V-310 ANALYSIS OF ULTIMATE BEHAVIORS FOR CONCRETE SLABS UNDER IMPULSIVE LOADS

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1. INTRODUCTION: A dynamic analytical method for predicting the ultimate behaviors of concrete slabs under impulsive loads, which can be considered necessary for further applications towards designing impact resistible structures, is proposed in this study. The method is based on the layered finite element procedure with provision for material nonlinearity, triaxial failure criterion for concrete, elasto-plasticity, cracking in concrete elements and the loading and unloading phenomena. Verification of analytical results are carried out through comparisons with experimental results.

2. CONCRETE MODEL: A triaxial failure criterion for plain concrete which was proposed by Ottosen [1] is applied here. The failure surface for Ottosen's Model can be expressed as,

$$f(\rho,\sigma_m,\theta) = \rho - \rho_f(\sigma_m,\theta) = 0\ ,\quad |\theta| \leqq 60^\circ \qquad \cdots\cdots(1)$$

where, $\rho = \sqrt{2J_2}$, is the stress component perpendicular to the hydrostatic axis; $\rho_f(\sigma_m,\theta)$ is the failure envelope on the deviatoric planes; $\sigma_m = I_1/3$, is the octahedral mean stress; and I_1, J_2, θ are stress invariants (refer Fig.1).

The yield criterion for concrete is modified from the Ottosen failure criterion using a nonhardening plasticity model proposed by Han and Chen [2]. The yield surface is assumed to be as shown in Fig.1. During hardening, the loading surface expands and changes its shape gradually from the initial yielding surface to the failure surface. A plastic potential other than the loading function (nonassociated flow rule) is applied here in view of the fact that inelastic volume contraction at the beginning of yielding and volume dilatation at the ultimate stages is known to occur in concrete. The Drucker-Prager type of plastic potential is used here. The total strain is assumed to be composed of the elastic and plastic strain components. The loading and unloading criteria in stress space based on Drucker's stability postulate are applied at each load stage and only the elastic strain components are allowed to decrease during unloading.

3. ANALYTICAL METHOD: A quasi-3-dimensional step-by-step finite element method is employed in this study. The Newmark-β method is also employed to solve the equations of motion during discrete time intervals [3]. Reinforced concrete slabs with doubly reinforced sections are modeled using the layered finite element procedure as shown in Fig.2. The slab is divided into 8 hypothetical layers, 6 of concrete and 2 of reinforcement. The layering approach allows the strains and stresses to be varied with member thickness and permits the inclusion of steel reinforcement at proper levels within the slab.

The 20-DOF 4 node rectangular element, which consists of the inplane, plate bending and coupling effects, is applied here. The total strains for each layer is considered to be made up from the inplane element strains and the plate bending related strains. The total stiffness

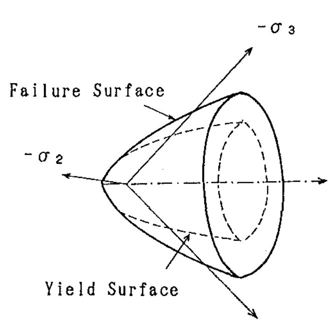


Fig.1 Yield and failure surfaces

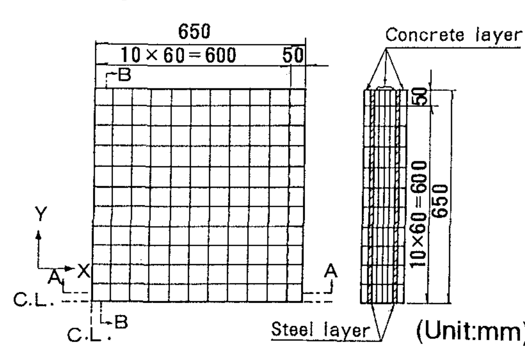


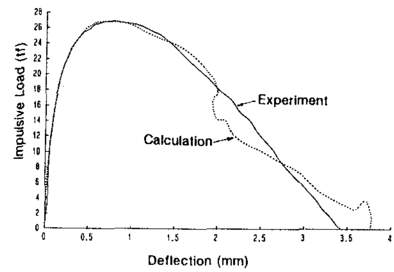
Fig.2 Layered finite element meshes (1/4 model)

matrix for the composite element is obtained by integrating the stiffness matrix for each layer and summing up for the total stiffness. The effects of transverse shear stresses in moderately thick plates are considered to affect the ultimate behaviors of concrete slabs such as the failure mode and crack distribution. The transverse shear stresses for each element are calculated from the equation of equilibrium at each time interval and then applied to the triaxial model for concrete.

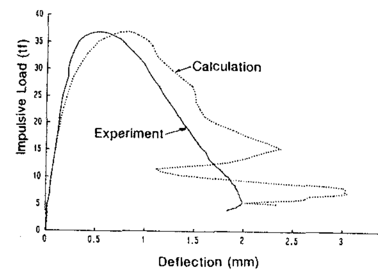
4. RESULTS AND DISCUSSIONS: Results of tests carried out on concrete slabs are used to verify the validity of the calculations. Details of the test procedure can be found in Ref.[3]. The types of concrete slabs tested are the ***normal strength*** reinforced concrete (RC) slabs and ***high strength*** reinforced concrete (HRC) slabs. The load function measured during tests are used as input for the analysis. Material test results such as Young's modulus, Poisson's ratio, uniaxial material characteristics from uniaxial compressive (concrete) and tensile (concrete and reinforcement) tests are used as the input data for the various materials.

Figs.3(a) and (b) show comparisons of the impulsive load versus midspan deflection curves for the calculations and experiments of RC and HRC slabs, respectively. Fig.3.(a) shows that the calculations give a very good approximation of the ultimate behaviors of RC slabs even in the unloading stages. A slight difference between the calculated values and the experiments begin to appear at the final stages of the curve. The result for the HRC slab is shown in Fig.3(b). A difference in the curves can be noticed after cracking in the HRC slab. The calculation predicts a larger amount of deflection but on the overall, the response is similar to the experimental result. The difference can be attributed to the fact that the Ottosen model might not be suitable for application to high strength concrete.

Fig.4 shows a typical result of the midspan total concrete strain at the bottom surface of a RC slab obtained from the analysis. It is clear that the concrete strain increases even during the initial stages of the unloading process. The strains begin to decrease only at a later stage. Therefore it can be concluded that consideration of the unloading stages is important during impulsive loadings as structural failure might occur at these stages.



(a) RC slab



(b) HRC slab

Fig.3 Impulsive load-midspan deflection function

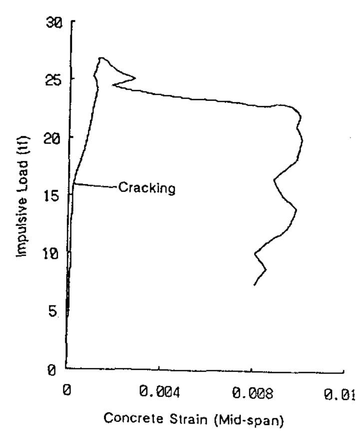


Fig.4 Impulsive load-concrete strain function

5. CONCLUSIONS: The main conclusions from this study can be summed up as:
① The layered finite element method together with the Ottosen failure model can simulate the ultimate behaviors of RC slabs to a very high degree of accuracy. ② The effects of unloading has to be considered when dealing with structures under impulsive loads.

REFERENCES: (1)Ottosen,N.S.:A Failure Criterion for Concrete,J.of Eng. Mech. Div, ASCE, Vol.103, 1977, pp.527-535. (2) Han,D.J. and Chen,W.F.: Constitutive Modelling in Analysis of Concrete Structures, J.of Eng. Mech. Div, ASCE, Vol.113, 1987, pp.577-593. (3) Miyamoto,A. and King,M.W.: Nonlinear Dynamic Analysis and Evaluation of Impact Resistance for Reinforced Concrete Beams and Slabs under Impulsive Load, Memoirs of the Fac. of Engng., Kobe University, Nov.1989, pp.37-62.