A Critical Review on Evaluation of Stresses in Whitetopping

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ABSTRACT: Whitetopping is a PCC overlay on detorated flexible pavements for functional or structural strengthing of the pavements. Whitetopping is classified into 3 types depending on the bonding condition below the layer of PCC and the thickness of the PCC layer) Unbonded white topping, also called conventional white topping where PCC layer thickness is more than 200mm b) TWT (Thin White Topping), PCC layer thickness is between 100 mm to 200mm, and bonding to the existing asphalt concrete layer is not mandatory, Joints spacing ranging from 0.75 m to 1.5 m c) UTWT (Ultra-thin White topping) thickness of PCC layer between 50 to 100mm and bonding to the existing asphalt concrete layer and Joint spacing ranging from 0.75 m to 1.5m.Simulation models were developed using advanced software for evaluation of load and temperature stress and validation with Experimental or parametric studies but very limited or no validation was performed with field observation. Limited work on instrumentation in pavements such as Strain gauges and thermocouples embedded in CC overlays at various depths to assess the exact condition of the composite action of the overlays which will also help to study the correlation between temperature and traffic loadings with the stresses and strain development over a period of time.

Keywords. Whitetopping, Ansys Software, Finite Element Model, Edge load stress, Curling Stress, Sub Grade Modulus

I. INTRODUCTION

Pavements are constructed predominantly flexible in nature. Cement concrete (CC) pavements are constructed generally in places where there is heavy traffic corridors and maintenance of bituminous roads is the main challenge. The primary cause for not preferring rigid pavements by the Government Highway authorities or local bodies is the high initial cost. Once built, concrete pavements require minimal maintenance and have a lower overall life cycle cost compared to asphalt pavements if well designed and constructed. The deterioration and deformation caused by heat create issues on the top surface, in addition to the fatigue damage that starts at the bottom of the bituminous layer, requiring frequent overlays for functional or structural reasons. The TWT (Thin White Topping) is a smaller panel-size concrete overlay that is applied over the existing bituminous pavement. It has a reduced thickness of the concrete layer and requires very little or no base preparation compared to thick concrete pavements. Thin white topping (TWT) is a cost-effective alternative to constructing a new rigid pavement without the need to remove existing bituminous pavement. It involves using a Dry Lean Concrete (DLC) base and a thicker layer of concrete. The cost of TWT will be 50 to 60% less than the cost of constructing a conventional CC pavement. PCC overlays have been used to rehabilitate both the existing bituminous (flexible) pavement since 1918 and existing concrete pavement since 1913. Portland Cement Concrete (PCC) overlay on detorated existing bituminous pavement is commonly termed White Topping. White topping is thus PCC overlay is a rehabilitation technique or structural strengthening of the flexible pavements. Depending on the Bonding condition below the PCC layer and thickness of the PCC layer, White topping is classified into three types a) Unbonded white topping, also called conventional white topping where PCC layer thickness is more than 200mm b) TWT, PCC layer thickness is between 100 mm to 200mm and bonding to the existing asphalt concrete layer is not

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mandatory, Joints spacing ranging from 0.75 m to 1.5 m (Refer to figure 1). c) Ultra-thin Whitetopping (UTWT) thickness of PCC layer between 50 to 100mm and bonding to the existing asphalt concrete layer and Joint spacing ranging from 0.75 m to 1.5 m.

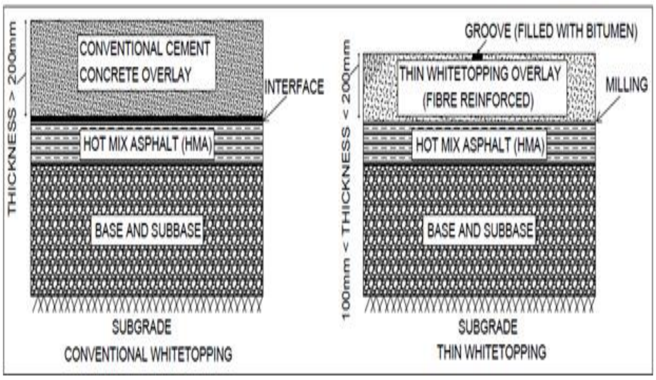

Figure.1 Typical Crust Composition of Conventional and Thin White topping

II. BACKGROUND

White topping has been used in the United States of America and Europe on Airports, Local Roads, Inter-state roads, Primary & Secondary Highways, Parking, and Streets lots to enhance the durability, riding & performance quality of weakened bituminous pavement surfaces. Traditional white topping and TWT, both with a design life of 15-20 years, provide a more effective rehabilitation approach for Indian roads. Many successful projects were completed in Mumbai, Pune, Nagpur, Delhi, Jaipur, Bangalore, and Hyderabad in recent years.

III. BENEFITS OF WHITE TOPPING

Whitetopping on existing detorated bituminous pavements or new roads of heavy traffic gives several additional benefits in comparison to the traditional HMA overlay. Following are the few benefits.

- Long life, improved safety, and environmental benefits Improve the service ability of detorated pavements at critical locations.
- Rutting and cracking in asphaltic roads are normally absent with Whitetopping.
- Improves the structural capacity and less maintenance of the existing Bituminous pavements.
- Due to less maintenance of Whitetopping roads, less frequent lane closures of road.
- Concrete's light color makes its surfaces highly reflective of light, resulting in lower heat absorption and a reduction in the ‘urban heat island’ effect.

IV. BEHAVIORS MECHANISM

Conventional PCC or flexible pavement are designed pavement layers based on the layer theory concept, there is no bonding between the two consecutive layers. TWT and Ultra-thin Whitetopping overlays are based on the composite pavement structure concept. Because of the composite action among the top layer of the pavement and the bottom layer of detorated HMA layer. Hence the neutral axis shifts downward, so that predominant of the predominant PCC slab which comes under the compression (Refer to figure.2). Hence, compared to conventional PCC pavements bonded white topping requires less thickness to carry the load.

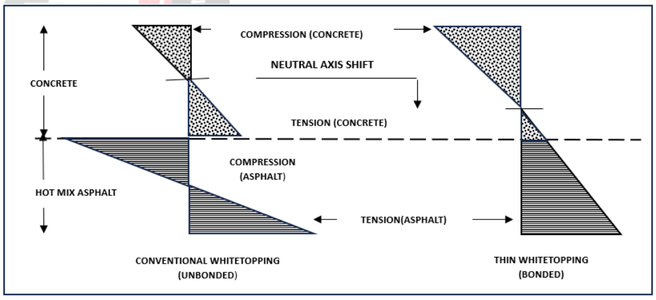

Figure 2: Stress distribution in Unbonded and Bonded Overlays

The primary principle in white topping that resulted in a decreased thickness requirement for CC is • Strong base presence • A smaller panel size decreases flexural stresses by reducing the bending moment caused by a shorter span. • When the Base and CC layers bond together, the overall flexural stiffness increases, causing a decrease in flexural tensile stress in the CC layer. When the Base and CC layers bond together, the overall flexural stiffness increases, causing a decrease in flexural tensile stress in the CC layer.

V. FACTORS AFFECTING THE PERFORMANCE OF WHITE TOPPING

The performance of the Whitetopping depends on the

a) Current state of the pavement
b) Preparation of the pre-overlay repairs
c) White topping Design features
d) Traffic and Behavior
e) Climatic conditions and Environment

f) Quality of Construction and Curing

2.0 LITERATURE REVIEW

IRC-SP-76-2-15[1-3] Published that the primary distresses observed in the Thin White Topping are the corner breaks and mainly because of upward curling at corners at night time. Hence the critical stress location for TWT design is the corners and stresses because of the load along with temperature are the critical stresses. Hence IRC-SP-76-2015 has been published for computation of stresses due to temperature curling and the combined effect of load and temperature curling at corner location are as follows.

1) Stresses due to Temperature Stress (σt):

$$\sigma T = 1.933 - 241000(\alpha \Delta T) + 1.267(L/le) \text{ ......1}$$

wherein,

σT	curling tensile stress at the corner, kg/cm2
ΔT	negative temperature differential, oC
le	radius of relative stiffness, cm
L	length of square slab, cm
α	coefficient of thermal expansion, /oC

2) Stresses due to load and temperature:

Equations 2 and 3, which were presented by Mack et al. in 1997, can be used to determine the corner tensile bending stress in a slab caused by an 8T single axle load and a 16T tandem axle load.

$$\text{Log}(\sigma 8) = 3.6525 - 0.465\log(k) + 0.686\log(L/le) - 1.291\log(le) \text{ ......2}$$

$$\text{Log}(\sigma 16) = 3.249 - 0.559\log(k) + 1.395\log(L/le) - 0.963\log(le) - 0.088\,(L/le) \text{ ....3}$$

Where in,

$\sigma 8$	bending tensile stress at corner for 8T single axle load, kg/cm2
$\sigma 16$	bending tensile stress at corner for 16T tandem axle load, kg/cm2
L	square slab length, cm
k	modulus of subgrade reaction, kg/cm3
le	relative stiffness radius, cm

Venkata Joga Rao Bulusua Et Al. 2020 [4], has discussed and compared in detail on design methods of PCA (Portland Cement Association) and IRC of TWT pavement design. PCA built test sections of TWT and formed eqns for load and temperature stress at various locations of the TWT based on the test sections' performance. IRC implemented these eqns and simplified them with minor modifications for computing the stresses at critical locations as per the Indian conditions. When comparing TWT to traditional CC pavement, these modifications cause an overestimation of stresses, which lowers cost savings. By taking into account a number of factors, they compare the IRC as well as PCA design approaches for TWT in this study. In order to estimate the stresses in the CC layer, PCA and IRC Design Methods take into account 8T single axle load and 16T tandem axle load. In comparison to the stresses estimated using PCA equations, which range from 0-22% for a 16T tandem axle load to 40 -50 percent for an 8T single axle load, the stresses estimated using IRC equations are higher. The thickness requirement for the TWT is more based on the IRC method of Design, and the cost of construction of TWT projects is more compared to conventional pavement. This might not promote the adoption of TWT technology. PCA equations are designed for US traffic conditions and may not be applicable to Indian traffic conditions for pavement design. Evaluating the TWT performance for Indian conditions as well as emerging performance eqns for designing new TWT pavements is necessary.

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B.N. Skanda Kumar et al, 2014 [5] has explored the evaluation of the Thin Whitetopping on the project Stretch near the Madiwala underpass (Bangalore). Non-destructive tests like Rebound Hammer & Ultra Sound Pulse velocity test have been performed for pavement structure Strength and material properties without disturbing the pavement structure and concluded that the quality of concrete and strength of concrete is good. For evaluation of pavements using FWD is more popular in some countries but due to the high cost and difficulties encountered for the use of falling weight Deflectometer (FWD), Benkelman Beam Deflection test methods were adopted as per the IRC–81-1997 to know the deflection of the pavement under standard loading conditions and concluded that deflection values are 0.369 mm , 0.39mm , 0.32 mm and 0.510 mm for corner and interior wheel paths on left and right stretches of the pavements respectively. These deflections were compared with the FEM model and showed pavement layers are Good.

U. Shivaram Krishna et al 2022[6], A model was developed using ANSYS software considering the subgrade layer as an elastic solid layer instead of a Wrinkler foundation for ultra-Thin White Topping. Performance analysis was conducted using the critical corner stress at various points on the pavement's cross-section. The stress generated on the surface will not only be present at the load application point but will also have an effect on the area and depth to some extent. The semi-scale experimental study was also carried out using a quaternary blended sustainable concrete mix laid on the Bituminous layer. The stress was computed as per the Westergaard’s equations at critical load conditions and compared with the FEM model. He concluded that the thickness and modulus of elasticity increased, and critical corner load stress was reduced by 40 %. Increasing the thickness of the UTW concrete overlay and the elastic modulus of the bituminous concrete layer results in a 51.7% reduction in corner stresses. The addition of the granular layer and increased elastic modulus of the UTW concrete overlay resulted in a 58.15% reduction in critical stresses and a 64.2% decrease in interface shear stress. The elastic strain in the UTWT concrete overlay decreases by 73.22%.

Jundhare D.R et al 2012[7], has studied the edge load stress, and deflections were computed using the FEM model developed on the Winkler foundation instead of the elastic solid subgrade model. A parametric study with dimensions of 3650 x 4500mm and a thickness of 320mm was conducted. The qualities of the concrete taken into consideration are i) Modulus of elasticity, = 31625 MPa ii) Poisson’s ratio, μ=0.15, density=24kN/m3, and thermal expansion Co-efficient, α=1.0X10-5 per °C (IRC: 58-2002). The dimensions of the plain cement concrete overlay slab are comparable to those of the 150mm thick asphaltic treated base. The HMA pavement base properties are: Modulus of elasticity, E=800MPa μ=0.3 The subgrade properties are: Modulus of elasticity, E = 200 MPa, μ=0.35. It is believed that a dense liquid foundation supports the cement concrete overlay slabs. From Westergaard ‘s equations, critical stress and deflections were computed and compared with the FEM results and ALIZE method. For the edge load case, the approach of Westergaards stress 21.81 percent and deflection 29.45 percent more compared to 3-D FEM model outcomes.

Sankaran V et al 2021[8] In this study, the author focused on the impact of interface friction on the deflection and stress of UTWT. FEM model was developed for a single panel of concrete slab of size 1 m × 1 m under which a 100 mm thick HMA layer, granular base course of 450 mm, and a Winkler foundation of 500 mm thickness. The bottom and edge of the foundation were fixed and the only constraint for the slab was the friction among the slab as well as asphalt layer. Half of the Standard Axle single Wheel load 5.1 tone i e 10.2/2 has been applied on the slab edge. It is observed from the model that, with an increase in slab thickness deflection and magnitude of stress reduces. There is a reduction in the magnitude of stress and deflection with an increase in the coefficient of friction. The coefficient of friction increases, reduction in deflection shows the necessity of field operation.

Arthi et al 2015[9] has studied the edge load stresses and deflections and temperatures stress of thin Whitetopping overlay for different bonding conditions and different subgrade conditions and temperature stresses using ANSYS software by developing a FEM Model. And concluded that,

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with the increase in thickness of the pavement, concrete tensile stress along with deflection decrease for various subgrade CBR values. Stress because of a temperature differential of 15 -20 oC temperature stress rises by about 80percent in unbonded pavement than in bonded pavement. It is determined that the primary factor influencing the behavior of TWT pavements is bonding at the interface.

Maojiang Zhu et al 2018[10] Explored the stress variation at the overlay slab bottom by developing the FEM software ANSYS and applying loads. examined the effects of altering the overlay slabs' dimensions and thickness along with the circumstances surrounding the bonding of the UTW overlay and asphalt overlay. Concluded that critical stress is significantly influenced by the thickness as well as the elastic modulus of the material. The recommendation is to strictly control the thickness along with the size of the UTW overlay. The dimensions must be no more than 1.8×1.8m and the thickness must be at least 7 cm. To reduce tensile stress at the slab bottom and increase the longevity of the pavement structure, it is recommended to use asphalt with an elastic modulus greater than 1,500MPa as the base material for the overlay.

Moinul Mahdi, et al 2021[11] evaluated the performance of BCOA (Bonded Concrete Overlay of Asphalt) pavement 3 full-scale BCOA test sections, measuring 6 in., 4 in., and 2 in. in thickness, of PCC were tested on aged asphalt pavement in southern Louisiana under APT loading. Every section failed due to trafficking under alternating load magnitudes of 9kips & 16kips from the ATLaS dual-tire wheel load, causing all slabs in the loading path to crack. A trench-cutting investigation was carried out, the effective thickness was determined by the falling weight deflectometer (FWD), and an in-situ pull-off test showed a robust initial bond among the PCC as well as the AC layer. Non-destructive testing (NDT) techniques revealed that possible separation at the PCC-asphalt interface could be connected to problems with a BCOA slab.

Mack. J.W et al.2011[12] has developed a Mechanistic design of three-dimensional finite element models. The study concluded that UTW pavements behaved as partially bonded systems, and must be designed accordingly. From the field experience, a joint spacing of 1.2 m is desirable for a UTWT concrete overlay. An interface bond between the bituminous and cement concrete layers of the composite concrete will be created by milling the bituminous concrete overlay that currently exists.

Nishiyama, T et.al. 2005[13] has created a three-dimensional model using data from the literature to measure the thin concrete overlay bond by adding a spring with different stiffness between the concrete and bituminous layer and measuring strains.

Kumara, W. et.al [14] have developed a three-dimensional FEM model for stress analysis of UTW concrete overlays with critical test conditions to understand test conditions in Florida and further carried out a parametric study on the FEM Model.

F M and Vandenbossche J et al 2007[15] has created a superimposed cohesive model by investigating the interface bonding at the interface between asphalt as well as cement concrete overlays. The subsequent findings were noted 1) The joint spacing determines the failure mode; 2) To more accurately forecast the critical stresses, a new structural model for longitudinal cracking for 6-foot by 6-foot (1.8m by 1.8m) concrete overlays was formed; 3) performance data has been utilized to calibrate the stress adjustment factors; 4) The pavement structure and project location are taken into consideration when defining the equivalent temperature gradients that are utilized as design input and 5) Consideration is given to how temperature changes affect the underlying HMA stiffness.

Sharmin Sultana and Mustique Hossain 2010[16] The PCO equation was used to calculate the expected lifetimes of the overlay in a three-dimensional finite element method thin white topping model created with SOLID Work software. The interface bonding condition between the TWT and AC layer, particularly for smaller TWT thickness, is the main factor affecting the service life of thin white topping. The service life of bonded TWT is significantly longer than that of unbonded TWT.

W.K. Mampearachchi et.al [17] utilizing SAP2000 structural analysis software to simulate field conditions, the possibility of concrete overlays resurfacing asphalt pavement with a thickness of less than 100 mm was

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investigated. Strain data was used to validate the developed model data. According to the study's findings, the stress in the concrete layer rises as bituminous concrete layer stiffness falls, and both the concrete layer thickness as well as bituminous layer decrease.

Vandenbossche et al., 2017[18], In order to predict longitudinal cracking, a novel structural model was developed that took into account the combined effects of temperature gradient and wheel load. This made it possible to use a specialized 3D FEM to design bonded concrete overlays over asphalt pavement with greater accuracy. Additional investigation was carried out on building ultra-thin white toppings at airports to reduce the tensile stress at the base of the overlay slab and increase the pavement structure's lifespan. The following results were drawn: the UTW overlay's thickness and size should be closely regulated, with a maximum size of 1.8 x1.8 m.

4.0 DISCUSSIONS AND CONCLUSIONS

- Experimental work and simulation models were developed using advanced software for analysis of load and temperature stress at various depths and the interface of overlay, but validation with field observation is very limited.
- Very limited long-term and continuous performance evaluations of various Whitetopping projects in India were observed by way of conducting various tests such as FWD, Benkelman Beam deflection, compressive strength by core cutting and other NDT testing, road surface, roughness test, etc.
- Limited work on instrumentation in pavements such as Strain gauges and thermocouples embedded in CC overlays at various depths to assess the exact condition of the composite action of the overlays which will also help to study the correlation between temperature and traffic loadings with the stresses and strain development over a period of time

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