3.1 Numerical Analysis of Multi-Layered Road Systems

A numerical scheme and computer software was developed to evaluate the stress, strain and displacement at any arbitrary point in an *n*-layered system. The model and the numerical scheme have been validated for the published numerical study for a three-layered system. The model results have been compared with the field values obtained by using a falling weight deflectometer (FWD). Towed by a vehicle, the FWD system comprises of a trailer with sensors and a falling weight assembly unit attached at the rear. The field data collection procedures are fully automatic and the data is downloaded to a computer. The basic output of the FWD is in terms of transient pavement surface deflections collected by seven sensors for a given load generated by a circular falling weight of radius 30 cm. The sample output of FWD for a two-layered system for four test points is given in *Table 3.1.1* for a single load case.

Variation of vertical deflection with radial distance is determined by the above numerical analysis for both the two-layered and three-layered systems for

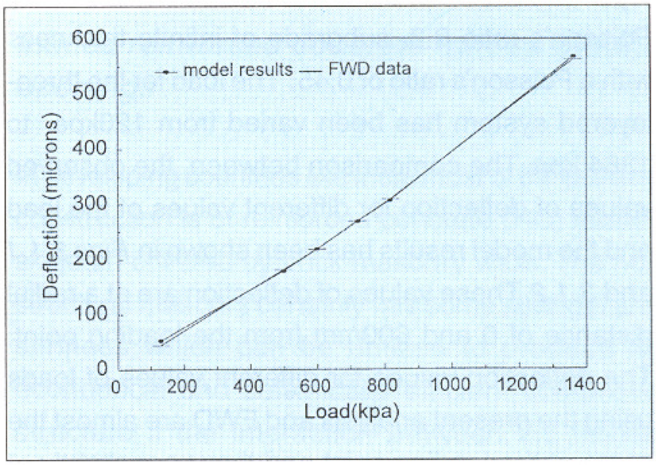

Fig. 3.1.1. Defelection at 0mm from the loading point.

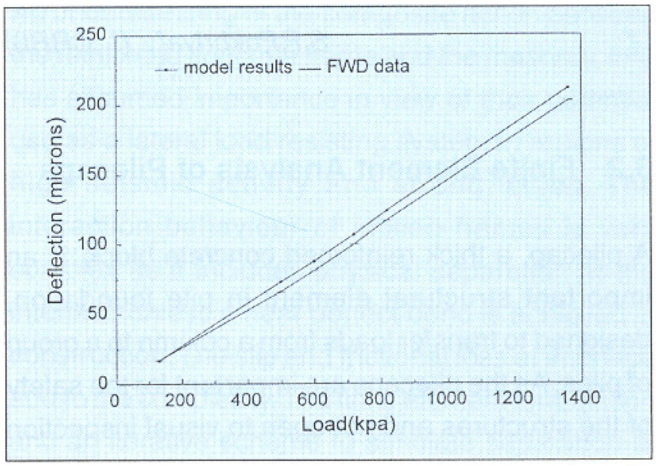

Fig. 3.1.2. Defelection at 600mm from the loading point.

Table 3.1.1 Sample output of FWD for four test points for a single load case for a two-layered system

	Load per unit area	Deflection values in microns at the indicated radial distances in (mm) from the loading point							E (Mpa)	
Test Point	(kpa)	0	300	600	900	1200	1500	1800	E_1	E_2
1	490	385	180	76	48	31	20	16	489	124
2	496	856	214	88	46	35	19	18	204	110
3	455	513	151	68	41	28	18	11	251	128
4	482	598	169	66	48	32	23	20	227	108

different load cases. The three-layered system consists of a top layer of bituminous macadam of thickness 75mm and Poisson's ratio 0.35, middle layer of stabilised soil of thickness 430mm and Poisson's ratio 0.3, subgrade of infinite thickness with a Poisson's ratio of 0.45. The load for the three-layered system has been varied from 120kpa to 1384 kpa. The comparison between the observed values of deflection for different values of the load and the model results has been shown in *Figs 3.1.1* and *3.1.2*. These values of deflection are at a radial distance of 0 and 600mm from the loading point. The deflection values for different values of loads using the present analysis and FWD are almost the same at the loading point and they vary slightly at points away from the loading points.

(Sridevi Jade, P.K.Nanda , K.K.Verma', S.P.Pokhriyal'. (* CRRI))*

3.2 Finite Element Analysis of Pilecaps

A pilecap, a thick reinforced concrete block, is an important structural element in pile foundation, designed to transfer loads from a column to a group of piles. As the pilecaps are important for the safety of the structures and not open to visual inspection under service, a sound knowledge of their realistic behaviour is essential. To understand the realistic behaviour, a finite element approach, both linear as well as nonlinear, is necessary. Three dimensional linear finite element analysis of four-pile group and three-pile group specimens for square pilecap, T shaped pilecap and triangular pilecap has been done taking into account the various parameters like depth of the pilecap, size of the pilecap and size of the finite element mesh.

The reinforced concrete pilecap with four pile group and three pile group, with different shapes are modelled and analysed using the finite element analysis by applying unit pressure over an area of 400mm x 400mm to correspond the load transferred from the column. The total concentrated load considered is 440kn. Three dimensional eight noded isoparametric element is used to model concrete elements of the pilecap. The self weight of the pilecap is not taken into account. Here the column is at the centre of the pilecap. The size of the column and the size of the piles are assumed to be the same and square in shape. The piles are situated at an offset of 200 mm from the sides of the pilecap and the location of the piles are kept same for all the parameters considered. The material properties used in the analysis are M25

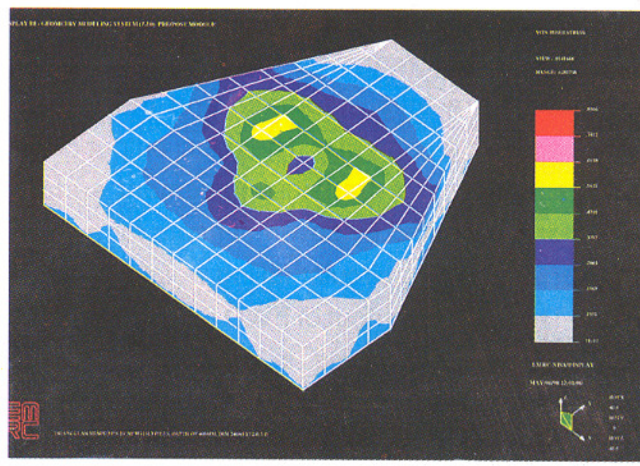

Fig. 3.2.1. Stress contours for triangular shaped pilecap.

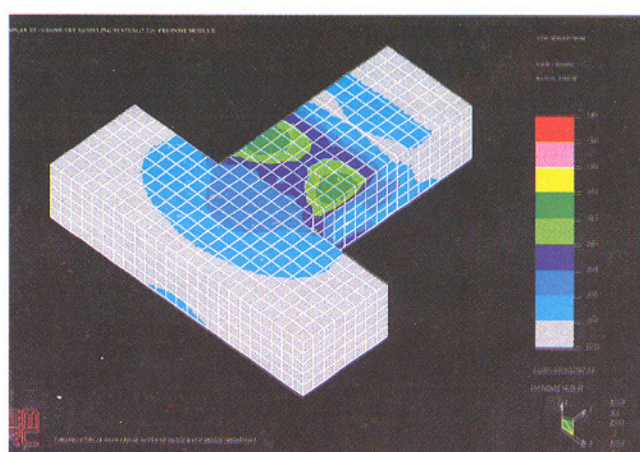

Fig. 3.2.2. Stress contours for T shaped pilecap.

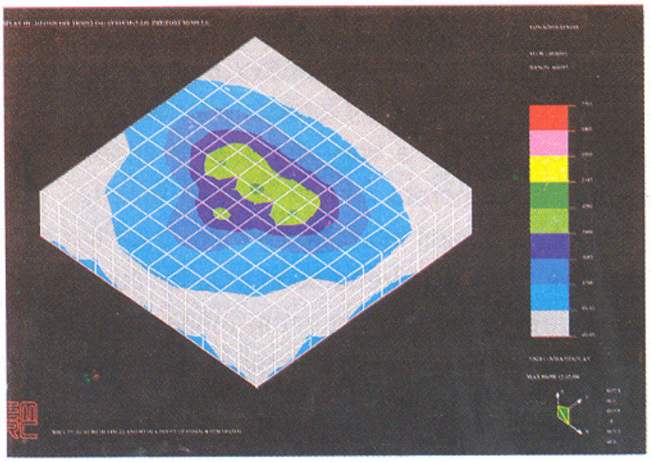

Fig. 3.2.3. Stress contours for rectangular shaped pilecap.

concrete grade, modulus of elasticity is 2.85×10^4 N/mm^2, Poisson's ratio is 0.15.

In all the cases it is observed that as the depth of the pile cap decreases there is an increase in stresses and so is the quantity of reinforcement. It is also seen that as the size of the pilecap increases there is an increase in stress which is due to bending action and so is the quantity of steel. From the stress contours (*Figs. 3.2.1, 3.2.2* and *3.2.3*) for all the cases we can see a common phenomenon that the concentration of stress is more near the location where the load or pressure is applied and also at the places where there are piles. The stresses are compressive in nature in the top layers and tensile in the bottom layers. T shaped sections of pilecaps are more economical compared to square and triangular shaped pilecaps as they involve use of less concrete and steel. As the size of the pilecap increases it is found that the quantity of steel required also increases. Hence, it is preferable to use the minimum size of the pilecap. In this analysis an attempt has been made to provide a simplified design method which can be used by the structural designers.

(Sridevi Jade, H.S.Sumanth, A.Prabhakara**
(Bangalore University))*

3.3 Behaviour of Infilled Reinforced Concrete Frames under Combined Lateral and Vertical Loading

Infilled reinforced concrete frames without openings

In developing countries like India most of the building construction is of reinforced concrete (RC) frames skeleton covered by brick masonry walls. The non structural masonry certainly has some strength and stiffness which can be utilized to produce an economical and seismically efficient composite structure if the interaction between the infilled masonry and the bounding RC frame is considered in design.

An understanding of the composite action between the reinforced concrete frame and the masonry infill has assumed importance in view of their potential use as a lateral load resisting system in regions of high seismic activity and strong winds. The interaction behaviour of infilled frames is very complex as it includes physical separation at the interface unless a near perfect bond is achieved in construction. The slip and frictional loss at interface add to the complexity. The finite element formulation and an iterative scheme to simulate separation at the interface has been employed in the present study. The study incorporates the various other structural parameters which affect interaction viz., aspect ratio, relative stiffness, number of storeys, absence of wall in ground floor (for parking/other purposes), openings in the wall (for doors/windows), lack of fit, load ratios etc.

The masonry infill is modelled by 2-D plane stress elements with two degrees of freedom at each node. The bounding RC frame is represented by 3-D beam elements with three degrees of freedom at each node. The interface is simulated by short and very stiff 3-D beam link elements wherein the node connecting the masonry is made into a structural hinge as no moment is to be transferred to masonry. The physical separation at the interface is simulated by carrying out an iterative scheme wherein for each run the link elements are checked for axial force and they are delinked if found in tension. The iteration is continued till a stable configuration of separation is reached.

Linear elastic analysis is carried out for stresses in masonry and deflections, bending moments, shear forces and axial forces in the members of the frame as these are the parameters necessary for design. The results of the study on one storey infilled frames have shown very encouraging results to facilitate design of low cost and highly efficient structures for areas of high seismic activity and strong winds. The moments have reduced by around 90% in almost all cases over their conventional counterparts. The columns have shown increased axial forces but reduced moments which is a favourable situation for optimum design. The beam has to be designed as a beam-column and with reduced moments it is inconsequential. The combined load system improves the contact at interface and the masonry stresses, in particular tensile principal stresses show considerable reduction. The compressive stresses, in fact tend to increase particularly in separation. However, it gives little problems for the masonry. The good results continue to occur in case of two storey infilled frames. Because of increased overturning effects of the lateral loads, the windward columns go into an unfavourable state of tension. But the presence of vertical loads nullifies it to a good extent. As in one storey infilled frames, there is a substantial reduction of more than 90% in deformations and forces and bending moments.

For a two storey infilled frame with still floor, the trend of diminishing effects reverses. The first floor beam experiences very heavy axial forces and sometimes large tensile forces under separation at interface. This is a very dangerous situation as reinforced concrete cannot sustain tension. The masonry stresses increase by more than ten fold. However the good trend continues for the second floor beam and the columns. Infilled reinforced concrete frames with still floors cannot be recommended in view of these facts. However, further work must be done before recommending a blanket ban.

Finally, masonry infilled reinforced concrete frames can be very effective, efficient and economical composite structures in areas of high seismic activity and strong winds. An improved behaviour is certainly evident under combined load systems. However, further work is underway for including the effects of various other parameters aforementioned particularly multistorey situations, to come up with a design solution.

(Sridevi Jade, R.Jagadish, D.S.Prakash**
*(*Bangalore University))*

Infilled reinforced concrete frames with openings

The effect of the openings on the behaviour of one storey infilled frames has been studied taking into account relative stiffness, load ratios and type of contact at interface.The bending moments in beams and columns are found to reduce by up to 70% in comparison to conventional frames and increase by around 20% in relation to solid infilled frames. There is a marginal increase in case of separation at interface. Shear in beams have shown a reduction of 70 to 90% depending on the extent of the opening in the wall. The lateral and vertical deflections reduce considerably from 40 to 99% depending on the extent of opening and the contact at the interface.

The columns show reduced moments and increased axial forces by up to 70% and 300% respectively with the leeward column going into a favourable state of compression from tension in case of combined loads.

The masonry stresses show a favourable change by showing decrease in tensile stresses and increase in compressive stresses under full contact at interface. However, under separation they tend to increase beyond the permissible limit. Finally, openings in the infill reduce the efficiency of the composite system, however, in relation to conventional RC frames, a definite advantage can be achieved by considering the interaction of the infill with the frame.

(Sridevi Jade, R.Jagadish, B.S.Seshadri**
*(*Bangalore University))*

3.4 Non-Newtonian Fluid Flow Simulation

Non-Newtonian fluid flow is encountered in many industrial applications. A numerical method for solving Navier-Stokes equations has been extended to compute flow of a viscoelastic fluid at moderate Reynolds number where inertial terms cannot be ignored. Maxwell and Oldroyd B models of viscoelasticity are employed. The method is applied to solve for flow in the entrance region of a channel. Most conventional rheological models of polymers are mechanical models. These models do not take into account the chemical structure of the polymer, and hence are unable to explain some of the unusual rheological phenomena. An energetically crosslinked transient network (ECTN) model has been recently given by Lele & Mashelkar (*J. Non-New. Fluid Mech.*, 75:99-115, 1998). The flow of ECTN model fluid in the entrance region has also been considered. Further experimentation with these models is being continued.

(A. Kumar, R. Mashelkar, R. Hema*
(CSIR, New Delhi))*

3.5 Flow-Consistent Grid in CFD

The computational grid can play a crucial role in accurate CFD simulations. This is considered here through the examples of flow over delta wings. Conventional grids for flow over sharp-edged delta

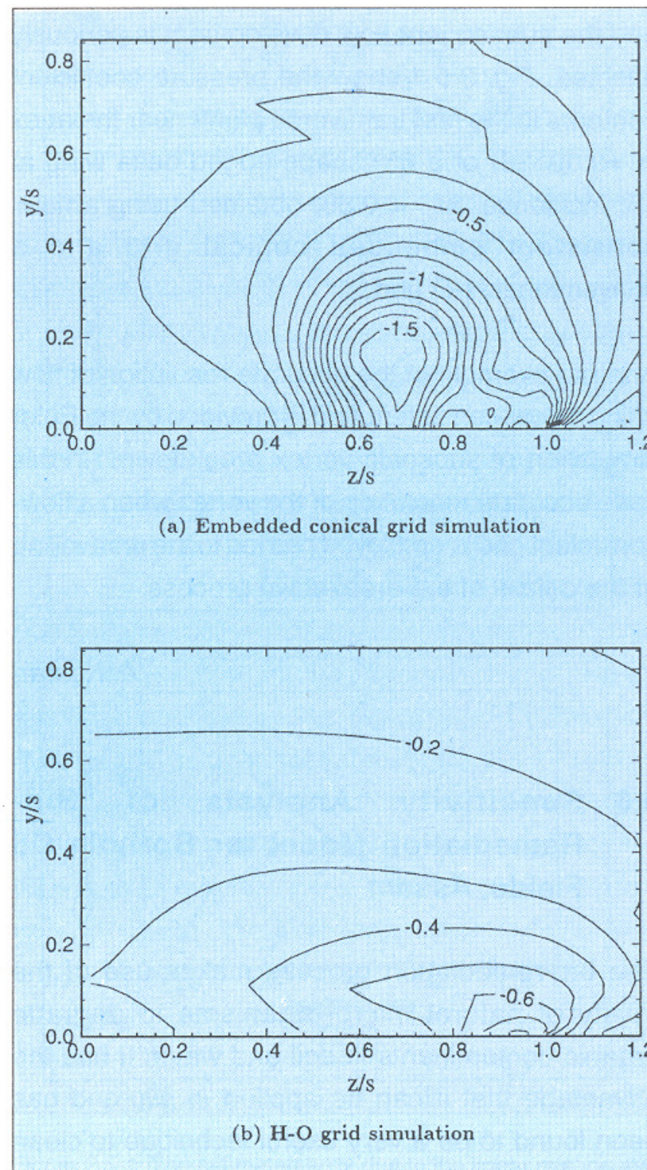

Fig. 3.5.1. Pressure coefficient contours.

wings do not resolve the near-apex flow due to dissimilar length scales of the flow and the grid. This in turn can affect the simulation of many vortex related phenomena. A grid that is consistent with the special nature of the flow is required to overcome the difficulty. The Euler simulation of transonic vortex is considered where employment of a flow-consistent grid is found to give a well-resolved vortex with cross-flow shock and also the shock induced secondary vortex, right from the apex. On the other hand, when a conventional H-O grid is employed these features are absent in the near apex flow, and the subsequent flow development is seriously affected. *Fig. 3.5.1* show the pressure coefficient contours in the first transverse plane near the apex (x =0.00128) of a 65° shape-edged delta wing at 15° incidence, M_∞ = 0.85, obtained using a flow-consistent embedded conical grid and a conventional H-O grid.

Another example of the accurate resolution of flow using a flow-consistent grid is provided by the Euler simulation of subsonic vortex breakdown. In this case accurate resolution of the vortex when a flow-consistent grid is employed has led to the unravelling of the details of the breakdown process.

(A. Kumar)

3.6 Sensitivity Analysis of Bio-Remediation Model for Borhola Oil Fields, Assam

The bio-remediation process makes use of the ability of natural micro-organisms to degrade organic contaminants in soil and water. It has the advantage that it can be applied *in situ* and has been found to be a very useful technique to clean up oil contamination. Simulation models for designing an optimized bio-remediation system is an invaluable tool because the laboratory experiments take periods of the order of months making it difficult to tune the various parameters. Agreement betwen these models and experimental results are reasonably good justifying the use of models for design optimisation. Such a model system has been under development for a couple of years and sensitivity studies were carried out with respect to some of the key parameters this year with a view to comparison with experimental values which are available now; the experimental system is based on the site specific features of Borhola oil fields in Assam.

The system model has three variables in a set of ODEs representing the macropores where transport is dominated by convection, and in a set of PDEs representing the micropores where diffusion is dominant. Soil aggregates have a structure where each aggregate has interstitial spaces with diffusive transport and much freer convective motion in the macropores between the aggregates. The dimensionless system has, in addition, thirteen parameters.

K_{ds} is a parameter representing the soil-water partition coefficient: it is large for compounds that adhere strongly to soil particles. In *Fig. 3.6.1* we have given the sensitivity curve for K_{ds}; on the x-axis we have K_{ds} and on the y-axis, the average substrate concentration (weighted 85:15 for micropores:macropores) after 370 days. The kind of nonlinear dependence exhibited in the figure is indicative of the complexity in the model.

While the biological process is sensitive to the adsorption factor, K_{ds}, the relative importance of diffusion process is controlled through ε_m, the ratio of the aggregate pore liquid volume to the mobile macropore liquid volume. The sensitivity with respect to ε_m is shown in *Fig. 3.6.2*; what is plotted

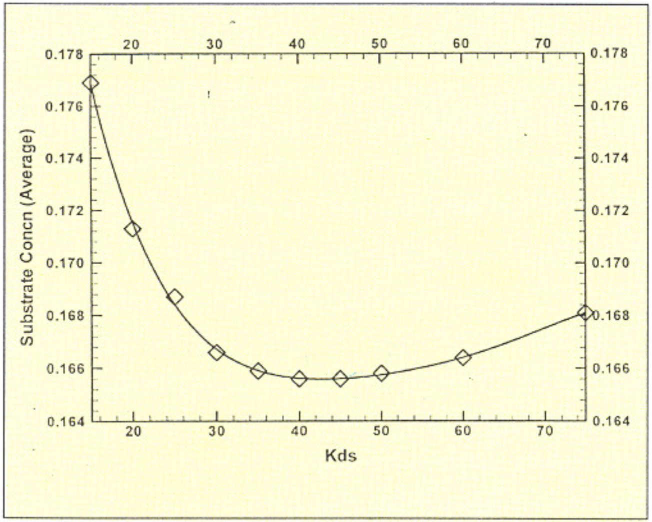

Fig. 3.6.1 Sensitivity curve for K_{ds}, the soil-water partition coefficient, which is large for compounds that adhere strongly to soil particles. The average concentration plotted on the y-axis is weighted 85:15 vis-à-vis micropores:macropores; the solid line is a polynomial fit of fifth order to the data points.

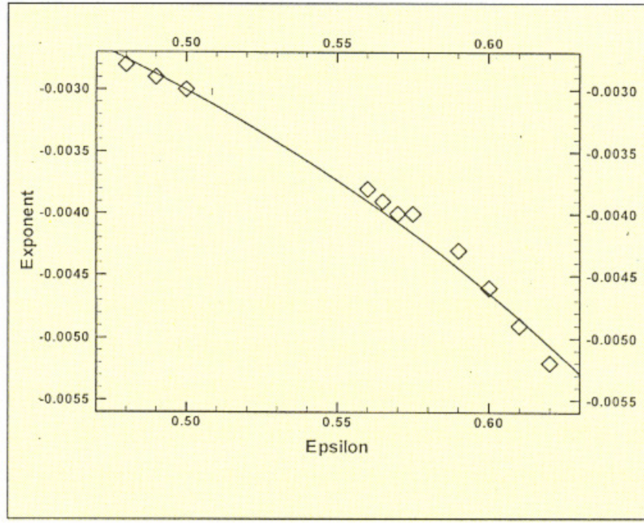

Fig. 3.6.2 Sensitivity curve for ε_m, the ratio of the aggregate pore liquid volume to the mobile macropore liquid volume. The degradation of substrate is an exponential process and its exponent is plotted on the y-axis; the solid line is an exponential fit to the data points.

is the exponential (degradation) exponent (computed over 370 days) against ε_m.

Work is in progress to determine the key parameters and their optimal values which control the bioremediation process significantly and allows matching with the available experimental results.

*(T.R. Krishna Mohan, N.N. Dutta**
(RRL, Jorhat))*