Transactions on the Built Environment vol 14, © 1995 WIT Press, www.witpress.com, ISSN 1743-3509

Comparison of experimental and dynamic analysis results for soil structure interaction problems

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Abstract

In this study a comparison between experimental results of Scattering problems are compared with corresponding results of Analysis by finite element method. In the experimental process, a stress pulse propagation in a plain strain model made of PMMA and representing a half space uniform soil in which a typical footing of a structure is founded, was studied by means of the method of caustics. The ANSYS program is used for the analysis with finite elements and especially the Transient Dynamic Analysis. The comparison of the experimental and Dynamic Analysis results is carried out using the principal stresses, principal stress differences, and max stresses.

Introduction

Experimental results of stress pulse propagation have already been presented in previous works by the authors [1,2]. In these works an experimental approach to the difficult problem of soil structure interaction was presented. In this work a dynamic analysis using finite elements was used to solve the problem, and a comparison of the two works is presented.

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Experimental Arrangement

The specimen was made from PMMA of thickness 0.3cm and had the form and the dimensions presented in Fig.1. The specimen consisted of two parts, the "base" simulate the soil, and a press-fitting part, simulating the structure (footing). The specimen was impact by a projectile which was fired out of an air gun with a velocity of about 10m/sec. The caustics formed around small holes perforated in square arrays of the complex specimen constitutive stress-rosettes [3,4]. The shape and dimensions of the caustics, see Fig.2, depend on the stress distribution and the orientation of the principal stresses at the boundary of the hole. These yield directly the principal stress directions of the stress field, as well as the principal stress difference from the follow equation:

$$D_{\max} = \frac{8}{3}\left(12C\lambda_i^3 R^2 \left|\sigma_1 - \sigma_2\right|\right)^{1/4} \tag{1}$$

where $D_{\max}$ is the maximum diameter of caustic, λ_i is the magnification ratio of the optical setup, R is the radius of the hole.

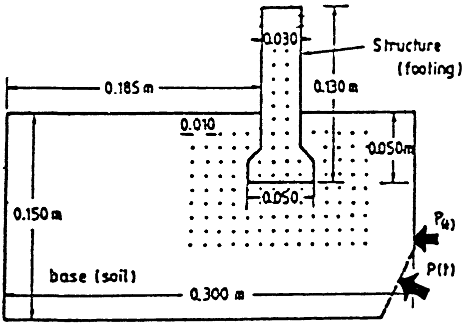

Figure 1 : Geometry of specimen.

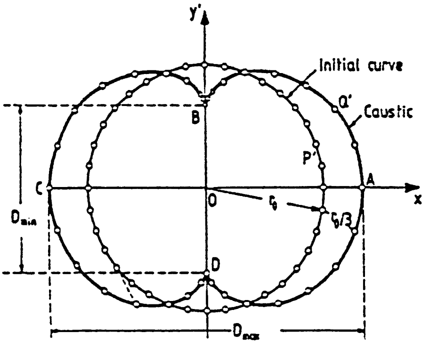

Figure 2 : The caustic.

For the recording of the stress pulse propagation a Cranz-Schardin high-speed camera was used disposing 24 sparks with a maximum frequency of 10^6 frames per sec.

Transient Dynamic Analysis (T.D.A)

T.D.A. is a technique used to determine the dynamic response of a structure under the action of any general time-dependent loads. By this type of analysis

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we can determine the time-varying displacements, strains, stresses and forces in a structure as it responds to any combination of static, transient and harmonic loads.

The Basic equation of motion solved by a T.D.A. is:

$$[M]\{\ddot{u}\} + [C]\{\dot{u}\} + [K]\{u\} = \left\{F_{(t)}\right\} \qquad (2)$$

where

$[M] =$ mass matrix

$[C] =$ damping matrix

$[K] =$ stiffness matrix

$\{\ddot{u}\} =$ nodal acceleration vector

$\{\dot{u}\} =$ nodal velocity vector

$\{u\} =$ nodal displacement vector

$\left\{F_{(t)}\right\} =$ load vector.

The ANSYS program uses the Newmark time integration method to solve these equations at discrete time-points.

As the effect of the damping forces, $[c]\{\dot{u}\}$, is usually insignificant, especially for the PMMA, and because we wanted to make the problem easier, the damping forces ware neglected.

Three methods are available to do a T.D.A.: full, reduced, and mode superposition. First we started with the reduced and mode superposition methods because these are faster. The nonlinearity that is allowed by both methods is the simple node-to-node contact (gap condition). This was considered more suitable for the better correspondence of the contact condition of the footing in our problem. Unfortunately these models failed to produce results so we were came to use the full method, which allows all types of nonlinearities.

Build the model

Four-nodal elements, plane 42, (42 means 4 nodes with 2 D.O.F. per node), ware used for the wide area of the “base”. This element has a good correspondence for angles between $45^{o} - 135^{o}$. So, some elements (with different angles) at the corner at the contact area ware substituted by rectangular and triangular elements. For better accuracy quadrangle eight-nodal elements, (plane 82), were used at the contact area of the "base" as well as at the footing, especially at the right side. For the rest of the footing, four-nodal elements (plane 42) were used. See Fig.(3,4). The thickness of all these elements was set at 0,3cm. Material properties was also defined as follows: The dynamic Young's modulus $E = 43 \cdot 10^9$ dyn/cm^2, the Poisson ratio $v=0,34$ and the PMMA density $d=1,1$ gr/cm^3.

For modeling of the contact condition the elements LINK 10, Compression-only, (spar with 1 D.O.F.) was used (See Fig. 4c). LINK 10-tension only was also used for the hanging up condition. In both cases the spar had a section of 0,1 m^2. All the LINK10-compression only-elements had to have the same length, so the coordinates of the corners were slightly modified. The distance between the elements LINK 10 was 0,5 cm and its section equal to $0,5 \cdot 0,3$ cm^2.

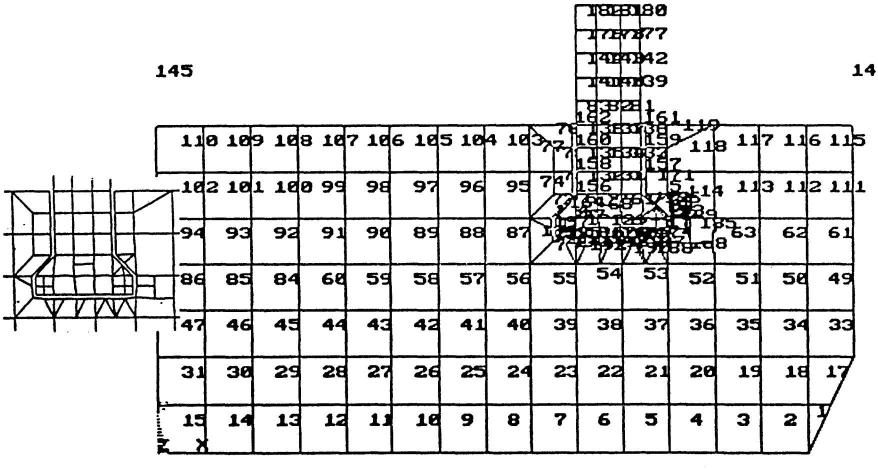


Figure 3 : The finite element model

A T.D.A., by definition, involves loads that are functions of time. To specify such load, we need to divide the load-versus-time curve into suitable load steps. Three load steps were specified. For each of them both load values and time values were specified. The structure was step-loaded (by constrained nodes) as follows: First step: Time 0-50 μsec. Forces Fx,Fy 0-50 Kp at 10 substeps, Second step : Time 50-100 μsec. Forces 50-0 Kp at 10 substeps,Third step : 0 load for 100-μsec. Forces 0Kp at 10 substeps.

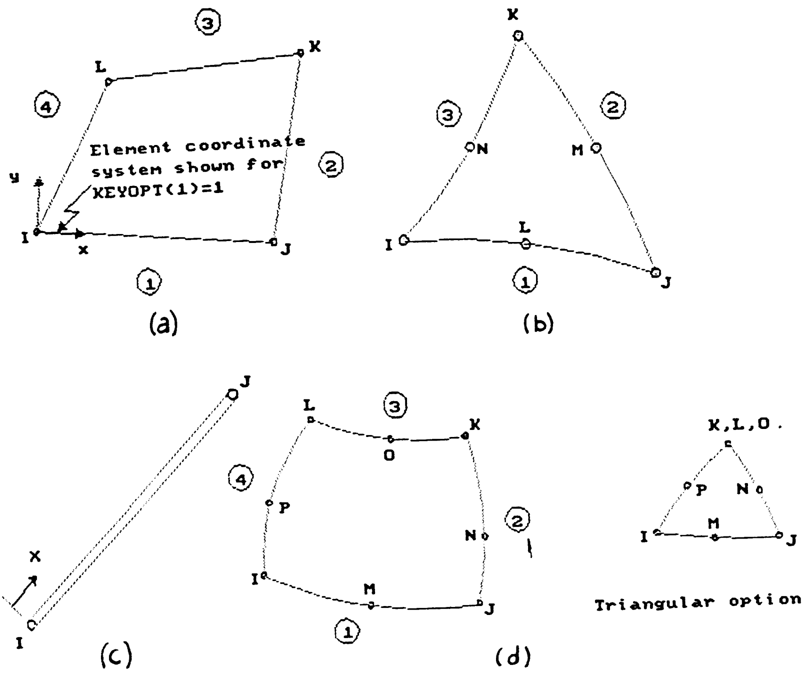


Figure 4 : The elements.

Results

In Fig.5(a), 6(a), 7(a) and 8(a) we show the principal stresses by T.D.A. In Fig 5(a) and 6(a) the footing is shown envarged. In Fig.5(b), 6(b),7(b) and 8(b) we show the principal stresses by the method of coustics corresponding to the same propagation time. As we can see, there is a very good agreement between the results of two methods both regarding the orientation of principal stresses as well the stress pulse front. This good agreement is also observed within the footing as regards the incoming direction of the principal stresses. In Fig. 9(a) and 9(c) we can see the regions of maximum stresses whitch are at right and left of the footing at different time respectively. In Fig.9(b) and 9(d) we can see the coresponding frames of caustics where the position of crack initiation and propagations is the same.

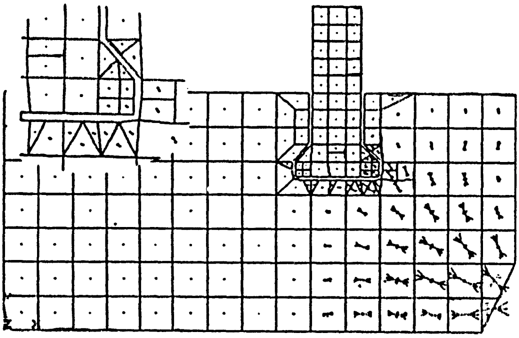


Figure 5 (a) : Principal stresses by D.T.A.

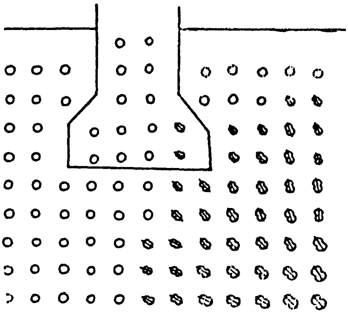


Figure 5 (b):by caustics

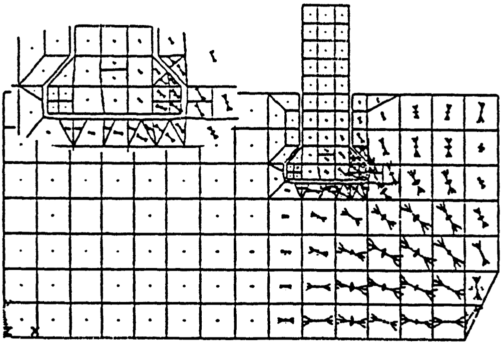


Figure 6 (a) : Principal stresses by D.T.A.,

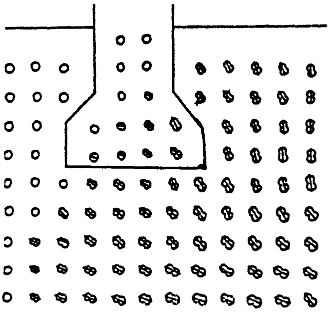


Figure 6 (b) by caustics

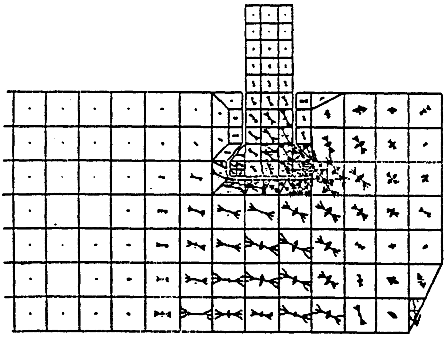


Figure 7 (a): Principal stresses by D.T.A.

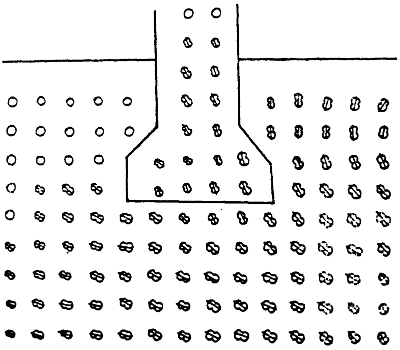


Figure 7 (b): Pr. str. by caustics

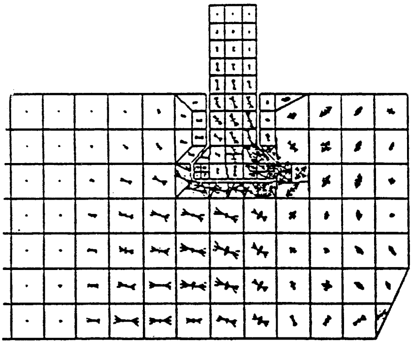


Figure 8 (a) : Principal stresses by D.T.A.,

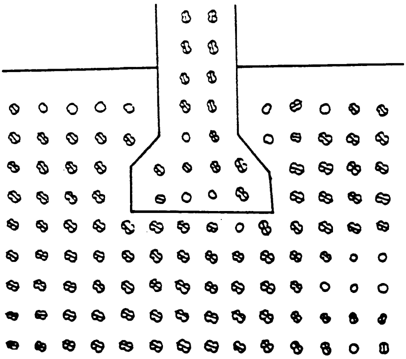
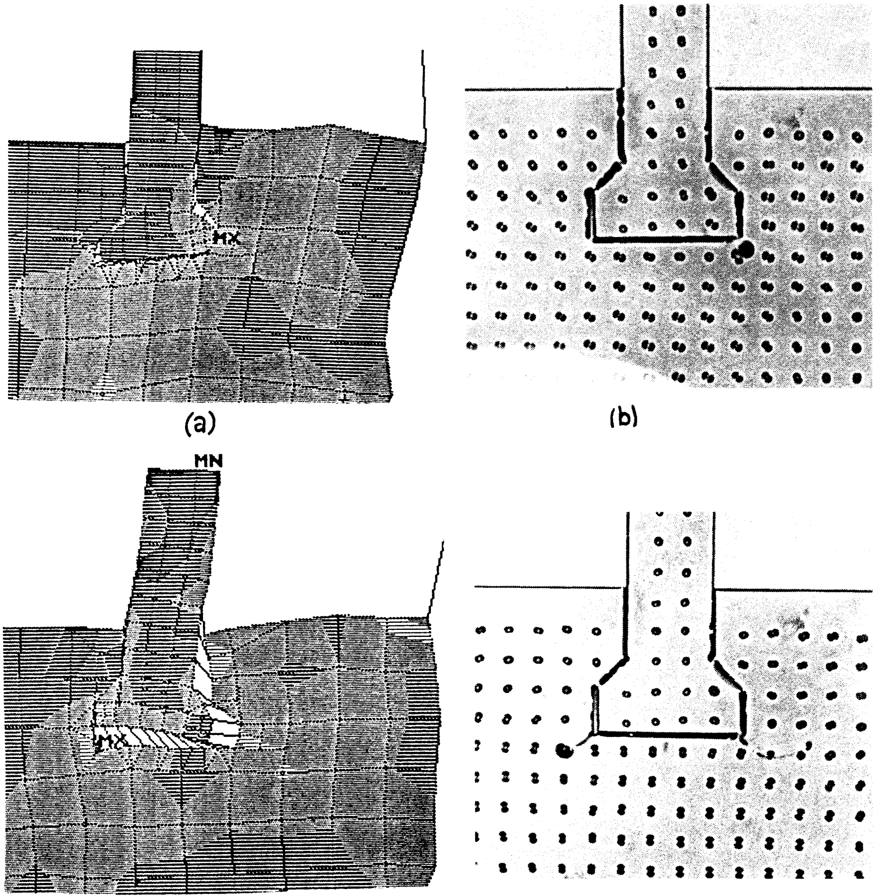


Figure 8 (b) by caustics



(a)

(b)

(c)

(d)

Figure 9 : The maximum stresses

Conclusions

From the comparison of the two methods shows that:

1. The finite element method can be used for the scattering problem of a wave propagated from the soil to the footing.
2. The elements LINK-10 (spar) compession only which are placed normally to the suface of the footing can represent the problem with high accuracy.
3. The experimental method of caustics gives good results regarding the orientation of principal stresses, the velocities and the wave front at the "base" as well within the footing.
4. In closing we can say that the experimental results of the caustic method can be used as quidance in building the finite element model which in turn will best dercribe the problem at hand.

Acknowledgement

The authors are indebted to Academicient Professor P.S. Theocaris, who set out the quidelines of the experimental aproach to the problem.

We are also thankful to G. Badaloukas for his help in using the ANSYS software.

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