Application of the Finite Element Method to a microzonation study of the Salonica Region

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Summary. — The main object of the present paper is an attempt to present a model for the estimation of the ground movements during an earthquake, using the Finite Element Method. Some preliminary results for the subsoil of the Salonica region are subsequently calculated, using this model, according to the existing geological and seismological data of the region. Finally, some general conclusions are derived.

Riassunto. — Scopo principale di questo lavoro è un tentativo di presentare un modello per la valutazione dei movimenti del suolo durante un terremoto usufruendo del Metodo dell'Elemento Finito. Usando quest'ultimo ed in base ai dati geologici e sismici già esistenti, si sono prima calcolati alcuni risultati per il sottosuolo della regione di Salonicco traendone, infine, alcune conclusioni di carattere generale.

1. – INTRODUCTION

Among the various existing definitions, Microzoning can be defined as the study of small land areas under local geology conditions and earthquake characteristics, serving as a guide for safer land use and safer construction, according to the specified local differences in earthquake attack on structures.

In November 1971 during the first meeting of the working group on Microzoning in Belgrade, Salonica was chosen as a site for the Pilot Microzoning study according to the plan of operation of the UNDP-UNESCO Project for the seismicity of the Balkan Region.

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The purpose of the present paper on Microzonation is an attempt by the authors to present a model for the estimation of the ground movements during an earthquake, using the Finite Element Method. Using this model, some earthquake characteristics of the subsoil of Salonica are subsequently calculated according to the existing geological and seismological data for the region and some general conclusions are derived, as a contribution to the UNDP-UNESCO Programme.

The main idea of the model proposed in this paper was discussed during the "Seminar on Microzonation" held by UNESCO in Thessaloniki, on April 9-13, 1973.

2. – Model characteristics

For the development of the model, an elastic layer of uniform thickness H and width equal to unity is considered, based on the bedrock (sublayer) which is assumed to be plane (Fig. 1).

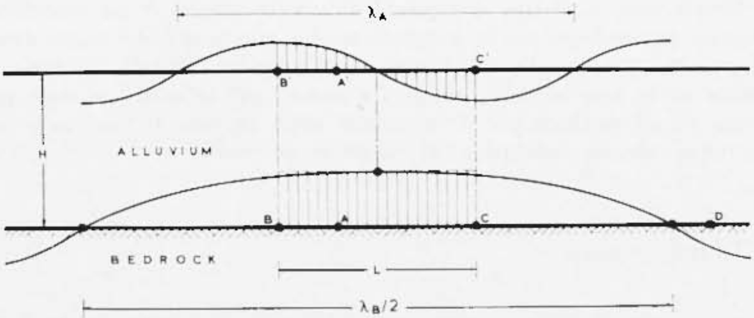

Fig. 1

The present study is concentrated on the effects due to shear waves which are of primary importance in the microzoning problem. Moreover it is assumed that the direction of wave propagation in the rock is irrelevant and so the bedrock is translated bodily. Though, the motion of the bedrock surface between points B and C is assumed as a rigid body motion and the acceleration is taken constant along the surface BC of the bedrock. This is possible as the wave length λ_B in the bedrock is expected to be much greater than the wave length λ_A in alluvium (Fig. 1).

It is also assumed that the main contribution for the excitation of soil at a point A' (Fig. 1) of the surface is from the region B-C of length L. Points out of the region B-C, such as point D, have not significant effect on point A' since the energy at D will be refracted at the rock-soil interface and propagated vertically. For the purpose of determining the displacements of the ground surface during the earthquake the lenght L is taken as a varying parameter.

During the present study the distribution of acceleration along the height of the alluvium for the region B-C considered is assumed parabolic with a law of distribution:

$$\varepsilon(x, y) = \varepsilon_o + c(x) \cdot y^2 = \varepsilon_o + \varepsilon_A$$

where $c(x)$ is a function of x.

In the above expression the first term ε_o is the constant acceleration of the alluvium layer due to the bedrock movement. The second term $\varepsilon_A = c(x)y^2$ describes the acceleration at each point of the alluvium layer, due to relative movement of the layer to the bedrock.

A cosinusoidal distribution of accelerations along the length of the layer:

$$\varepsilon_A = K(y) \cos \frac{2\pi}{\lambda_A} x$$

is assumed with $K(y)$ varying from zero at the bedrock surface to its maximum value at the ground surface. This maximum value is the difference between the maximum accelerations at the ground surface and the bedrock surface. On fig. 2 this cosinusoidal distribution of

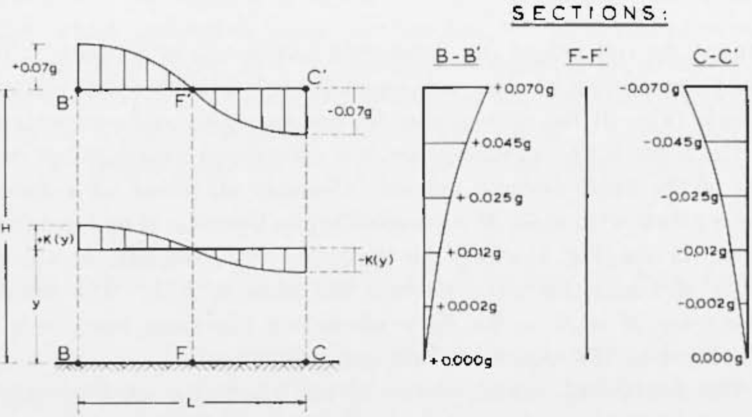

Fig. 2

accelerations is shown for the subsoil of Salonica considered in the present paper, for which the ground surface acceleration and the bed-rock surface acceleration are found equal to 0.17g and 0.10g respectively, as shown in the next paragraphs.

During the present study a section $BCC'B'$ of the layer is considered at a moment where the cosinusoidal acceleration wave has the shape of fig. 2. The separation of this section is permitted because the axes CC', BB' are axes of antimetry of loading and so no horizontal forces act along them after separation.

For the determination of the characteristics of the ground movements, the Finite Element Method is applied (¹²). A suitable computer programme was used for the case considered.

The surface of the layer examined of length L and height H is divided by horizontal and vertical lines into equal rectangular elements of lenght Δx and height Δy, ordered in l lines and m columns. These rectangular elements are subsequently subdivided into triangular elements (Fig. 3) for convenience of programming and computing.

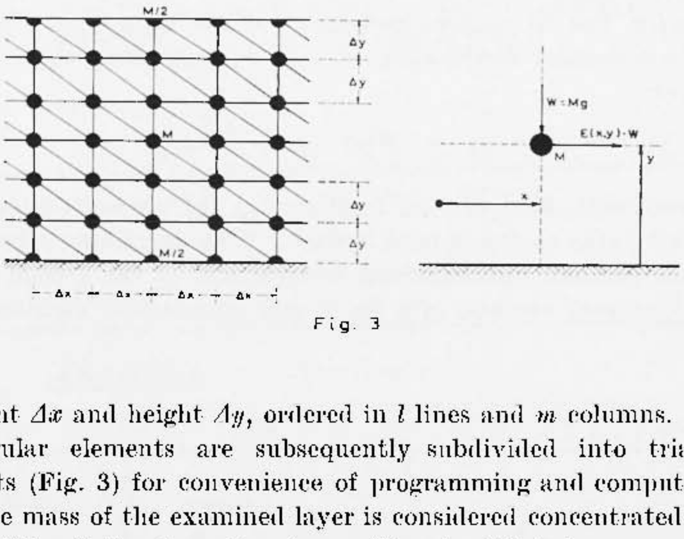

Fig. 3

The mass of the examined layer is considered concentrated on the joints of the finite element system. Namely all joints are considered as mass points with mass M corresponding to the mass of one rectangular element $\Delta x \cdot \Delta y$ (Fig. 3) except for the joints of the boundaries where the mass is $M/2$ and the corners where the mass is $M/4$. The weight B of the mass M is $B = \Delta x \cdot \Delta y \cdot \gamma$ where γ is the mean specific weight of the layer at the region of the joint considered.

The horizontal seismic force acting statically on each joint is $W = \varepsilon(x, y)B$ where $\varepsilon(x, y)$ is the function describing the distribution of the seismic acceleration over the surface of the layer.

3. – SEISMICITY OF THE REGION

The urban area of Salonica is not aseismic. Many strong earthquakes have shaken the region with destructive results in the past. The most destructive earthquake for the city of Salonica seems to have been the shock of July 5, 1902 with maximum intensity VIII-IX of the Mercalli-Sieberg scale.

The maximum intensity observed in the area of Salonica over the period 1800-1972 is, according to the existing map of isolines of maximum intensities of the region, IX degrees of the Mercalli scale.

According to the empirical formula for the ground seismic acceleration a_g for the region of Greece:

$$a_g = 0.26 — 0.1 \cdot I + 0.01 \cdot I^2$$

where I is the Maximum expected intensity of the Mercalli scale, the maximum acceleration expected at the ground surface for the region of Salonica is $0.17g$.

The predominant period T of an expected earthquake is given by the formula:

$$\log T = 0.26M - 1.32$$

given by muramutsu (1966) and found equal approximately to 0.40 sec, for a magnitude $M = 6.5$.

Salonica is near in the center of the area bounded by the parallels 40°N-41°N and the meridians 22.5°E-23.5°E. The nearest foci around Salonica which generated large earthquakes are at distances 15km-30km, but the stronger near destructive earthquakes are from 60 km epicentral distances. The return periods for shallow shocks which occured in the region of Salonica are 18-23 years for $M = 5.5$, 45-55 years for $M = 6$, 110-135 years for $M = 6.5$, and 275-335 years for $M = 7$ (³).

4. – GEOLOGICAL AND TECTONIC CHARACTERISTICS OF THE REGION

The subsoil of the region of Salonica is not homogeneous and varies from place to place. Alluvium consolidated sand dunes, granitic metamorphics etc, are the usual types of soil which compose the subsoil of the region.

The surface layer may be assumed to have a mean thickness of 20m above the bedrock. In Fig. 4 are shown some typical boreholes of the region of Salonica. From these characteristic boreholes and others existing we can also accept an average water level at a depth of 8m.

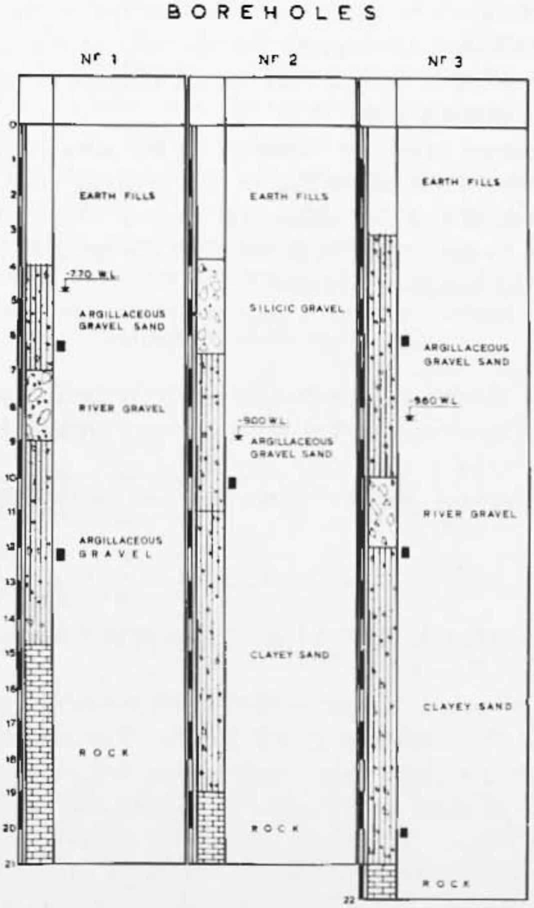

Fig. 4

Although the mechanical characteristics of the surface layer may vary from place to place, the small quantities of the existing sand, permit us to consider the layer during the present preliminary study as alluvium.

The characteristics of this alluvium are estimated as following:

Below the water level the alluvium is completely saturated and the specific weight is given by the formula: $\gamma = \gamma_s - n(\gamma_s - \gamma_w)$ where n is the porosity, γ_s is the specific weight of the solid particles, and γ_w is the specific weight of the water. For the values of $\gamma_s = 2.75$, $n = 0.40$ and $\gamma_w = 1$, the value of the saturated specific weight of the layer is found $\gamma = 2.05$ t/m³. Above the water level the alluvium is partly saturated and the existing measurements show a mean value of $\gamma = 1.80$t/m³.

The laboratory tests from examined specimens showed a quite satisfactory strength permitting us to accept a modulus of elasticity $E = 300$kg/cm². The Poisson's ratio is taken equal to the value $\nu = 0.45$.

Finally, the velocity of S-waves in the alluvium is assumed equal to $v_s = 0.25$ km/sec.

The aforementioned alluvium deposit is considered to be strong enough enabling the application of the elastic theory and microtremor techniques.

According to the existing geological data, the bedrock of the region of Salonica consists mainly of limestones and marbles. The mechanical characteristics of limestone are density $\varrho = 2.30$, modulus of elasticity $E = 83.4 \times 10^{10}$ kg/cm² and of marble $\varrho = 2.30$, $E = 37.5 \times 10^{10}$ kg/cm². The high values of the modulus of elasticity are due to the small deformability of the rock.

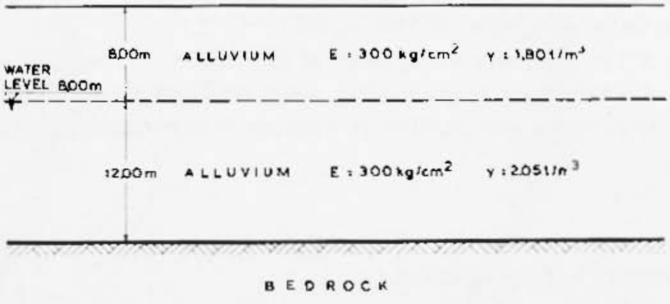

Fig. 5

The velocities v_p of the dilatational P–waves and v_s of the distortional S–waves are estimated for the bedrock of the region of Salonica equal to $v_p = 2.5$ km/sec, $v_s = 1.0$ km/sec. These values are approximate estimations, since there are no yet accurate measurements of the wave velocities of the region.

As mentioned before the maximum acceleration on the ground surface is calculated according to the existing data, for an intensity $I = \text{IX}$ and found equal to $0.17\ g$.

The corresponding intensity I_o at the surface of the bedrock is calculated from the Medvedev formula (9):

$$I_o = I - \Delta I$$

where I is the surface intensity and ΔI is given by the expression:

$$\Delta I = \Delta I_g + \Delta I_w = 1.67 \log \left(\frac{\gamma_o v_o}{\gamma_1 v_1} \right) + \nu \cdot e^{-0.04h^2}$$

where $\gamma_o v_o$ and $\gamma_1 v_1$ are the values of seismic impedance or rigidity for the bedrock and the alluvium respectively, h is the depth of the water level in meters and ν is a constant coefficient taken equal to 0.8 for the region considered. For the values $\gamma_1 = 2.0$ t/m³ $v_1 = 0.25$ km/sec $\gamma_o = 2.30$ t/m³, $v_o = 1.0$ km/sec and $h = 8.0$ m, we have that $\Delta I = I$ and hence $I_o = \text{VIII}$, corresponding to a bedrock surface acceleration equal to $\varepsilon_o = 0.10g$. This approximate value for the bedrock acceleration is used in the present paper because, there are no other, more accurate data, available for the region.

From the seismotectonic map of the region of Salonica we can observe the following zones having common borders: *a*) post-tectonic deposit; *b*) complex geosyncline of Vardar; *c*) Serbomacedonian massif (Ridge).

5. – RESULTS – CONCLUSIONS

Four cases of free zones of a depth 20m are considered with values of the parameter L equal to 25m, 50m, 75m, 100m, respectively.

The steps Δx, Δy along the axes ox, oy are taken equal to 5m and 4m respectively for all cases.

In Figs. 6*a*, 6*b*, 6*c*, 6*d* the horizontal relative to the bedrock displacements δ_x along the depth d of the alluvium layer considered are shown. Namely, for each case of length L, the horizontal displacements along vertical sections of the alluvium layer, taken every 5m, are presented. The ordinates x of each section are written on the corresponding curve.

L = 25 m

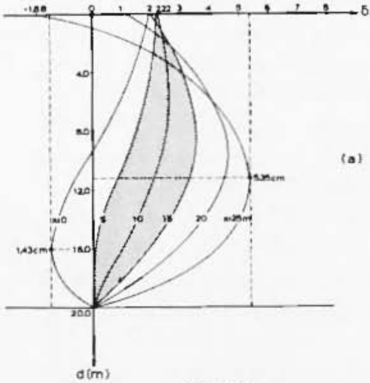

Fig. 6a

L = 50 m

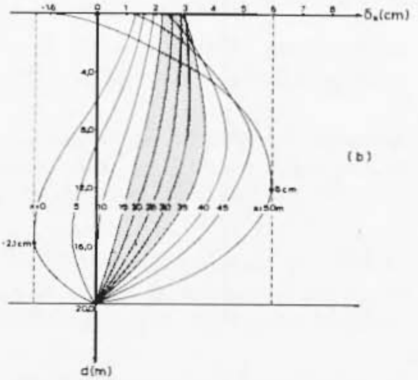

Fig. 6b

L = 75 m

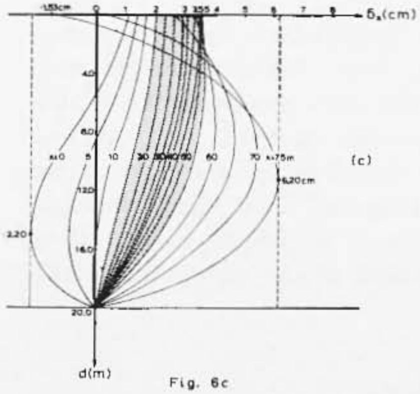

Fig. 6c

L = 100 m

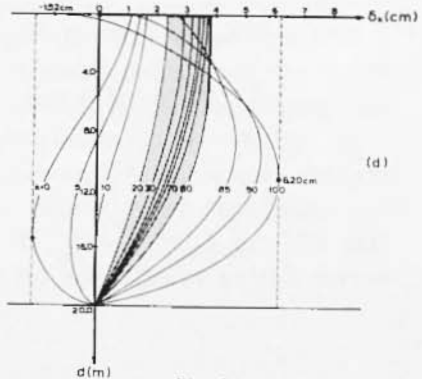

Fig. 6d

In Fig. 7 the variation of the horizontal displacements δ_x with the length L is shown for the ground surface. As seen from the figure 7 the maximum displacements do not vary significantly for relatively high values of the length L.

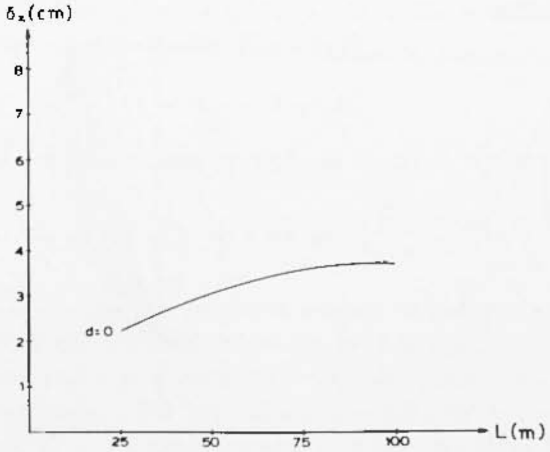

Fig. 7

It is to be noted finally that the calculation of the displacements of the alluvium layer according to the Finite Element Method must take into consideration the elastic or anelastic properties of the alluvium considered and mainly its anisotropic strenght, with the best possible accuracy. On figures 6, in the shaded regions the curves which are not influenced significantly by the boundary conditions of the edges BB', CC' (fig. 2) are shown. It is suggested to take into account these curves during calculations for the subsoil of the region considered.

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