, the concrete was designed for use in road construction; the mix was designed for the slump value of 25 mm. Cubes after 3 and 7 days of curing were tested for compressive strength. .

The cardinal principle in the design of concrete mix for UTW is that, 2/3rd of the concrete strength should be developed within a period of 48 hours, because such a pavement can be opened to traffic within 72 hours of its laying. This principle was found to be satisfying for the trial mix and hence after few adjustments, the mix proportion was finalized as given in Table 1.

Table 1: Concrete mix proportions

Ingredient	M60
Cement (kg/m^3)	440
Water/Cement ratio	0.28
Water (kg/m^3)	164.36
Fly Ash (kg/m^3)	88
Silica Fume (kg/m^3)	59
Air content %	2
Fibers (kg/m^3)	2.5
Coarse aggregate 12.5 mm (kg/m^3)	670.86
Coarse aggregate 6.3 mm (kg/m^3)	625.51
Sand (kg/m^3)	369.63
Superplasticizer (%)	1.078 %
Density (kg/m^3)	2419.86

As rigid pavement resists loads and temperature effects its flexural strength and therefore getting high flexural strength is the true concern in case of whitetopping. Beams of 100 mm × 100 mm x 500 mm were casted to measure flexural strength of the concrete after 28 days of curing. It is desired to have a flexural strength of 5 to 6 MPa. The beams were tested for flexural strength using four point bending test. Loading rate was 30 N/sec with the peak load of 30 kN. Compressive strength and flexural strength of the concrete as obtained from the tests are presented in Table 2.

Table 2: Compressive strength and flexural strength of finalized mix

Sl. No.	No. of days after curing	Compressive strength (MPa)	Flexural strength (MPa)
1	3	48.89	-
2	7	64.2	-
3	28	81.7	7.35

3.2.Preparation and testing of composite beams

Composite beams (Fig.3) with bituminous material and concrete were casted to simulate the field white topping condition. A layer of 75 mm of M60 grade concrete was casted over 25 mm of OGPC for beams of size 100 mm × 100 mm x 500 mm. OGPC was prepared in the beam mould according to IRC:14(2004), using bitumen grade VG30 (viscosity of bitumen at 60 ^{o}C is arround 3000 Poise). Three days after preparation of bituminous surface, concrete (M60 grade) was laid over it in the mould. The composite beams were then tested using four-point bending test to find flexural strength and elastic moduli of the samples.

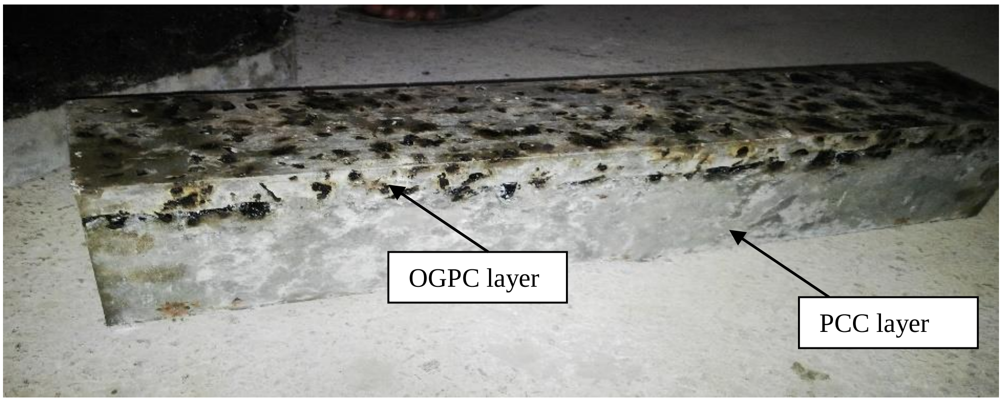
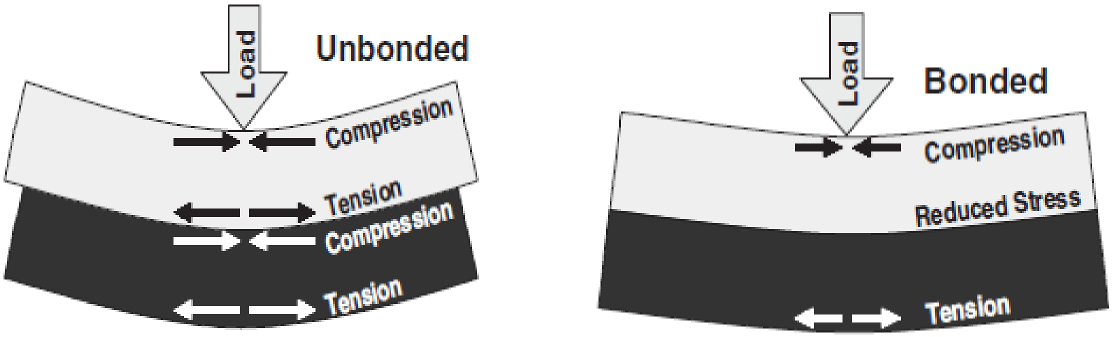


Fig 3: Composite Beam (OGPC-PCC) after demoulding

Bond is a major criterion in the design of UTW as perfect bonding will reduce the flexural stress to a much lesser level than critical. With proper bonding both the layers will behave as the monolithic layer and will participate in resisting flexure as the single compound rather than behaving individually which will increase the total depth of beam and therefore increasing its flexural strength.

Due to the composite action, the neutral axis shifts downwards while resisting curling of beam and much of PCC layer remains is compression and as it is well known that concrete is strong in compression and weak in tension, thus design for the slab will result in thinner PCC overlay. In case of no bonding the pavement layers behave independently and thus there are chances that most of PCC layer is in tension because there will be two different neutral axis for PCC layer and bituminous layer as shown in Fig.4.



(a) (b)

Fig. 4 Fundamental behavior of whitetopping under loading (a) Unbonded (b) Bonded
(Rasmussen and Rozycki, 2004)

To increase the bond strength between the PCC layer and existing bituminous layer in the mold, very thin layer of cement slurry of 1:2 (1 Cement : 2 Water) proportion was evenly applied over the already prepared bitumen surface. Cement used for making the cement slurry was OPC grade 43. After the application of cement slurry, PCC was laid over it and was compacted by vibratory hammer. Compaction of PCC was done in two different layers. Beams were then left for curing for 28 days. After curing period of 28 days, the beams were tested for flexural strength. The load was applied at two points through loading noses spaced at 150 mm apart as per the arrangement shown in Fig. 5. Peak load and flexural strength of the composite beams are as shown in the Table 3.

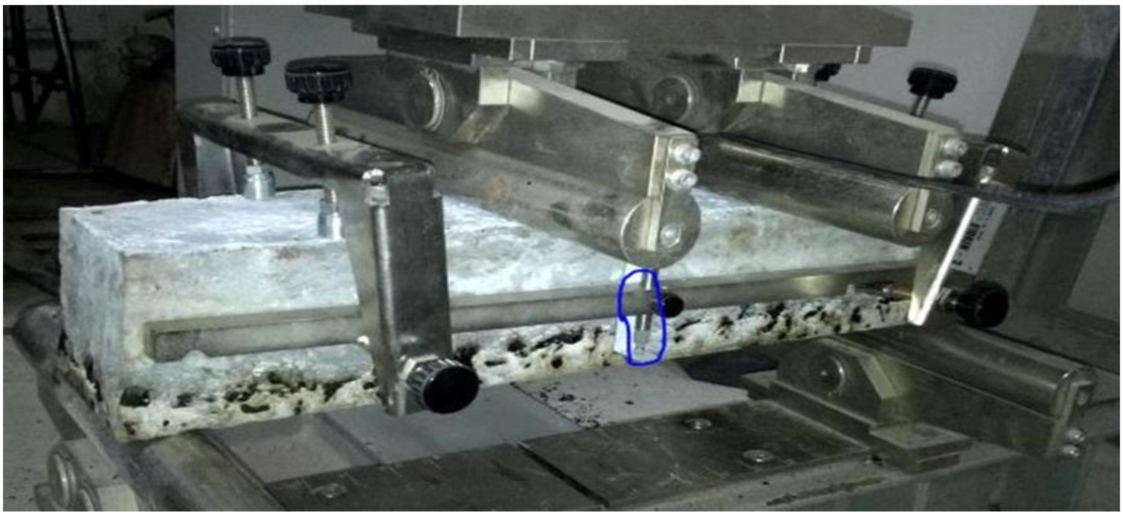


Fig. 5: Testing of OGPC-PCC beam in using Four-Point Bending Test

Table 3: Flexural strength of composite beams

Sample name	Composition		Peak load (kN)	Flexural strength (N/mm²)
	Bitumen layer thickness (mm)	PCC thickness (mm)		
Open-graded Premix surface sample-1	25	75	12.45	5.6
Open-graded Premix surface sample-2	25	75	13.2	5.94

Two electrical Linear Variable Differential Transforms (LVDTs) were placed at the center to find displacement of the beam at the center of the beam which is shown in Fig.5. With the help of LVDT data, load vs deflection curves were plotted. Deflection was taken as the average of deflections of both the LVDTs on opposite faces. The various load vs deflection curve are shown in Fig.6. Initial tangent modulus of elasticity was obtained by plotting the tangent to the initial part of the load-deflection curve and finding its slope (Fig. 7). Eq. 1 was used to estimate the initial tangent modulus as mentioned below:

$$E_B = 0.21\ L^3\ m/bd^3 \qquad \ldots (1)$$

Where,

E_B = Modulus of elasticity in bending, MPa

L = Support span, mm

b = Width of beam tested, mm

d = Depth of beam tested, mm

m = Slope of the tangent to the initial straight line, N/mm

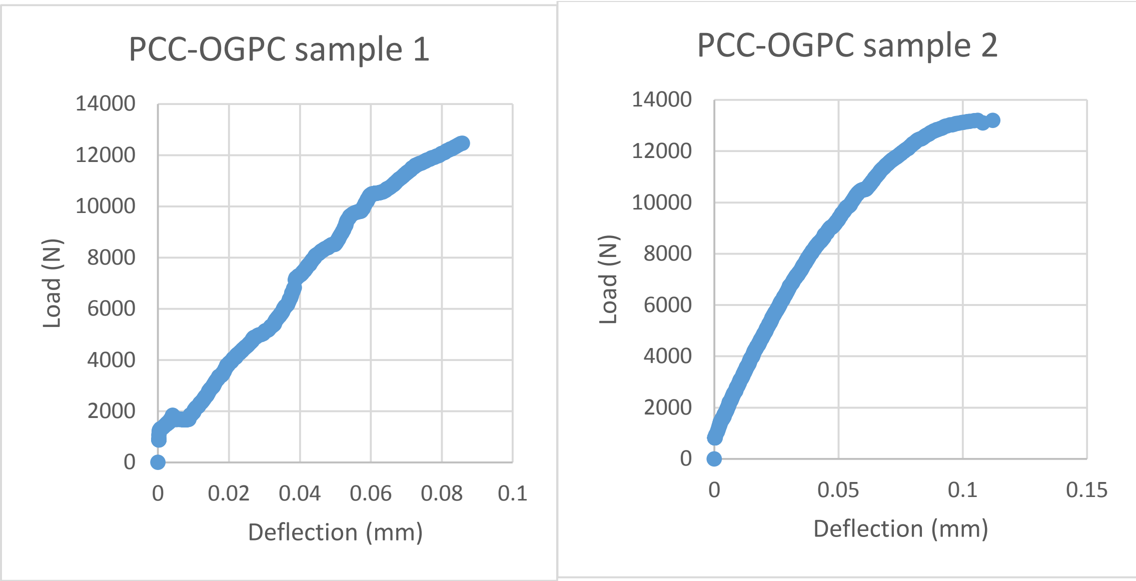


Fig. 6: Load-displacement curve for OGPC

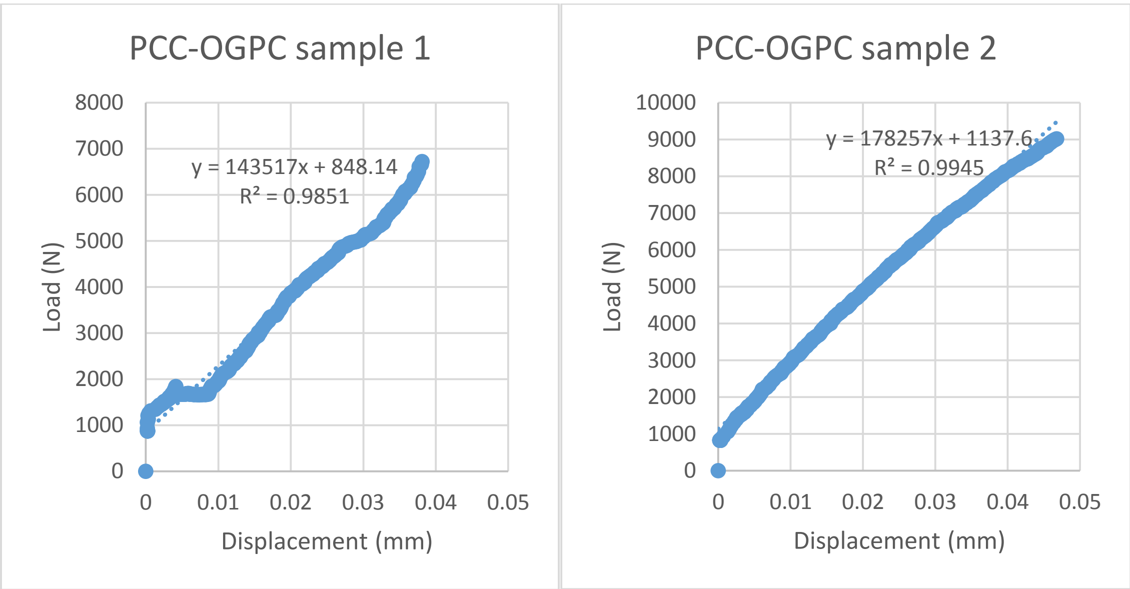


Fig. 7: Initial portion of load-displacement curve

The average slope (m) of the samples 1 and 2was found to be 160887 N/mm. Using Eq. 1, the elastic modulus of the composite sample was found to be30,788 MPa.

4. ANALYTICAL INVESTIGATIONS

Two dimensional analyses of UTW slabs was carried out using KENPAVE program to know the position and magnitude of the critical stress. Fatigue lives of the pavement were estimated using the Portland Cement Association (PCA) method.

Analyses were performed for two conditions as mentioned below:

1. Analysis of individual layers of 75 mm thickness of UTW constructed over 25 mm of OGPC without bonding.
2. Analysis of 100 mm thickness of composite pavement comprising of 75 mm PCC and 25 mm OGPC by using modulus of composite beam as an input.

Total six slabs were modelled in KENSLAB for analysis; three slabs in one row placed adjacent to three slabs in another row along the direction of the traffic movement (Fig. 8). Critical stress estimation and fatigue life estimation were carried out by placing the load at edge of the middle slab. The load was placed symmetric along the Y-axis. Slabs were connected with each other with a joint in transverse direction and longitudinal direction along the movement of traffic. 7 joints and 54 nodes were used in the analysis.

As the load transfer between adjacent slabs in UTW occurs typically by aggregate interlocking, joints considered in all types of models were undoweled with load transfer by aggregate interlocking only. Load transfer by aggregate interlocking takes place by shear and by moment transfer between the adjacent slabs. Load transfer by moment is too small as compared to former one therefore it is neglected in the analysis. It is assumed in KENSLAB that load transfer by shear takes place through springs and a constant shear spring constant is taken as input in software. Shear spring constant was taken as 600 MPa for transverse joints and 200 MPa for longitudinal joints as recommended by Huang (1993).

Wheel load considered to be 54 kN taking into account 108 kN single axle load with single wheels on both sides, which is the legal axle load limit in India. Since only two slabs were considered in the direction of movement of traffic, the other wheel was assumed to be lying at a far off distance from the slabs on the interior part of the model and therefore effect of other wheel load was neglected in the design. The contact area of wheel load was assumed as rectangle of dimension 240 mm × 300 mm, with a contact pressure of 750 kPa. The position of the wheel load is shown in the Fig.8.

Temperature curling was considered for all types of models with the temperature differential value of 0.15 ^{o}C/cm of slab as recommended by IRC:SP:76(2015). But the weight of the slab was neglected in the analysis due to small size of slab panel. The slab and foundation was assumed to be in contact at each and every point. Coefficient of thermal expansion of concrete was taken as 12 × 10^{-6} /^{o}C.

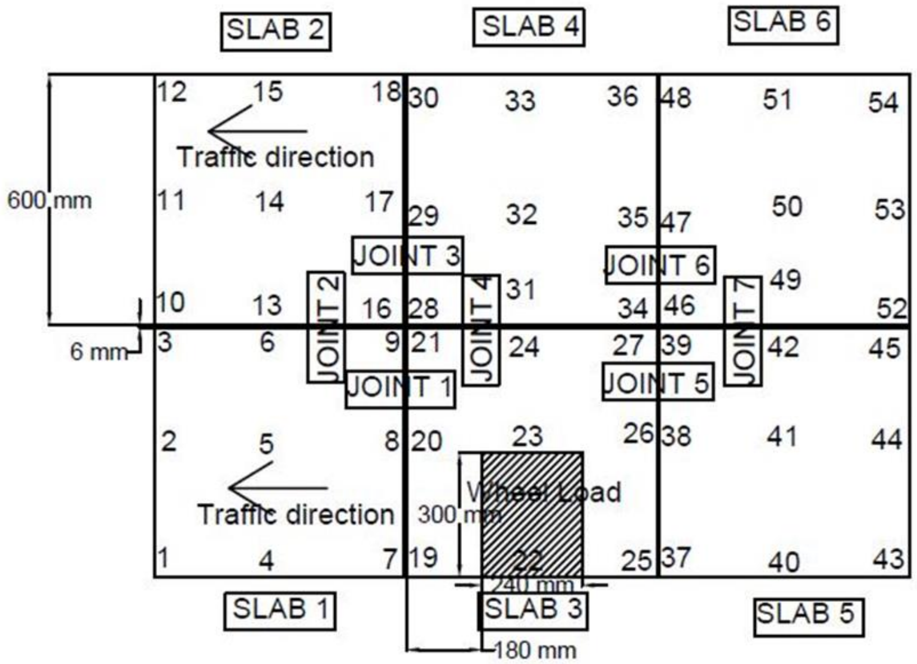


Fig.8: Arrangement of slabs and joints considered for KENSLAB analysis

4.1. Analysis of 75 mm thickness of UTW constructed over 25 mm of OGPC with no-bonding

A typical rural road pavement section as shown in below Fig. 9 was adopted for the analysis. Properties of the slab and different layers of foundation for this type of analysis are shown in the Table 4.

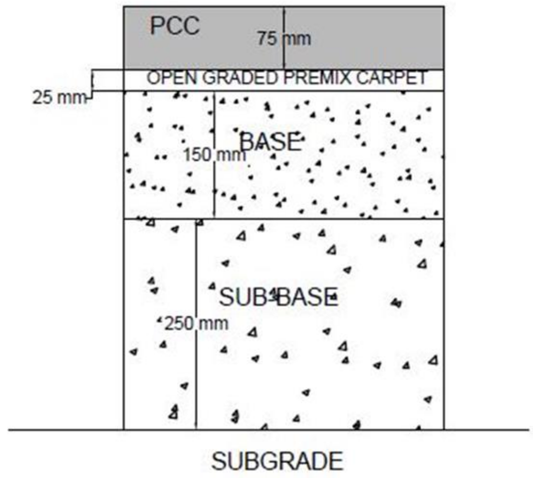


Fig. 9: Layer configuration for analysis of white-topping layer without bonding

Table 4: Layer properties of PCC-OGPC individual layer analysis

Layer No.	Name of layer	Thickness, T (mm)	Elastic modulus, E (MPa)	Poisson's ratio, μ	Flexural strength, PMR (MPa)
1	Slab	75 mm	42,000	0.15	7.35
2	Deteriorated OGPC	25	800	0.35	-
3	Base	150	250	0.4	-
4	Sub-base	250	150	0.4	-
5	Sub-grade	Infinite	50	0.4	-

The magnitude of the maximum stress generated from this analysis was 3.7 MPa (tensile) and location of this maximum stress was the edge of the slab where load was placed. The fatigue life for this arrangement was found to be 12.86 years (1year accounts 50,000 axle repetitions).

4.2. Analysis of 100 mm composite layer of PCC-OGPC with full bonding

In individual layer analysis, it was assumed that the slab is casted directly over the bituminous layer and therefore one of the most important criteria of bond in design of UTW between the PCC and existing bituminous layer was neglected. To account for the bond between the two layers, composite slab of bituminous layer and PCC layer were modeled as one layer resting directly on the base layer. Thus this type of analysis assumes the perfect bond between the two layers and it is assumed that failure of both the layers in composite section will be at the same time and at same level of stress.

For this analysis two inputs are required for analysis, one is elastic modulus of the composite material and second is Poisson's ratio of composite material. Elastic modulus of composite material was found from experimental investigation as stated earlier. Poisson's ratio was assumed as 0.2 for the composite pavement. Foundation layer properties were same as used in previous analysis (Fig. 10). Composite slab properties are shown in Table 5.

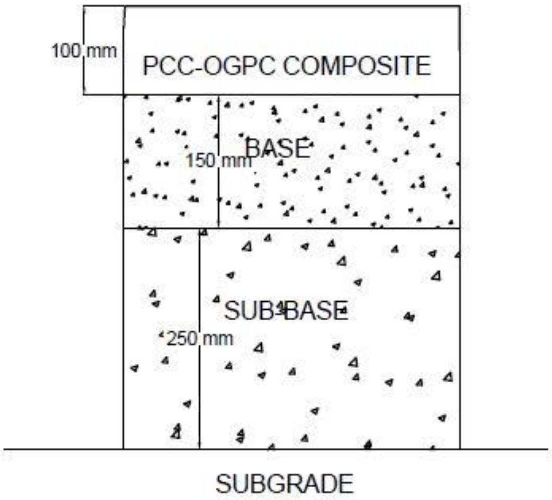


Fig. 10: Layer configuration considered for analysis with PCC-OGPC composite layer

Table 5: Layer properties of PCC-OGPC composite layer analysis

Layer No.	**Name of layer**	**Thickness, T (mm)**	**Elastic modulus, E (MPa)**	**Poisson's ratio, μ**	**Flexural strength, PMR (MPa)**
1	PCC-OGPC composite	100	30,790	0.2	5.77
3	Base	150	250	0.4	-
4	Sub-base	250	150	0.4	-
5	Sub-grade	Infinite	50	0.4	-

The magnitude of the maximum stress obtained from this analysis was 2.5 MPa (tensile) and location of this maximum stress was at the edge where load was placed. The fatigue life for this configuration was found to be infinite.

5. CONCLUSIONS

The following conclusions can be drawn from the present study carried out on UTW on rural roads in India:

1. UTW requires considerably high strength of concrete than required for conventional

concrete pavement. Use of SCMs in the mix leads to high strength, increased durability etc., but its use in concrete should be judicial so as to maintain the economy of the project. Fibers should be used in the concrete to reduce its tendency for plastic shrinkage cracking and it also increases its ductility and abrasion resistance which are key factors in successful working of concrete pavements. Fibers are also known to increase the flexural strength of concrete however further studies should be made in this regard.

2. Cement slurry works as a good bonding agent if the existing bituminous road has sufficient percentage of air voids as in case of OPGC as it has open grading of aggregates in it. If sufficient air voids are not present then efforts should be made to create the sufficient air voids by mild chiseling on the field.
3. Elastic modulus of composite beam of PCC-OPGC was found to be approximately the weighted average of the elastic modulus of individual layers.
4. The fatigue life of the OGPC-UTW pavement without bonding was found to 12.86 years (1year accounts 50,000 axle repetitions) whereas it becomes infinite when perfect bonding is assumed.
5. 75 mm thickness of UTW of square panel with joint spacing 600 mm may be recommended over 25 mm thick OGPC for low volume rural roads as a durable rehabilitation measure. However field studies should be carried out to know the exact behavior of UTW slabs under loading.

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