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VISCOELASTIC THERMAL STRESS ANALYSIS OF ROAD BRIDGE WITH FLEXIBLE PAVEMENT UNDER TEMPERATURE VARIATIONS

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INTRODUCTION:

The influence of temperature needs to be taken into account when designing a structure that is to include full temperature variations likely to be encountered during design life. Although there has been a considerable studies on temperature influence but predicting thermal stress involving viscoelasticity is much difficult. It is really hard to obtain the accuracy of a solution due to complicated behavior of viscoelasticity and more complicated if the load and material compliance are time-temperature dependent. Through a hereditary integral form of stress-strain relationship, it is convenient to solve the solution if the viscoelastic response is characterized by relaxation modulus function in the form of exponential series in time. In this paper, by means of plane strain finite element formulation a numerical analysis based on time-dependent thermal conduction(1) and viscoelastic constitutive theory(2) is applied to a model chosen representing part of road bridge section. Thermal stress distribution under cool temperature variations is predicted.

ANALYTICAL THEORY:

The governing equation of time-dependent thermal equation is

$$div\,(KgradT)+q-C\frac{\partial T}{\partial t}=0 \qquad \cdots\ 1$$

On discretization, the integral functional energy X of a domain for 2-Dimensional problem in finite element derivation is

$$X=\iint\left\{\frac{1}{2}K\left[\left(\frac{\partial T}{\partial x}\right)^2+\left(\frac{\partial T}{\partial y}\right)^2\right]-\left(q-C\frac{\partial T}{\partial t}\right)T\right\}dxdy$$

$$-\int_{s_1}QTds+\int_{s_2}\alpha'\left(\frac{1}{2}T^2-T_{\alpha}.T\right)ds \qquad \cdots\ 2$$

where, K = thermal conductivity, T = temperature, q = heat flow; C = thermal capacity, t = time, Q = heat flux; T_{α} = thermal transient, α' = transient coefficient. Through minimization the unknown values of T is determined in the following equation

$$\left([H]+\frac{2}{\Delta t}[P]\right)\{T\}_t=$$

$$[P]\left(\left\{\frac{\partial T}{\partial t}\right\}_{t-\Delta t}+\frac{2}{\Delta t}\{T\}_{t-\Delta t}\right)+\{Q\}_t \qquad \ldots 3$$

where, $[H]$= thermal conductivity matrix; $[P]$ = thermal capacity matrix. Once temperature distribution in a body is determined, its effect on the properties of viscoelastic is expressed by time-temperature superposition principal. The hereditary stress-strain relations of viscoelastic property is

$$\sigma(t_k)=E(0)\varepsilon(t)-\int_0^t\frac{dE(t-t')}{dt'}\varepsilon(t')dt' \qquad \ldots 4$$

where, E = stress relaxation modulus. In solving viscoelastic problem, at each time increment the solution must be saved and used to generate new solutions involving summation back to time origin.

Thus the merged element matrices yield to extremely large system. Assuming linear viscoelasticity, bulk modulus and thermal expansion coeff. is constant with time, the following incremental stiffness equation for an element is formulated to minimize regeneration of stiffness matrices at each time increment.

$$\left(K_1+\left[G(0)-G(\xi_k-\xi_{k-1})\right]K_2\right)r(t_k)=$$

$$F(t_k)+H(t_k)+V(t_k) \qquad \ldots\ 5$$

where, K_1 and K_2 are the constants contain matrix coeff. and material constitutive matrix, G = shear relaxation modulus expressed by recurrence relation $G(t)=A_0+\sum_{j=1}^{q}A_j e^{-\frac{t}{\tau_j}}$; ξ = shifted time relates to real time t through $\xi(t)=\int_0^t 10^{h\left[T_m(t')\right]}dt'$, h = sift factor at specified reference temp., T_m = average nodal temp., r = displacement; F = mechanical load, H = $-3K\alpha T$ as thermal load, V = memory load which accounts for the history of loading and expressed as

$$V(t_k)=-\frac{1}{3}\phi^T\begin{bmatrix}-4&2&0\\2&-4&0\\0&0&-3\end{bmatrix}\left(\sum_{j=1}^{q}A_j\alpha_{j,k}+N\right)$$

where, ϕ has the relationship of $\varepsilon(t)=\phi r(t)$

$$N=\frac{1}{2}\left[G(0)-G(\infty)-\sum_{j=1}^{q}A_j\exp\left(-\frac{\xi-\xi_{k-1}}{\tau}\right)\right]\varepsilon(t_{k-1})$$

NUMERICAL MODEL AND RESULTS:

The finite element mesh representing a segment of an idealized road bridge cross-section is shown in *Figure 1* below. It consists of 208 mm concrete deck overlaid with 40 mm thick each of asphaltic concrete wearing and bearing surfaces. Top and bottom of the exposed faces are prescribed to cool temperature variations.

Figure 2 shows time-temperature distribution occurred at the exposed faces of asphalt layer and concrete deck. Asphalt pavement conducted greater temperature than concrete material. We can see that after 18 hours onward the internal temperatures at the exposed faces are greater than ambient temperature field. At this stage the internal temperature in concrete material seemed as being saturated. The stress distribution corresponding to time in each material is shown in *Figure 3*. Near the top face of wearing course layer, the compressive stress increased steadily until reaching peak at 10-hour period. The curve then decreased and changed to tension state after 18-hours. When we compare with temperature curve, compressive stress reduction has taken placed while cool temperature keeps on increasing. This demonstrates that dissipation of energy has taken place and the phenomenon of losing the stress is known as stress relaxation. The induced stress near the top face of concrete deck is greater than bottom face although the bottom face is exposed to ambient temperature field. It is felt that the increase is due to transient effect from asphalt layer. In *Figure 4* illustrates time-vertical displacement curve at the middle top of wearing layer and bottom face of concrete deck. The displacement curve at asphalt face is increased progressively through out the prescribed period. In spite of decrease in cool temperature field after 16 hours, asphalt continued to deform. Where as at exposed face of concrete deck, displacement gradient getting reduced and almost constant after approaching 16-hour period.

CONCLUSIONS:

The following conclusions may be drawn;

1 Under cooler environment, asphalt pavement exhibits viscoelastic characteristic between -8°C to -15°C.

2 Viscoelastic response could be a source of substantial energy dissipation, hence would influent the strength of the materials considerably.

3 It is revealed that asphalt layer received greater thermal influence among the bridge components.

4 It is apparent that concrete deck induced additional stress at the interface due to intact with asphalt layer.

5 With the absent of external loading, deformation is very much minimal as to be negligible. How ever the development of internal stress should not be over looked.

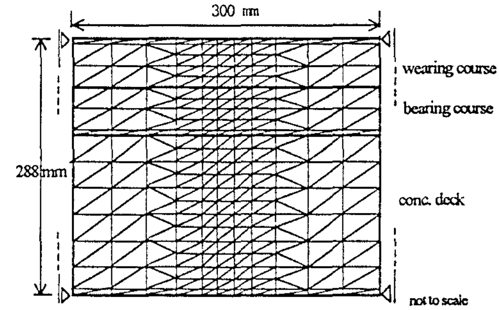

Figure 1 Segment of road bridge

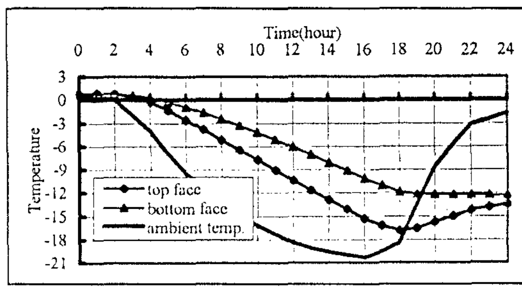

Figure 2 Time-temperature distribution

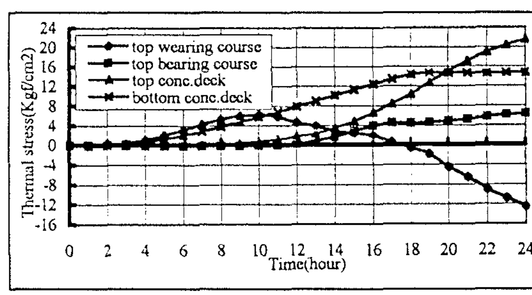

Figure 3 Time-stress distribution

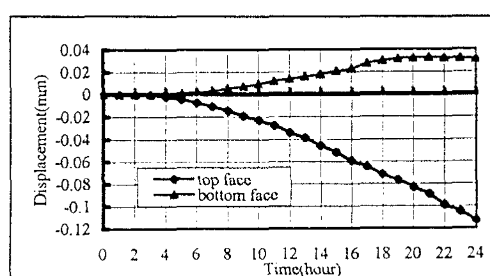

Figure 4 Time-vertical displacement

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