PROBLEM OF THE BUILDING AND THE BASE INTERACTION UNDER SEISMIC LOADS

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SUMMARY

The dynamic intense state of the problem of interaction of a building, base and multilayer foundation is studied with the help of numerical modeling. To solve the formulated problem a set of programs in the Fortran-90 algorithmic language is written. The computing algorithm is realized with the help of a method of finite elements in displacements. The research of the convergence and stability of the applied explicit diagrams for the internal diagrams is carried out. The first order triangular and rectangular finite elements are used. The problem of the influence of the acceleration of the El-Center earthquake on the construction-foundation-base system (nine and ten-storey buildings in Uhlan-Ude. The initial conditions are assumed to be zero. On a certain section at a distance of 1.63H (H – the height of a building, H=31.5 m) for a nine-storey building and 1.5H (H=34.3 m) for a ten-storey building the velocity of displacements is attached. The waves reflected from the contour of the base do not reach the investigated points at large time intervals. The base of eight different materials is considered. On the borders of materials with different physical properties the continuity conditions of displacements are accepted. The investigated calculated area has 500 nodal points.

The circuit pressures in certain characteristic parts of a building are presented. Elastic circuit pressures on vertical opposite sides of the building are almost mirror reflection of one another, i.e. asymmetrical. The multiple superposition of direct, reflected and other elastic waves results in the concentration of stretching elastic circuit pressure in the neighborhood of angular points in the lower part of the building.

INTRODUCTION

The problem of the effect of a plane longitudinal elastic wave of the Centro earthquake acceleration type on the system building - foundation - base (nine- storied and 10- storied buildings in Uhlan-Ude) is considered. Calculations were conducted by the numerical modeling of equations in the elasticity theory. Results of numerical solution of some problem are presented.

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PROBLEM STATEMENT AND ALGORITHM REALIZATION

A body G that is exposed to some mechanical effect at the initial moment t = 0 is considered in the Descartes` rectangular coordinates XOY. The body G is supposed to consist of homogeneous isotropic material which meets the Gook`s law for small elastic deformations. The precise equations in two-dimensional (plane stressed state) dynamic theory of elasticity are:

$$\frac{\partial\sigma_x}{\partial x}+\frac{\partial\tau_{xy}}{\partial y}=\rho\frac{\partial^2 u}{\partial t^2}, \qquad \frac{\partial\tau_{yx}}{\partial x}+\frac{\partial\sigma_y}{\partial y}=\rho\frac{\partial^2 \upsilon}{\partial t^2},(x,y)\in G,$$

$$\sigma_x=\frac{E}{1-\nu^2}(\varepsilon_x+\nu\varepsilon_y), \quad \sigma_y=\frac{E}{1-\nu^2}(\varepsilon_y+\nu\varepsilon_x), \quad \tau_{xy}=\frac{E}{2(1+\nu)}\gamma_{xy},$$

$$\varepsilon_x=\frac{\partial u}{\partial x}, \qquad \varepsilon_y=\frac{\partial v}{\partial y}, \qquad \gamma_{xy}=\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x},(x,y)\in(G\cup S), \tag{1}$$

where

σ_x, σ_y and τ_{xy}- component of the elastic stressed tensor;

ε_x, ε_y and γ_{xy} - component of the elastic deformation tensor;

u and v - component of the elastic displacements vector along OX and OY axes respectively;

ν - Poisson coefficient;

E - elasticity module;

ρ - density of the material;

S (S_1 U S_2) - boundary contour of the body G.

The system of equations (1) in the domain occupied by the body G should be integrated with initial and boundary conditions. The initial conditions in the domain are the following:

$$u\,|_{t=0}=u_0, \qquad v\,|_{t=0}=v_0, \qquad \dot{u}\,|_{t=0}=\dot{u}_0 \qquad \dot{v}\,|_{t=0}=\dot{v}_0, \quad (x, y)\in G, \tag{2}$$

where u_0, v_0, $\dot{u}_0$ and $\dot{v}_0$ - the G functions given in the domain.

The boundary conditions are given in the form:

of components of the elastic stresses tensor of boundary S_1

$$\sigma_x l+\tau_{xy}m=A_x, \qquad \tau_{xy}l+\sigma_y m=A_y, \qquad (x, y)\in S_1; \tag{3}$$

of components of the elastic displacements vector at boundary S_2

$$u=B_x, \quad v=B_y, \quad (x, y)\in S_2, \tag{4}$$

where:

l and m - directing cosines;

A_x, A_y, B_x and B_y - function given for the S boundary.

To solve the two-dimensional (plane) dynamic problem in the elasticity theory with initial and boundary conditions [1 - 4] the finite element method is used [1-6]. The problem is solved by the method of heterogeneous algorithm. The main correlations of the finite element method are obtained by means of the possible displacements principle. Using finite element method we get an approximate value of the motion equation in the theory of elasticity

$$\overline{\mathrm{H}}\ddot{\vec{\Phi}} + \overline{\mathrm{K}}\vec{\Phi} = \vec{R},$$

$$\vec{\Phi}\,\big|_{t=0} = \vec{\Phi}_0, \qquad \dot{\vec{\Phi}}\,\big|_{t=0} = \dot{\vec{\Phi}}_0, \tag{5}$$

where:

$\overline{\mathrm{H}}$ - diagonal matrix of inertia;

$\overline{\mathrm{K}}$ - matrix of rigidity;

$\vec{\Phi}$ - vector of nodal elastic displacements;

$\dot{\vec{\Phi}}$ - vector of nodal elastic displacements speeds;

$\ddot{\vec{\Phi}}$ - vector nodal elastic accelerations;

$\vec{R}$ - vector of external nodal elastic forces.

Equation (1) is a system of linear ordinary differential equations of the second order in displacements with initial conditions. Thus using finite element method in displacements linear problem with initial and boundary conditions is reduced to linear Coshi problem (5). By integrating equation (5) using the Galerkin version of finite element method we obtain an explicit two-layer linear scheme in displacements for inner and boundary nodal points

$$\begin{aligned} \dot{\vec{\Phi}}_{i+1} &= \dot{\vec{\Phi}}_i + \Delta t \overline{\mathrm{H}}^{-1}(-\overline{\mathrm{K}}\vec{\Phi}_i + \vec{R}_i), \\ \vec{\Phi}_{i+1} &= \vec{\Phi}_i + \Delta t \dot{\vec{\Phi}}_{i+1}, \end{aligned} \tag{6}$$

where: Δt – step along the time coordinate.

System of equations (6) for inner and boundary nodal points obtained as a result of integrating the motion equation of the elasticity theory should provide a solution converging to the solution of the original system. The general theory of discrete equations of mathematical physics requires superposition for certain conditions on the step ratio along time coordinate and space coordinates, that is

$$\Delta t = (k \min \Delta l_i)/c_p \quad (i = 1, 2, \ldots, r), \tag{7}$$

where:

Δl – finite element side length;

C_p – speed of longitudinal wave propagation;

R - total number of finite elements in the domain.

The results of the numerical test have shown that at k = 0,5 stability of the explicit two-layer finite element linear scheme is ensured. For the domain considered consisting of materials with different physical properties a minimum step along the finite coordinate and a maximum speed of the longitudinal elastic wave are chosen (7).

On the basis of finite element method in displacements the algorithm and the set programs in FORTRAN-90 for IBM PC have been developed. A quasi-regular approach to solution of the system of linear ordinary differential equations of the second order in displacements with initial conditions and to approximation of the domain is purposed. The method is based on the schemes: a point, a line, a plane. The approach proposed allowing to reduce considerably the volume of input data and the time required for solving problem. For approximation along space coordinates the triangular finite element with three nodal points and linear approximation of elastic displacements and rectangular finite element with four nodal points and bilinear approximation of elastic displacements are used. The set of programs allows approximation of the domain considered along practically unlimited space coordinate that is much enough to get precise result.

SOLUTION OF SOME PROBLEMS

The results of studies for two problems are presented. The seismic effect is simulated in the form of the plane longitudinal elastic wave of El-Center acceleration type.

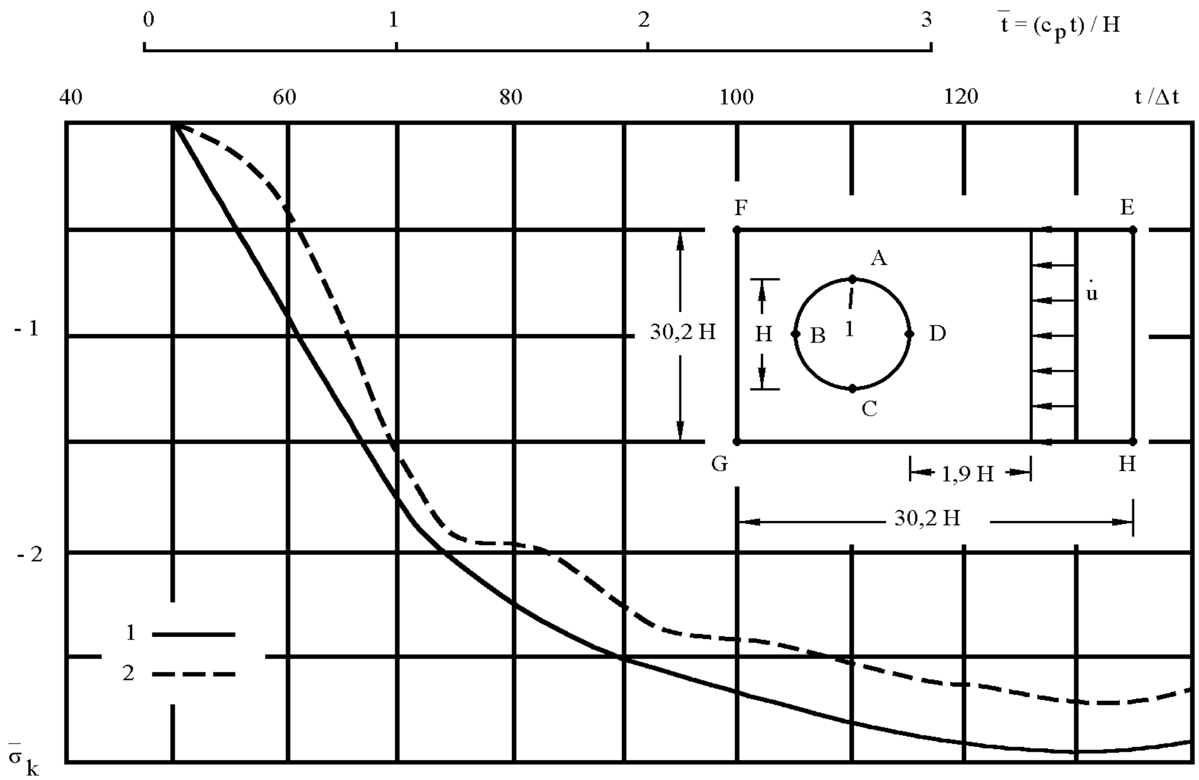

Fig. 1

Modification of elastic contour stress $\overline{\sigma}_k$ at point 1 in time $\bar{t}$
in a free round opening under effect
of the plane longitudinal elastic wave of the Heavyside function type

1. For verify the reliability of the method, the algorithm and the set programs the problem of the plane longitudinal elastic wave effect on a free round opening is considered. The initial conditions are assumed zero. In the section at distance 1,9H at $0 \le n \le 10$ ($n = t/\Delta t$) the elastic displacement speed $\dot{u}$ varies linearly from 0 to $P = \sigma_0 / (pc_p)$(σ_0 = -0,1 MPa (-1 kgf /cm^2)), while at n > 10 $\dot{u}$ = P. The round opening ABCD is supposed to bee free from loads at t > 0. The boundary conditions for contour EFGH at t > 0 are $u = v = \dot{u} = \dot{v} = 0$. The waves reflected from contour EFGH do not reach the points considered at $0 \le n \le 260$. The calculations were conducted with the following initial data:

H = 0,18 m; Δt = 0,407 · 10-5 s; E = 0,36 · 104 MPa (0,36 · 105 kgf/cm^2);
N = 0,36; R = 0,122 · 104 kgf/m^3 (0,122 · 10^{-5} kgf · s^2/cm^4); C_p = 1841 m/s.

The design domain has 1536 nodal points. The round opening contour is approximated by 28 nodal points.
Fig. 1 shown variation of elastic contour stress $\overline{\sigma}_k$ ($\overline{\sigma}_k = \sigma_k / |\sigma_0|$) at point 1 in time $\bar{t}$ ($\bar{t}$ = (c_pt) / H):

1 - results of the analytic solution [2];
2 - results of the numerical solution obtained by means of finite element method in displacements [2].
The divergence for maximum elastic contour stress is 6 %.

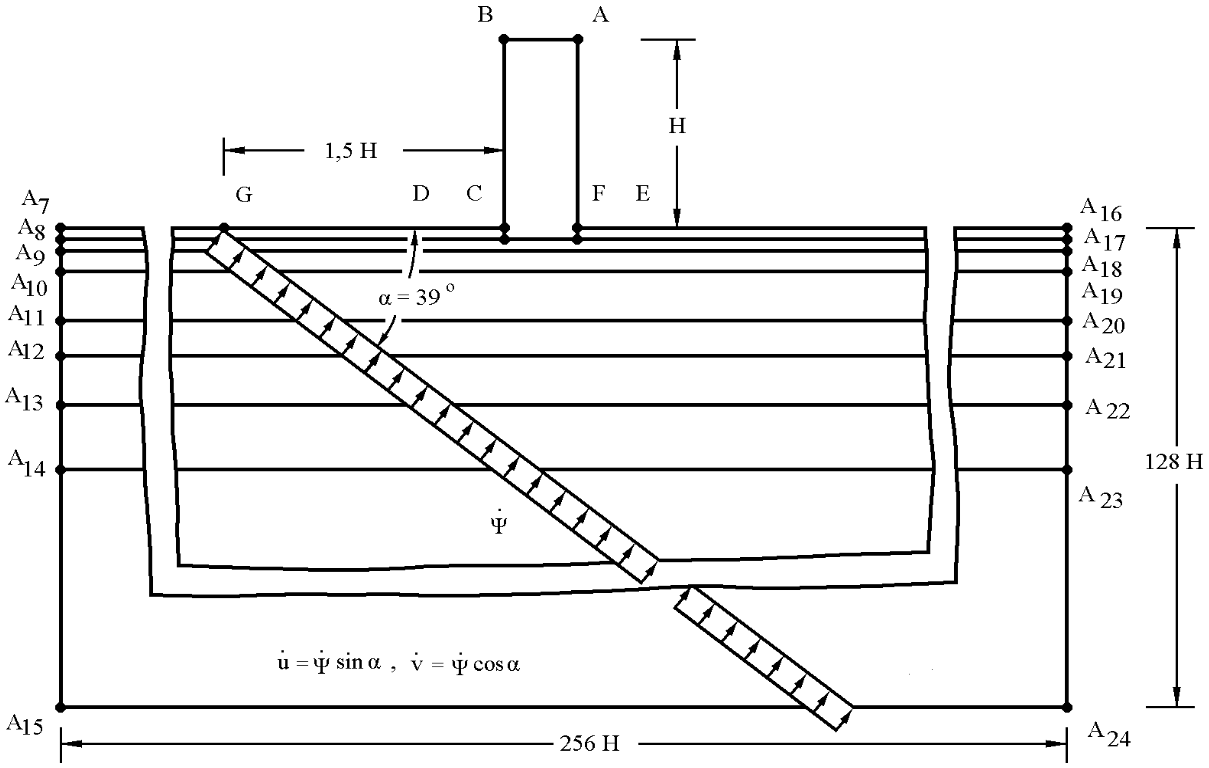

Fig. 2

STATEMENT OF A PROBLEM FOR 10-STORIED BUILDING IN UHLAN-UDE

2. The problem of the El-Center earthquake acceleration $\ddot{\psi}$ effect on the system "building - foundation – base" (9-storied and 10-storied buildings in Uhlan-Ude) at t = 0,98-2,98 s is considered. The initial conditions are assumed zero. To the section at distance 1,63H (H = 31,5 m) for 9-storied building and 1,5H (H = 34,3 m) for 10-storied building the speed of displacements $\dot{\psi}$ ($\dot{u}_i = \dot{\psi}\sin\alpha$; $\dot{v}_i = \dot{\psi}\cos\alpha$; i = 2, 3, …, 9) is applied. The boundary conditions for the contour $A_7 - A_{24}$ at t> 0 are $u_i = v_i = \dot{u}_i = \dot{v}_i = 0$. The waves reflected from the contour $A_7 - A_{24}$ do not reach the points studied at $0 \le n_1 \le 8000$ ($n_1 = t/\Delta t_1$). At the boundaries of materials with different physical properties conditions of the continuous displacements are assumed (1 – ABCDEF; 2 – $CA_7A_8DA_{16}FEA_{17}$; 3 – $A_{17}A_8A_9A_{18}$; 4 – $A_{18}A_9A_{10}A_{19}$; 5 – $A_{19}A_{10}A_{11}A_{20}$; 6 – $A_{20}A_{11}A_{12}A_{21}$; 7 – $A_{21}A_{12}A_{13}A_{22}$; 8 – $A_{22}A_{13}A_{14}A_{23}$; 9 – $A_{23}A_{14}A_{15}A_{24}$). The design domain has 500 nodal points. The calculation results have shown that maximum stresses are situated at the lower parts of buildings.

CONCLUSION

The analysis of numerical results shows that solution of the problem of the plane longitudinal elastic wave of the Heavyside function type effect on the free round opening and the El-Center earthquake acceleration effect are the system "building – foundation – multi-layer base" has given reliable results. Comparison with the results of the analytic method has shown their good matching which allows to infer that physical trustworthiness of the numerical results.

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