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Application of Infrared Thermography to Detect Debonding of Asphaltic Layer on Bridge Deck

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***Abstract*— In the recent past, the early, failure of asphalt pavement overlays on concrete bridge deck on newly constructed bridge in Goa has been noticed. The waterproofing membranes placed over the bridge deck has been recognized as a significant cause for this debonding. Potential reasons for the failure of the asphalt overlay were thought to be due to poor adhesion between the waterproofing membrane and the asphalt wearing course, and the complex behaviour of the asphalt layer. By studying the exact behaviour of the asphaltic layer overlaid on waterproofing membrane under the action of dynamic loads and cyclic temperature variation, it is possible to understand causes of such failure. It is also possible to study the initiation of debonding and its effect on pavement. It is important to detect the initiation of debonding at the early stage so as to take preventive measure to avoid further spreading along and across the deck. The passive thermography can be used to identify the damages below the asphaltic layer caused by the debonding. In this study passive thermography pseudo experiments are conducted on a bridge deck overlayed with asphaltic layer to detect and identify damages in asphalt and base course. The damages were artificially created in the FEM model and passive thermography is simulated using industry standard software COMSOL. It is found that thermographs obtained clearly shows the presence and extent of damages in the Asphaltic layer. It is also observed that damages up to dept of 70mm from the road surface identifiable. This study helps early detection of debonding and hence enabling repair and replacement strategies at appropriate location without losing much time in locating hidden damages below the road surface which in turn increase the service life of asphalt overlays on concrete bridge decks in Goa.**

Keywords— Debonding, Health Monitoring, service life, Temperature, Infrared Thermography

I. INTRODUCTION

Maintenance and preservation of transport infrastructure is a global issue that has an impact on the social and economic development of every nation. The pavement is an essential component of the road that contributes to enhances safety, increases vehicle comfort, and lowers fuel consumption. The pavement usually experiences heavy wear (such as cracks, voids, and delamination), so regular repair is required to keep the road in the best possible condition for use. To adhere to the conviction of restoring the pavement at the proper time, road authorities deploy pavement management systems that utilise inspection data combined with forecasting algorithms [16]. Extending the usable service life of structures and infrastructures has grown increasingly important in recent years. Development of Non-Destructive Testing is given particular priority as an assessment technique.

Delamination and rutting of asphaltic layers are commonly observed on the bridge deck which not only affects smooth flow of traffic but also causes further structural distress in the asphaltic layer. These delamination are mainly due to poor quality of asphaltic layer or sometimes it is also due to poor bonding between asphaltic layer and bridge deck. Extending the usable service life of pavement surface on bridge deck has grown increasingly important in recent years. It is important to have regular inspection to detect initiation of such defects so that corrective repairs are carried out to extend the service life of the pavement layer. Development of early detection technique for assessment of delamination of deck surface has become priority. In this report a simulation is carried out to find effectiveness of using infrared thermography to detect delamination defects in pavement layer on bridge deck. Most NDT for structural elements, such as ultrasonic, magnetic field, and eddy current methods, are suitable for finding flaws between 5 and 100 cm deep, and they have two major drawbacks: they require physical contact with the object being tested, and their scanning-based image generation process is slow. Infrared thermography, sometimes referred to as thermal inspection or infrared imaging, is a quick and distant technique that is increasingly employed in conjunction with other NDT techniques like Ground Penetrating Radar.

In the recent times a new technique is adopted to preserve bridge decks from moisture and temperature deterioration by introducing waterproofing membranes between the deck and asphaltic layer. Although there are many different types of waterproofing membranes, they all work by forming a water-impermeable layer on top of a concrete bridge deck to prevent water and chlorides from infiltrating the deck and causing corrosion of the steel reinforcement and deterioration of the concrete. The most often waterproofing systems are preformed roll-on membranes and liquid applied waterproofing membranes. Generally, preformed and liquid

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applied membranes are constructed by putting a priming layer to an exposed concrete bridge deck. After that, the waterproofing membrane is put on top of the priming layer. The membrane is sprayed with a tack layer before being paved over with typical paving asphaltic layer [6].

A variety of factors influence the performance and bond strength of waterproofing membranes with pavement layer. The temperature of the concrete bridge deck during waterproofing membrane installation has been found to have a substantial impact on the binding between the membrane and the deck. Another aspect influencing bond resistance and surfacing effectiveness is bridge deck roughness during construction. Application of primer layer also affects bonding, if the deck becomes too heated, the viscosity of the liquid membrane decreases, resulting in irregular thicknesses and if the deck is too cold, the primer layer will set before it can penetrate [8]. The loss of a bond between the surfacing and the deck prevents the system from functioning as a monolithic structure and diminishes structural integrity. Infrared thermography can be effectively used to determine delamination in asphaltic layer. Infrared thermography is a widely used technique for detecting of damages inside the concrete, railroads and highway bridge decks. Infrared thermography (IRT) can produce images of surface temperature fluctuations linked to subsurface damage at distances of up to 30 metres; it has the capacity to increase inspection efficiency without requiring physical access or traffic control. Additionally, it enables an inspector to quickly scan a vast area to determine which parts of a bridge require repair and which require additional inspection. The main objectives of this study are:

- To model the bridge deck using finite element method to simulate combined physical behaviour of asphaltic layer, waterproofing layer and bridge deck.
- To study the factors affecting debonding of asphaltic layer on the bridge deck
- Find the effect of waterproofing membrane on the behaviour of asphaltic layer under different loading conditions
- Using Infrared Thermography principles to identify variations of stresses and damages on a bitumen layer over bridge deck.

II. LITERATURE REVIEW

Sandra Pozzer et al. (2021) conducted numerical simulations to determine the best times for IRT-based subsurface damage detection in concrete bridge slabs with passive heating over a one-year period. The results of a set of thermographic field inspections on a sample concrete slab were used to calibrate the model, which was created using the Finite Element Method (FEM). A sample of a concrete bridge slab with artificial subsurface delamination was examined using a thermal camera in various weather and seasonal circumstances. The calibrated model was used to forecast the best times to find subsurface delamination in a concrete building. With 17.42% more accurate detections in the summer and spring compared to the autumn and winter, it can be seen that these seasons are ideal for conducting infrared thermographic inspections under passive heating.

M. Haynes et al. (2021) studied failure mechanisms as well as to evaluate the performance of pavement overlays by conducting field and laboratory tests. The moisture infiltration happened significantly more gradually in samples that had a coating of mastic asphalt over the roll-on membrane. The roll-on membrane technologies didn't offer enough im-permeability overall while waterproofing membranes that were sprayed on and those that were poured both displayed im-permeability. In comparison to the smooth-textured roll-on membrane, the high surface textures of the spray-on and poured membranes formed a significantly stronger bond with the asphalt overlay. The mastic asphalt layer were not affected by freeze– thaw cycles since water could not reach the mastic–impermeable membrane interface because of the low air void content of the mastic layer.

A. Alipour et al. (2017) has constructed numerical model of pavement layers that can forecast the compaction curve before construction could assist in calculating the impact of each influential parameters on the compaction curve. Study used COMSOL heat transfer module to simulate the heat flux in the asphaltic material during compaction and Cam-clay elasto-plasticity model was utilized to from Solid mechanics module. The results show that the created model is capable of simulating the temperature drop and the initial and gradual compaction of the asphaltic mixture.

B. Cannas et al. (2012) studied heat transfer mechanism caused by two halogen lamps into the concrete structure was simulated by a 3D model using the finite element method in order to locate the defects. Experimental thermal analysis has been carried out on a concrete wall 90×62×38 cm with an inside polystyrene cavity sized 20×38×14 cm^3 also plastic disc defects with diameter of 7.5 cm and thickness of 0.3 cm inserted at different depths. The laboratory results matched the numerical data, which enables the execution of parametric investigations without experimental testing. The position of the fault can be determined by comparing experimental and simulated thermograms.

III. METHODOLOGY

In this paper two types of bridge deck were modelled with identical geometry, Model 1 which has a concrete bridge girder, concrete deck slab and asphalt overlay, while Model 2 has a waterproofing membrane between the concrete deck slab and asphalt overlay. The geometry of models is meshed into finite elements [18]. FEM model is prepared using industry standard software COMSOL. The models were subjected to the heat load to simulate actual site conditions.

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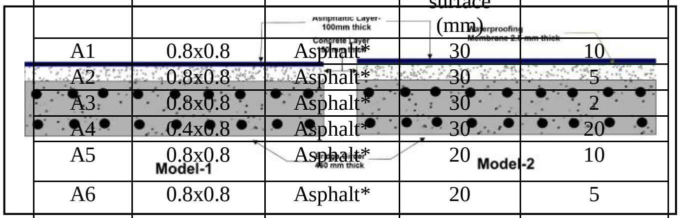

Fig. 1. Cross Section of bridge deck with and without waterproofing membrane

FEM Modelling

In this study to simulate the combined behaviour of asphalt, waterproofing membrane and bridge deck, time dependent heat transfer physics principles are incorporated in COMSOL Software. First, the geometry of the deck slab, waterproofing layer, asphaltic layer is created. The geometry details are as follows: the span of bridge deck is 10m, width 4.25m. The thickness of the girder 450 mm and concrete layer above bridge deck is 150mm. A waterproofing layer of 2.5 mm thickness and asphalt layer of 100mm thickness is provided. The bridge deck is provided with two layers of 20mm diameter bars @ 225mmc/c and distribution reinforcement of 12mm bars @200mmc/c. The material proprieties as shown in Table1, is assigned to each layer. The geometry is discretized into triangular and tetrahedral elements. The heat flux boundary conditions are assigned and the Heat Transfer module is set up. The heat flow by convection is included as boundary condition acting on all surfaces of bridge deck. The meshing is configured in such a way that adaptive refinement is achieved at boundary of each layer. The total geometry discretized into 11, 50,798 tetrahedral and 2, 60,346 triangular elements as shown in figure 2.

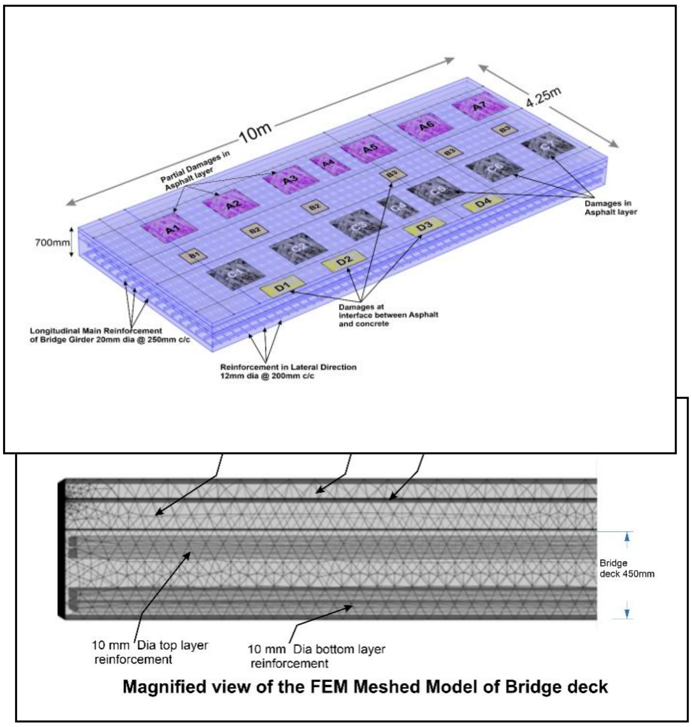

Fig. 2. FEM model of bridge deck with waterproofing memebrane with asphalt layer overlay

TABLE I. MATERIAL PROPERIES

	Materials			
	Concrete	*Steel*	*Asphalt*	*Membrane*
Thermal Conductivity **k**(W/mK)	1.8	44.5	1.63	0.8
Heat capacity $\mathbf{C_p}$(J/kgK)	880	475	1350	1700
Densityρ(kg/m^3)	2300	7850	2400	1150
Heat Transfer Coefficient $\boldsymbol{h}$(W/m^2K)	22.138	-	76	-
Youngs Modulus *E(GPa)*	25	200	8	1400

To simulate identification of damages using infrared thermography, the damages were incorporated in the model as shown the figure 3. The damages are incorporated in asphaltic layer as well as in the concrete base. The details of damages are provided in Table 2. The Model is subjected to Solar heating and surface temperature profiles are recorded to simulate the infrared thermography.

Fig. 3. Model with damages

TABLE II. DETAILS OR DEFECTS

Name	Size	Property	Depth from surface (mm)	Thickness (mm)
A1	0.8x0.8	Asphalt*	30	10
A2	0.8x0.8	Asphalt*	30	5
A3	0.8x0.8	Asphalt*	30	2
A4	0.4x0.8	Asphalt*	30	20
A5	0.8x0.8	Asphalt*	20	10
A6	0.8x0.8	Asphalt*	20	5
A7	0.8x0.8	Asphalt*	20	2
B1	0.4x0.4	Air	90	5
B2	0.4x0.4	Asphalt*	85	1
B3	0.4x0.4	Air	110	1
B4	0.4x0.4	Asphalt*	80	1
B5	0.4x0.4	Air	95	1
B6	0.4x0.4	Asphalt*	87	1
C1	0.8x0.8	Air	30	10
C2	0.8x0.8	Air	30	5
C3	0.8x0.8	Air	30	2
C4	0.4x0.8	Air	30	20
C5	0.8x0.8	Air	20	10
C6	0.8x0.8	Air	20	5
C7	0.8x0.8	Air	20	2
D1	0.8x0.4	Air	110	10
D2	0.8x0.4	Asphalt*	105	3
D3	0.8x0.4	Air	80	1
D4	0.8x0.4	Asphalt*	104	1

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FE Analysis

In the first analysis temperature load in the form of flux is applied to both models for 60 minutes and the temperature variation in each layers of both model are recorded. It is observed that in the model 1 the asphaltic layer temperature increased up to 55^{0}C while girder temperature reached to 34^{0}C steadily. It can be seen that there exists a temperature gradient between asphaltic and girder. In model 2 the temperature of waterproofing layer shown a nonlinear variation compared to temperature variation of asphaltic layer and girder. The temperature variations of different layer of both the models are shown in figure 4. The study reveals that the temperature gradient between various layers is clearly noticeable, and the temperature fluctuation results in unequal expansion under heat loading.

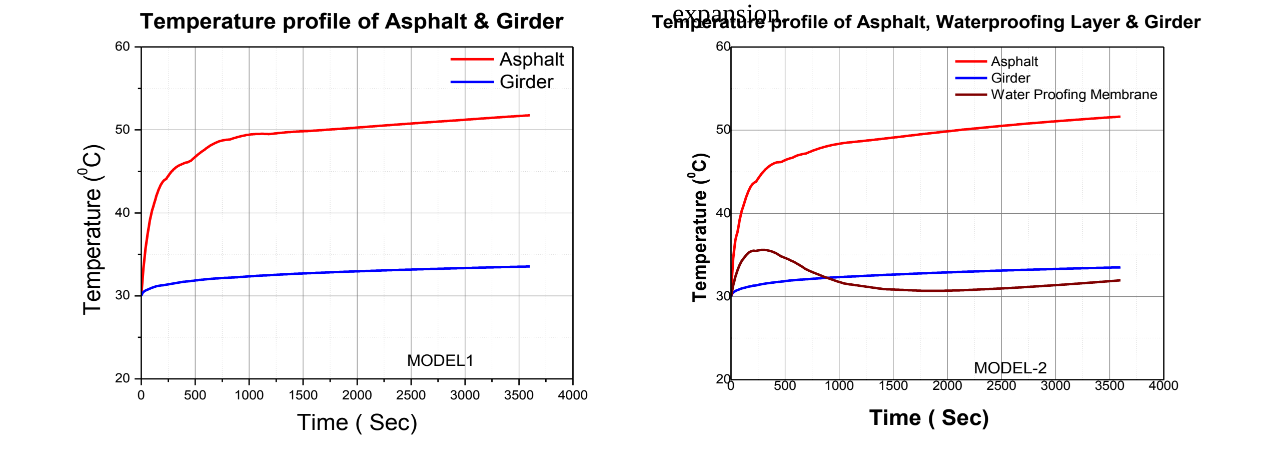

Fig. 4. Temperature profile v/s Time Graph Of Maximum Surface temperature of Model 1 and Model 2

In the second analysis to simulate the infrared thermography both the models were subjected to Ambient solar heating. The primary source of heat in this analysis is solar irradiation, which is included using the External Radiation Source feature available in COMSOL. This feature uses the longitude, latitude, time zone, day of year, and time of day to compute the direction of the incident solar radiation over the simulation time. The bridge location city Panjim – Goa has been taken with longitude 15.50N Latitude-73.830E, time zone +5.30 UTC, day of the year 17/02/2023, assuming no cloud cover, the solar flux at the surface is about 1000 W/m2. The temperature profiles are recorded at different time which shows the presence of damages.

IV. RESULTS AND DISCUSSION

Due to the temperature difference, a temperature gradient developed between layers, which resulted in unequal expansions of each layer. The temperature at the top of the asphalt layer and the bottom of the girder is significantly greater than the temperature at the membrane layer, causing a relative displacement between asphaltic and waterproofing membrane that resulted in a relative stress in the asphaltic layer and, ultimately, causes the asphalt to debond.

Also, from the graph in fig 5 it is seen that Temperature variations are proportional in Model 1, while model 2 doesn't show proportional variation in temperature between asphaltic layer and waterproofing membrane, this is due to the materials having different coefficient of thermal expansion.

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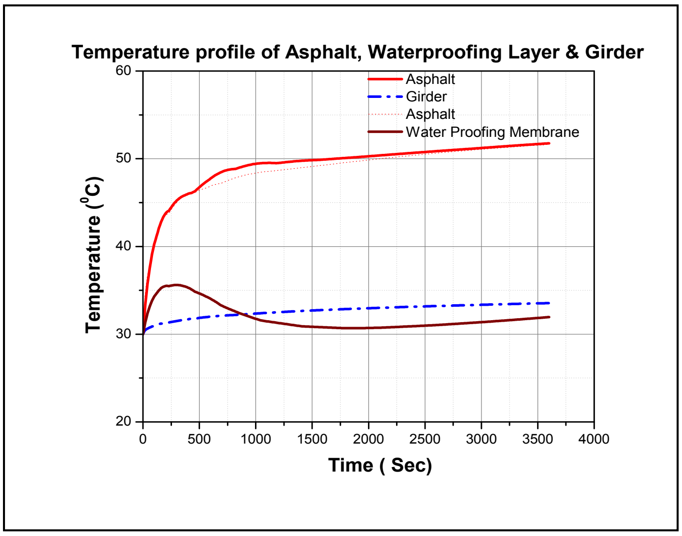
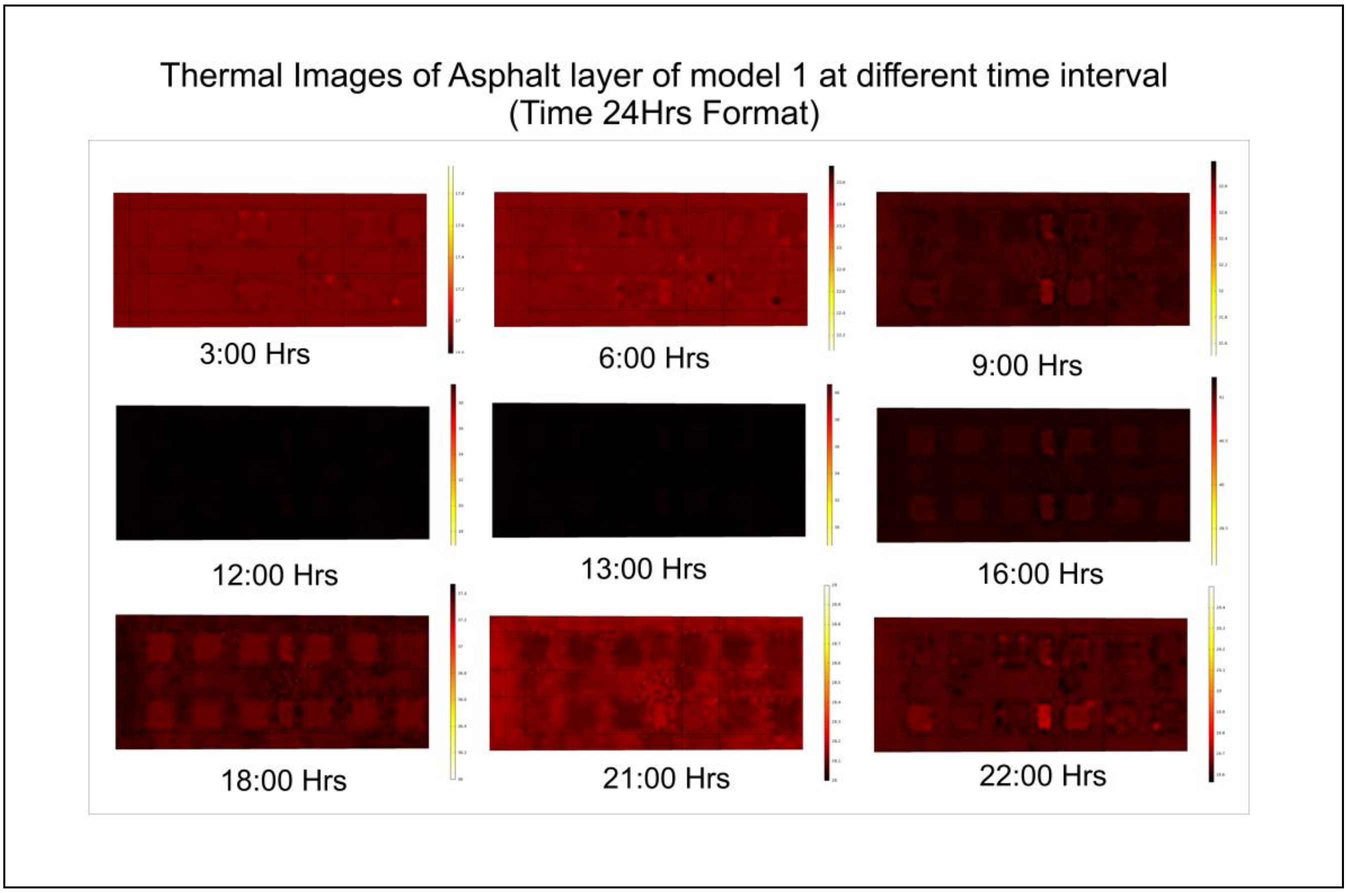
Fig. 5. Temperature profile v/s Time Graph of Maximum Surface temperature at top surface of asphalt, membrane and bottom surface of deck



The figure 6 and 7 shows the thermographs extracted from the second analysis. The thermographs are extracted at different time to ascertain the appropriate time for conducting infrared thermograph.

The figure 6 shows the temperature profile recorded on model 1 and figure 7 shows the temperature profile recorded on model 2. It is seen that thermographs taken at early morning up to 9 am and thermographs taken late in the evening after 6 pm shows the damages inside asphaltic layer very clearly.



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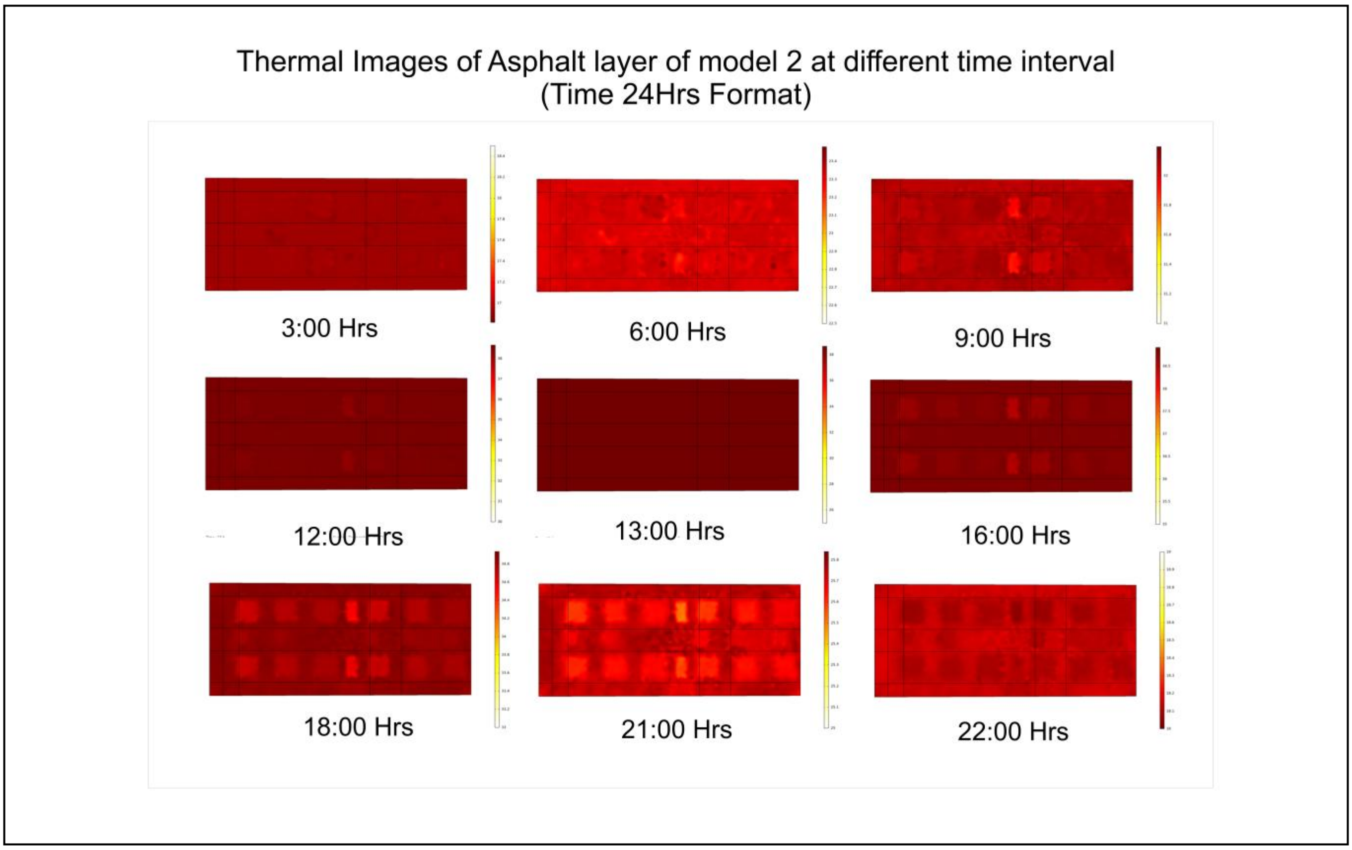


Fig. 6. Model 1: Thermal Images

Fig. 7. Model 2: Thermal image

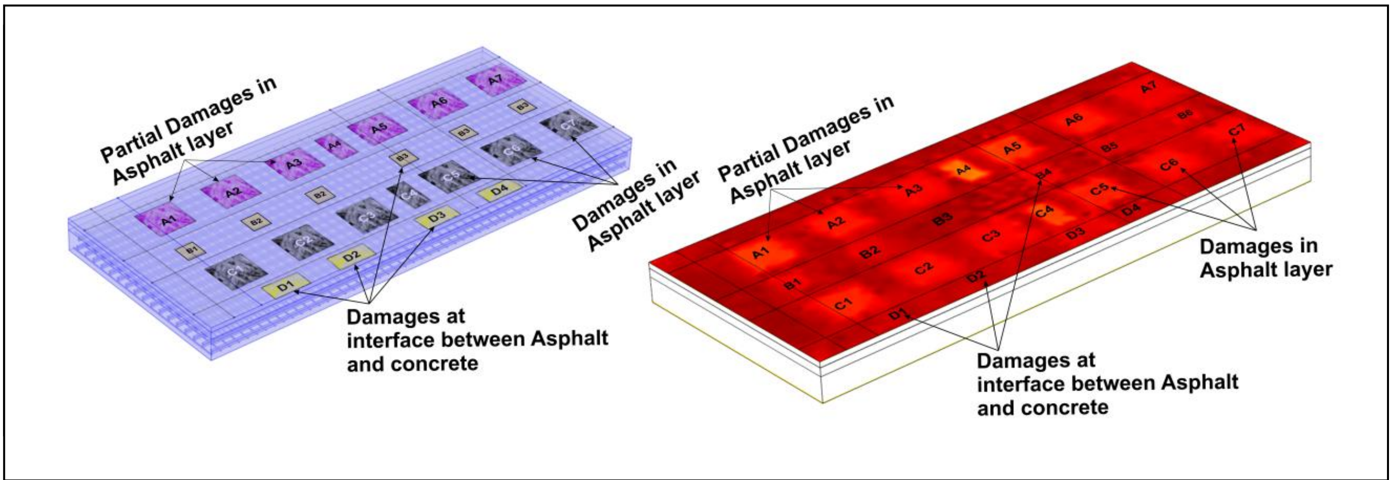
One of the thrusts in this study is to determine whether the damages which are much below the asphaltic layer are identifiable using thermographs. The figure 8 shows the details of damages seen on the thermographs extracted at 18:00 hours on model 1. it is observed that all the damages which are in asphaltic layer (100 mm thick) are visible. However, the damages which are below the asphaltic layer are not clearly visible. The damages incorporated in Model 2 are mapped in figure 20 on the thermograph recorded at 21:00 hours. The damages located below the surface up to depth of 100 mm are clearly visible.

Fig. 8. Model 1 :Thermal Image extracted at 18:00 hours

Fig. 9. Model 2:Thermal image extracted at 21:00 hours

V. CONCLUSION

The bridge deck with asphaltic layer and water proofing layer is studied for its thermal behaviour using heat transfer principle. The Finite element analysis is conducted to understand complex behaviour of pavement over bridge due



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to combined effect of waterproofing layer and asphaltic layer. It is found that the relative displacement due to unequal expansion caused to temperature gradient among different layers cased deboning of asphalt on bride deck. It is concluded that the waterproofing layer between concrete and asphalt is responsible for generating unequal thermal stresses in the pavement layer. It is suggested that waterproofing material which has similar thermal conductivity may be used between asphalt and girder. Further it is possible to detect the damages below the asphaltic layer using infrared thermography. Based on the numerical study conducted on bridge deck, it is concluded that infrared thermography can detect damages up to 100 mm below the road surface. The damages will be clearly visible if thermogram are obtained during early morning up to 9 am or late evening after 6pm. This is mainly because of distinctive temperature contrast over damages

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