Microzonation in the seismic area of Corinth-Loutraki

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ABSTRACT

The spotty distribution of intense damage during the 1928 earthquake, in structures of the same type strongly indicates that local subsoil conditions in the area were one of the governing factors in the assesment of damage to structures. The microzoning map of Corinth and Loutraki has been compiled using the microtremor method and it is in a rather good agreement with detailed information of damaged buildings during 1928 earthquake. The water table is within 10 meters of the surface in those areas of Corinth and Loutraki suffering the largest damages during 1928 earthquake and this confirms the influence of the water table elevation to the macroseismic field.

RIASSUNTO.

La distribuzione irregolare dei gravi danni durante il terremoto del 1928, sulle strutture dello stesso tipo, indica molto chiaramente che le condizioni locali del sottosuolo nella zona hanno avuto un peso fondamentale nella valutazione dei danni alle strutture stesse.

La mappa della microzonizzazione di Corinto e Loutraki è stata costruita usando il metodo di microtremori, il quale è risultato in buon accordo con le informazioni dettagliate sugli edifici danneggiati durante il terremoto del 1928. L'acqua minerale si trova entro 10 metri dalla superficie in cui le zone di Corinto e Loutraki hanno subìto i danni più gravi durante il terremoto del 1928, e ciò conferma l'influenza dell'aumento di livello dell'acqua minerale nel sottosuolo, sul campo macrosismico.

1. Purpose of the Present Investigation.

The purpose of the present investigation is directed on the possibility to identify the subregions in Corinth-Loutraki with dangerous soil conditions. This is of great importance in such an active area which two times has suffered from earthquakes during the last 130 years.

The towns of Corinth and Loutraki as well as the village of Perachora are indicated in the map (fig. 13). The population of Corinth is 25,000 while the population of Loutraki, where large hotels exist, is only 9,000 but it must be mentioned that during summer season the population of Loutraki increases and reaches 15,000 - 20,000. The village of Perachora which is in an average elevation of 300 m has a population of 2,000.

The geological and the seismotectonic conditions in and around Corinth area, its local seismic activity and its situation in respect to the adjacent seismic regions, and particularly the distribution of very peculiar soil conditions from very soft to very hard soil, represent a good area for the application of various current seismic microzoning methodologies.

It is also useful to be mentioned that the existing information of the Corinth earthquake during 1928 on some structure in different parts of the towns provide a rather tentative but good control of the microzoning investigation in Corinth and Loutraki. So we have to carry out a rough comparison of the results of the present study with the actual data on the influence of the 1928 shock on different parts in special structures.

The existing structures in Corinth and Loutraki are characterized by different structural material such as brick, stone and timber and reinforced concrete. Also the height of the structures today varies from 1 to 7 stories with different structural systems of rigid and flexible character.

The seismic area of Corinth - Loutraki is very active as a whole and the microzonation is an attempt for more detailed distribution of earthquake hazard within the towns since it is known that earthquake damage may change abruptly over short distances i.e. 0.5 to 1 km. It has been recognized by many authors that soil conditions are responsible for these highly localized damages. A detailed discussion for the reliability of the existing microzonation methods with emphasis in the microtremors method has been made (Drakopoulos, 1978), so in the present study we will not reconsider such problems.

We only have to underline that although the reliability of microtremors method is open to some criticism due to the nonlinear stress — strain characteristics of soils during strong earthquake shaking — we believe that the application of microtremors technique is an important contributing agent at least in the soil classification and not in the prediction of the strong motion response characteristics of a site. As it will be obvious, the results of the present study — especially the similarities of our results with actual damage due to the 1928 earthquake — confirm at least in some degree our thought.

2. Instruments Used for Microtremor Measurements.

Two types of instruments have been used for carrying out the measurements of microtremors in the ares of Corinth and Loutraki.

The first system consists of:

a) 3 velocity type seismometers with natural period of 1 sec, sensitivity $3V_{p\text{-}p}$ cm/sec and damping factor approximately 0.7. One seismometer is used for vertical and two for orizontal motions.

b) A three channel IC's solid state amplifier which offers four measuring modes by the built in differentiator, the direct amplifier, the integrator and the double integrator. and the double integrator. By this amplifier and the above mentioned seismometers the measurement of acceleration, velocity or displacement of the ground motion is possible. The frequency range covers from 0.5 to 30 Hz with frequency range covers from 0.5 to 30 Hz with frequency response within 0.5 db. Its gain is approximately 70 db and has a 7 ranges attenuator.

c) A six channels electromagnetic oscillograph using tungsten light as light source and record records on photosensitive paper with speeds of 1, 5, 10 and 50 cm/sec.

d) A portable magnetic tape recorder with three channels for the registration of signals and a fourth one for recording information and remarks from microphone. The block diagram of the above mentioned instruments is shown in fig. 1.

The second system consists of 3 ranger seismometers, a signal conditioner — with amplifier and filters — and a magnetic tape recorder. The system characteristics are almost the same with those of the first system.

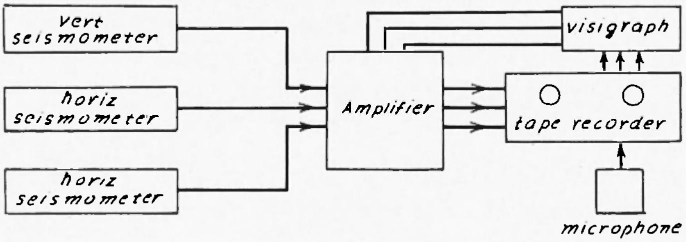

FIG. 1 - Block diagram of the instruments used.

3. Geological Tectonic and Neotectonic * Consideration of the Region.

In northern part of Peloponnesus where Corinth belongs, many faults originated or were reactivated during Quaternary and this area can be considered as a very dangerous one from geological point of view. The gulf of Corinth is a zone between regions of contrasting vertical movements of a great amplitude and therefore this indicates a rather recent tectonism.

According to geologists the Gulf of Corinth originated by trench sinking in period between Miocene and Pliocene and is the main character of the tectonic evolution of the area. The final formation of the Corinthian Gulf is due to the continuation of the tectonic stage of ruptures even during Quaternary.

From geological studies it is concluded that the tectonic movements results into intensive lifting of the surrounding mountain and high terrains, the displacement of which during the last years are estimated to 3 - 5 mm per year and that the formations into the valley are sinking, particularly in the recent time. The region belongs to tilting areas.

The channel of Corinth is schematically the junction of two upward - downward movements of opposite direction.

The high activity of the tectonic movements in the region of Corinth is conditioned by the local seismic activity which is manifested by earthquakes of different intensity which occur periodically in the region.

The recent and actual manifestations of the tectonic movements of Corinth region are as follows:

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* Dr. M. Sérbier visited the area and supply us with valuable Neotectonic information some of which are included in this chapter.

RECENT FAULTS.

I) *Great faults*

a) Fault of Loutraki to the North of the city (fig. 2). The big fault to the North of Loutraki represents one of the largest of the Gulf of Corinth and its activity is indubitable during Quaternary. The springs of Loutraki are on its contact. To the NE of the town, near the cemetery, the lower Quaternary formations are faulted. Other faults, not discernible certainly exist near this place.

b) A Fault North of Onia Mountains (fig. 2).

II) *Channel faults*

The majority of the faults of the channel are very recent. Unfortunately it is generally impossible to follow them out of the channel.

Actually the tectonic disturbances on the eastern extremity of the faulted zone in the northern part of the channel of Corinth caused probably the earthquakes of 1928 (Tanakadate, 1928). Such disturbances are subterranean and only a small trace of fissure along the ancient fault line, found by the channel, scarcely suggest the tectonic movements in the depth.

The periodical movements of such a step fault zone seems to have been the heredity in this region, from geological time and each movement causes the destructive earthquakes in the vicinity. The earthquake -heredity of this district will probably continue in the future.

III) *Other faults*

Faults of Kyra Vryse, Faults of Aghios Dimitrios, Faults between Examillia and Corinth, Faults to the North of Isthmia - Kalamaki (fig. 2).

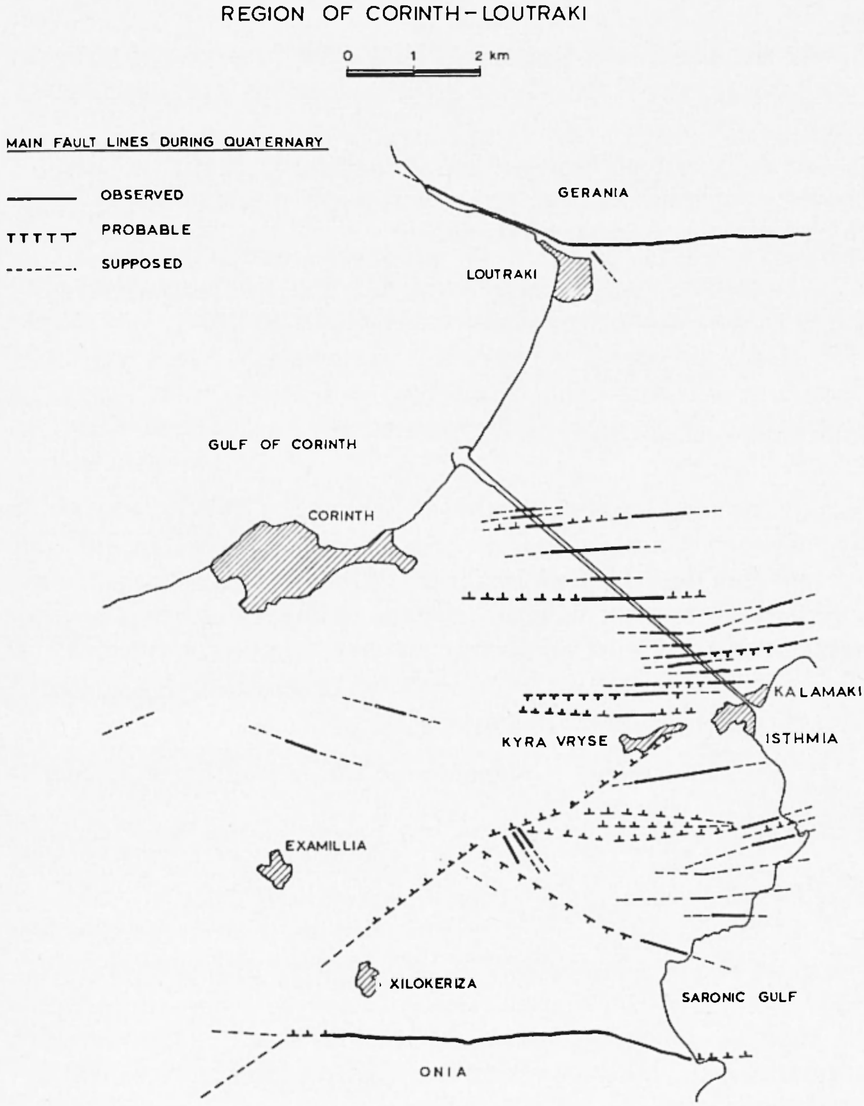


FIG. 2 - Neotectonic Map of the area (Sébrier, 1976).

IV) *Existing formations*

If we except the limestones and ophiolites of the substratum, the Neogene and Quartenary formations are represented by:

A thick *plio-pleistocene series* essentially marly, which becomes conglomeratic on the borders of the paleorelief. Its thickness may exceed 1000 meters.

Quaternary marine terraces, sands and conglomerates, generally not so thick, they form a system of terraces.

Continental Quaternary deposits.

Recent and actual alluvium, forming the valleys and Delta formations.

In the region of Corinth the Post - Pliocene terrains are represented by the marine terraces. The existence of three successive phases of deformation has been suggested as a result of a neotectonic study (Dufaure et al, 1975).

a) An intra Pliocene period of extension.

b) Compressive movements at the beginning of Quaternary and

c) A Quaternary period of extension which is still continuing.

All the qualitative and quantitative data given by the manifestation of the last period of extension are therefore essential for seismic studies.

In the following, some more details are given for the formations (and lithology) on which each of the cities of Corinth and Loutraki are situated.

3.1. Site of Corinth.

Formations on which the city of Corinth is constructed are:

Plio - Pleistocene series: Represented by the marls of Corinth, which form the substratum of the recent formations; their thickness is at least of some hundreds of meters. These white marls are very fractured.

Marine Terraces: They are of a quite various lithology. However sands and conglomerates predominate. In the limits of the city it was not possible to discover faults younger than these terraces. The average thickness is 2 meters. These terraces are often covereb by continental deposits, the thickness of which does not exceed some meters. (Serbier 1976, personal communication).

The Delta of Solomos river: It represents almost completely the substratum of the city. It is essentially formed by sands and river gravels with a thickness which is difficult to be estimated but not higher than 20 or 30 meters.

The Neogene sediments in Corinth are divided into several lithological types such as marlstone, marl, clay, sandstone, sand and other deposits. The major portion of Neogene sediments must be considered as rather compactible (not compressible).

The Quaternary sediments are divided into more complexes, the most important of which are the alluvial which are characterized by sands, sandstones, gravel, dunes, clays and marls. The thickness of the Quaternary deposits is generally very small (some decades of meters).

The geological background in the area of Corinth (under Quaternary and Neogene deposits) consists of limestones of Mesozoic age. The Akrocorinthos is based on these hard limestones while the foundation is tertiary in the village of Ancient Corinth.

From the two geological cross - sections AA' and BB' (fig. 3) it can be concluded that almost everywhere in Corinth we have Quaternary deposits on Neogene sediments. In the cross - sec-

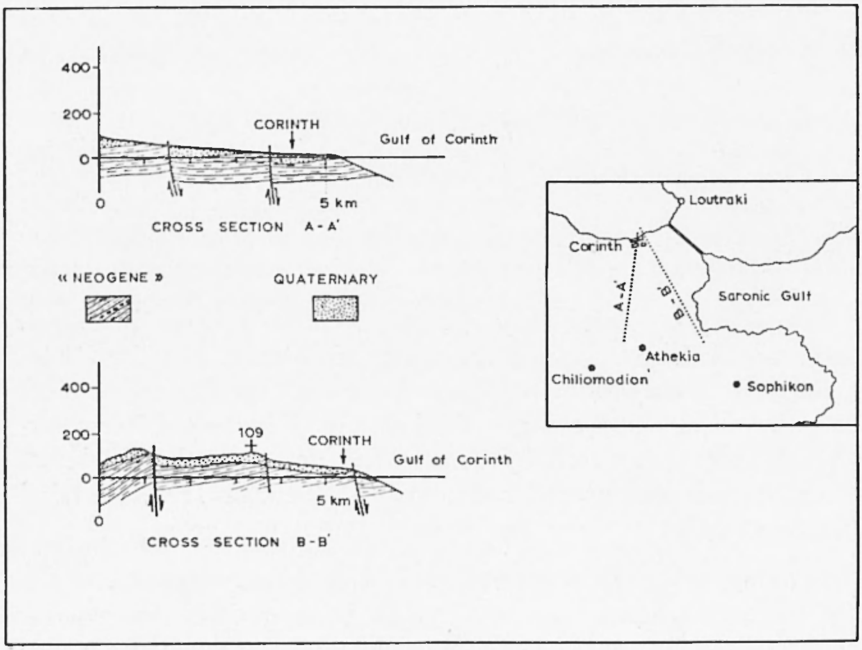


FIG. 3 - Geological cross Sections along two directions.

tion AA' in Corinth the depth of Quaternary deposits varies from few meters near to the coast and increases to the central and southern part of the town where abrubptly we observe Neogene on surface. In the cross - section BB' we have an almost constant depth of Quaternary of some meters.

3.2. SITE OF LOUTRAKI.

Formations on which the city is constructed are:

Limestones and Ophiolithes of the ex-subpelagonian zone: These rocks don't appear in the city, but just to the North of it.

Plio - Pleistocene series represented by an alternation of conglomerates and marly sands; They are visible to the NE of the city.

Quaternary Cones: They are breccias more or less compact of different ages (Early to Late Quaternary) which mark the escarpment of the Loutraki fault. The thickness is quite variable but not exceeding 10 meters.

Delta - Cone of Loutraki: Essentially formed by fragments of greenrocks (ophiolithes) which are situated to the ENE of the city at a distance of some kilometers.

The Gerania mountain consist of the hard limestones rock. So the uptown small part of Loutraki and mainly the village Perachora have generally such a hard subsoil. The limestones of Gerania mountain are presented in some cases up to the Gulf of Corinth with large slopes. In the major part of the town the limestones are covered from coastal deposits and these formations exist up to the channel of Corinth. The coastal zone of Loutraki in the surface consists of these recent deposits of sand, gravel, clay and loams.

The general picture of few characteristic drillings in Loutraki reveals that up to a depth of 20 m there are sands, gravels and clays. In the larger depths the percentage of clays decrease. This kind of soil is soft and compressible. We didn't find drillings in depths larger than 20 m because these tests were carried out only up to that depth by companies for building construction purposes.

In the evaluation of microtremor measurements, the sites of the previously mentioned drillings estimated to belong to kind of soil III or II - III. This was expected from the composition of the soil.

The high temperature of existing hot springs in Loutraki suggests that water follows a deep path and the existence of such hot springs is strongly related to the volcanism of the area (Sousaki volcano).

4. Hydrogeological Data.

The water tables which exist in the hydrogeological basin of Corinth are very shallow and this is very important since the results of a shock are strongly depended on that, as it is known from the Medvedev method.

According to Medvedev (1962), the increase of seismic intensity of a given region is related to water table elevation in the following way

$$\Delta j = e^{-0.04h^2}$$

where Δj = increase in seismic intensity
e = base of natural logarithm
h = depth (in meters) to water table below the ground surface.

The base of the water table in Corinth generally consists of water-tight Neogene marls. In the map of fig. 4 the depth of water level in the area of Corinth is indicated (data after Monopolis and Skayas, 1970). The hydrostatic level in the urban area of Corinth is very small and the smaller depth is observed generally in the more dangerous microzones near the seaside. As it is obvious from fig. 4 in the central and western part of the town the water table is within 10 meters of ground level while to the southern part we observe larger values. The data indicated in fig. 4 related to the water level of Corinth were chequed during summer season and so for winter periods the water level must be smaller by about 0.20 - 0.40 m. It seems interest to be mentioned that in the village Ancient Corinth which two times destroyed by shocks the water table generally is in large depths.

It was possible to concentrate few data for hydrostatic level at Loutraki. Estimates from hydrogeologists and ground water contacts in construction excavation shows that the water table in Loutraki is between 1 - 15 m and this must influence the macroseismic field after a strong earthquake.

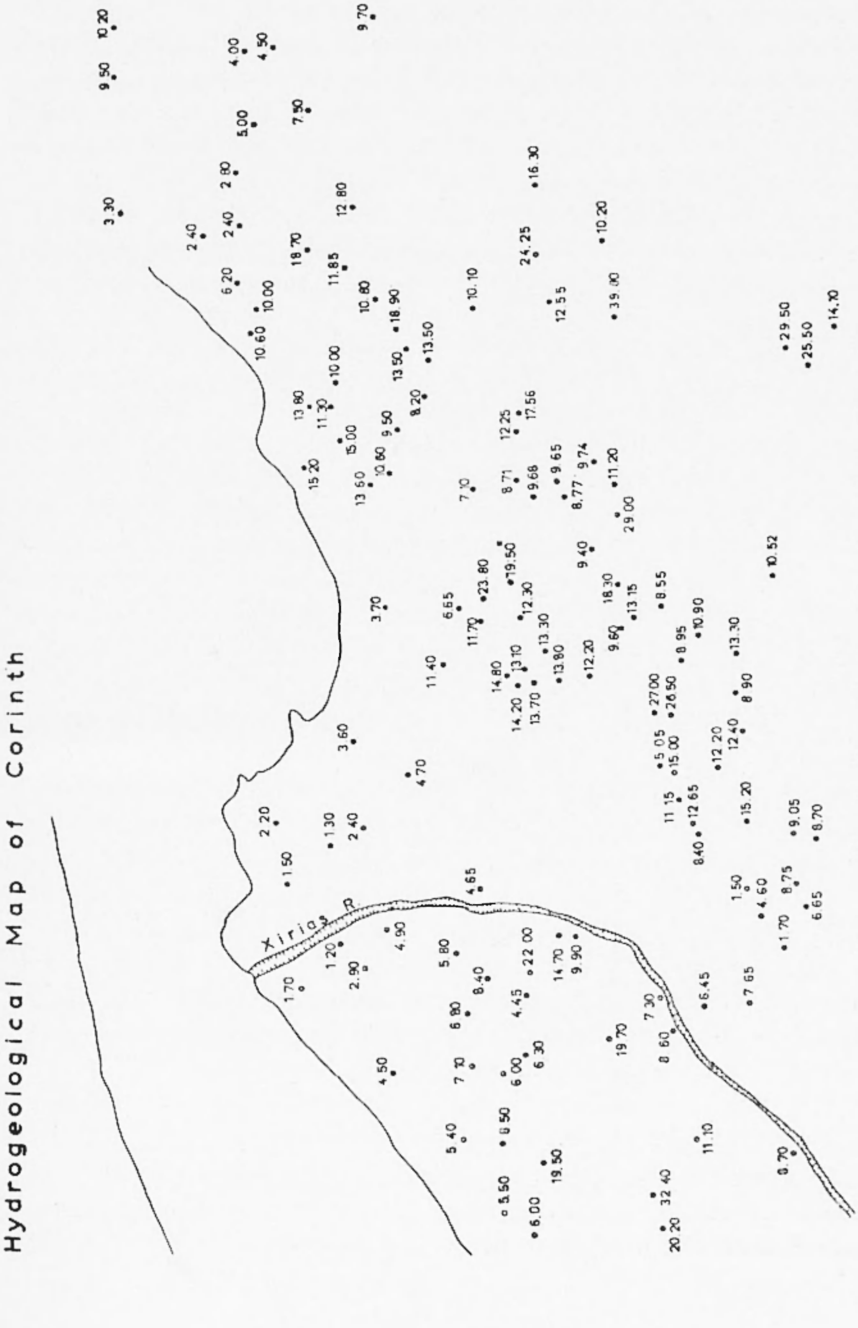


FIG. 4 - Depth of water level in the area of Corinth.

It is useful to underline that small values of water table in Loutraki and Corinth are near to the coast and the values generally increase versus the distance from the coast. This was approximately the picture of different degree of damage during the shock of 1928, as we will see. So we can say that the change in the physico - mechanical properties of the ground caused by the underground water contributed at least partly to the increase of the intensity during the shock of 1928. Strengh of sandy and clay soils depends on water saturation. In general the strength of these grounds decrease by increasing the water -saturation.

In fig. 5 the dependence of intensity increament on water table level depth (*h*) is indicated according to Steinberg (1973).

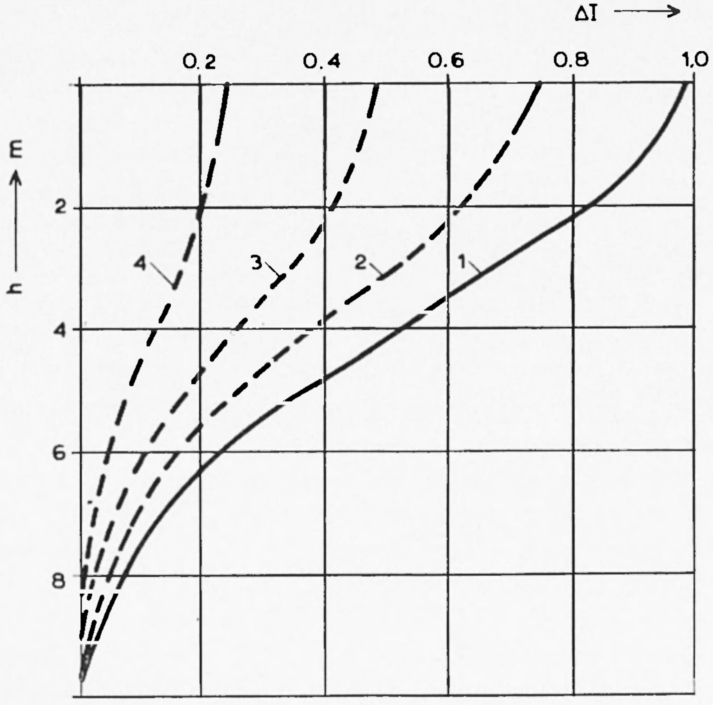


FIG. 5 - Dependance of Intensity ncreament on water table level (1. Sandy soil 2. Soft plastic 3. Tight plastic 4. Solid clay).

Based in this figure we estimated the intensity increament due to water-saturation in few representative points in different kinds of soils and different water levels in Corinth and Loutraki. The maximum increament reaches the value 0.7 in comparison with the intensity of hard rock of Gerania mountain.

5. Seismic Regime of the Area.

For the shallow shocks of the area around Corinth it has been found by Ritsema (1974) that *T* axis is almost horizontal and has an almost north-south direction and the *P* axis is almost vertical. Some related studies show that the stress pattern in the crust along the Saronic-Corinthian Gulfs is tensional with almost north-south direction. There is also strong seismological evidence that the acting stress component in the upper mantle at the Corinthian Gulf region is tensional. The mean direction of the *T* axis is towards NE-SW, i.e. almost vertical to the axis of the Graben of the Corinthian Gulf. This indicates that the Corinthian Gulf came into existence as a result of tensional stresses prevailing in the Upper Mantle.

Comparison of focal mechanism studies of local shocks in the area of Corinth and pattern of intensities and damages reveals that at least in the near field the earthquake mechanism and radiation pattern are not important determinants of the response.

As it is known from seismicity studies, a strong shock occured (38° N, 23° E) on February 21, 1858 in the area of Corinth. Maximum intensity was 10. The old town was destroyed as well as Kalamaki, Examillia, Periyali, Neochori etc. There are macroseismic evidences that the epicenter of that shock was near to Neochori. 19 persons were killed and 80 were injured. The aftershock activity continued for 13 months.

The Government decided that Corinth must be rebuilt in other position and the new town developed near the seaside, where unfortunately the soil conditions were not convenient from seismological point of view as was demonstrated 70 years later by the results of 1928 earthquake.

On April 22, 1928 (20h 13m, 38.0° N, 23.0° E) a strong shock destroyed Corinth and some villages in the area. The maximum intensity was between 9 - 10, while the magnitude was $6^1/_4$. The shock was very shallow (5 km in the UNESCO catalogues) and for that reason the damages were extended. 26 foreshocks were preceded the main shock and two of the (19h 01m and 19h 59m of 22 of April) were rather strong. The foreshock activity was an important factor for saving lifes in Corinth by the effect of the main event. The aftershock activity continued and within two days after the occurrence of the main shock 77 events were recorded by the Mainka seismograph (low magnification) of National Observatory of Athens at an epicentral distance of 70 km. The largest aftershock occurred on April 29 and by this shock some damages were caused in the villages such as Vello and Ancient Corinth (see Fig. 13).

The large number of shallow and intermediate earthquakes in the Corinthian Gulf region shows that the processes which are responsible for the genesis of the Gulf of Corinth are still in progress.

The earthquake risk expressed in recurrence rates for shallow shocks is high in Corinth - Loutraki (Galanopoulos, 1968). Corinth is located in 38° N, 23° E. So in the square degree which is bounded by the parallels 37.5° - 38.5° N and the meridians 22.5° - 23.5° E, we expect:

1	shock	with	$M \geq 7$	every	135 - 170	years
1	»	»	$M \geq 6^1/_2$	»	55 - 70	»
1	»	»	$M \geq 6$	»	23 - 28	»
1	»	»	$M \geq 5^1/_2$	»	9 - 12	»

If we take into consideration both shallow and intermediate shocks — which are very common in the area under investigation — the return periods above mentioned for certain levels will be much smaller.

According to seismic risk evaluation (Algermissen et al., 1974), in the area of Corinth — Loutraki the acceleration with 70 percent probability of not being exceeded in 25 years and in 200 years is 0.14 *g* and 0.28 *g* correspondingly. The calculated values of velocity under the same assumptions are 12 cm/sec and 22 cm/sec. The above mentioned short term risk (25 years) correspond to values with a return period of 70 years while the 200 years risk values correspond to a return period of 560 years.

In order to study the probable occurrence of maximum magnitude earthquakes around Corinth, Drakopoulos and Makropoulos (1977) applied the extreme value method using data from the UNESCO catalogue of the period 1900-1970, for three zones in the form of circles with radius:

a) 0.50 = 55.5 km.;

b) 1° = 111.1 km

and

c) 2.0° = 222.2 km

around Corinth. Some of their results are presented in the asymptotic distribution curves first type of fig. 6. This fig. is very practical and useful because it correlates a certain level of magnitude with probability (exceedance or not in one year) and the magnitudes are directly related in a certain seismic area with corresponding mean periods. The same authors using the formula of Donovan (1973) for peak acceleration

$$A = 1080 \cdot e^{0.54} (R + 25)^{-1.32} \text{ in cm/sec}^2$$

calculated the probability that during a known period of time a certain acceleration should not be exceeded in the town of Corinth. The results are presented in fig. 7 in the form of asymptotic distribution curve and hold for rock soil in Corinth as well as for Loutraki.

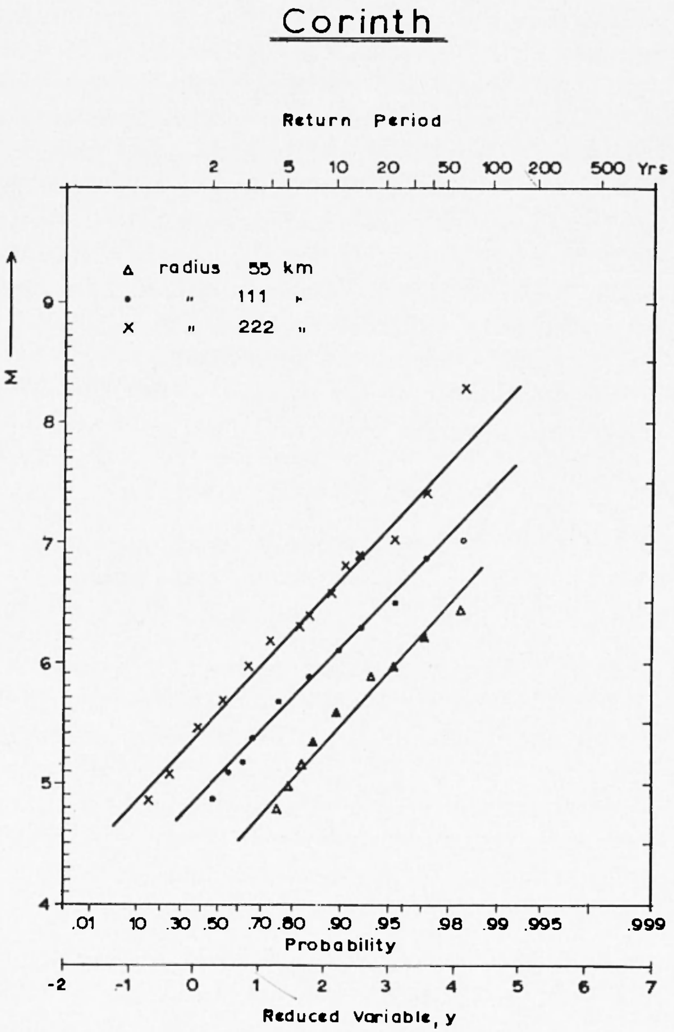


FIG. 6 - Asymptotic distribution curves for Magnitude.

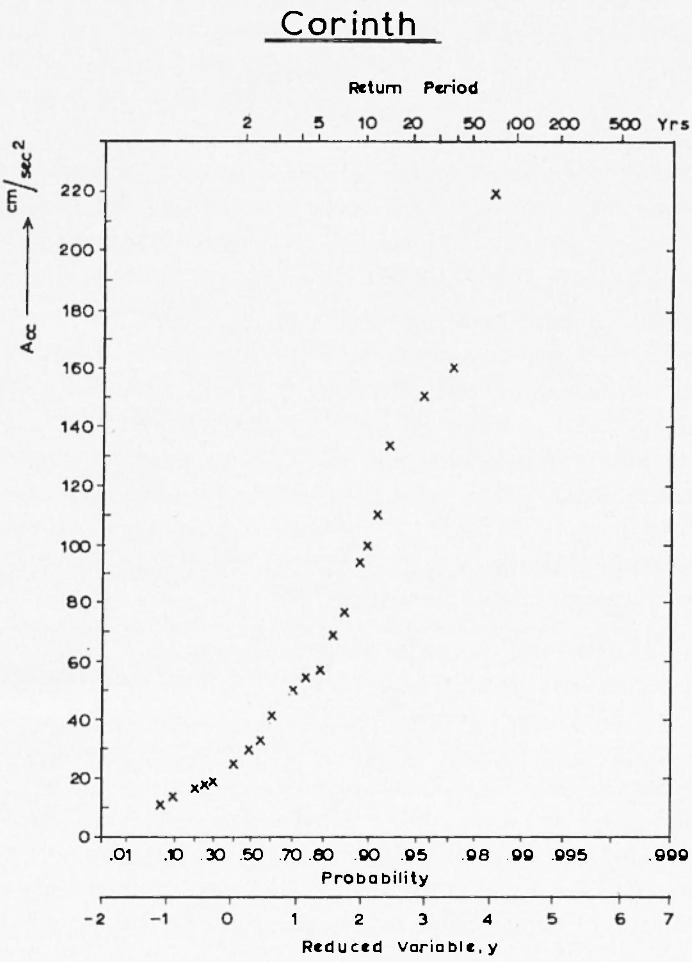


FIG. 7 - Asymptotic distribution curve for peak acceleration.

6. Measurements and results.

The information on the soil properties using microtremors is useful only in case of the waves propagating in the soil layers from the bedrock. Other excitations, e.g. direct waves of artificial origin are not useful. During the field work in Corinth — Loutraki, we tried to avoid the interference of both types of excitations but some of them were included in the records. In these cases we carefully avoided in the estimation of predominant period the use of unstable disturbances mentioned above.

In the present case of Corinth, Loutraki, Perachora and Kalamaki the measurements of the microtremors have been done in the day time but unwanted high frequency local traffic noises have been avoided. At each site we tried to have sufficient duration of recording in order to avoid noise variations mostly noise from local traffic and noise due to the windy local conditions.

The period of observation was for 15 days beginning from March 12, 1976.

The instruments were arranged always in a station wagon car and just the 3 seismometers of the first set had to be orientated and leveled for the time of measurements at each point. The two horizontal components were for detecting ground motion in the N-S and E-W direction. Two minutes records were obtained at each point where the nearby traffic noise wasn't high; otherwise 3 minutes of measurements were carrying out in order to cut later the frequency disturbance and to get a more representative character of microtremor at each site.

The second system of instruments was used only in interesting places where we wanted to check whether both systems were providing same results.

Such places were selected only for the town of Corinth and are the three points where we operated the three portable seismographs and the building of telecommunication company where a strong motion seismometer SMA-1 has been installed. All these points are indicated in the fig. 8. We want also to mention that the point where the second portable seismograph was operated, was selected as standard measurement station for daily fluctuation of microtremors as well as for chequing the change through 24 hours.

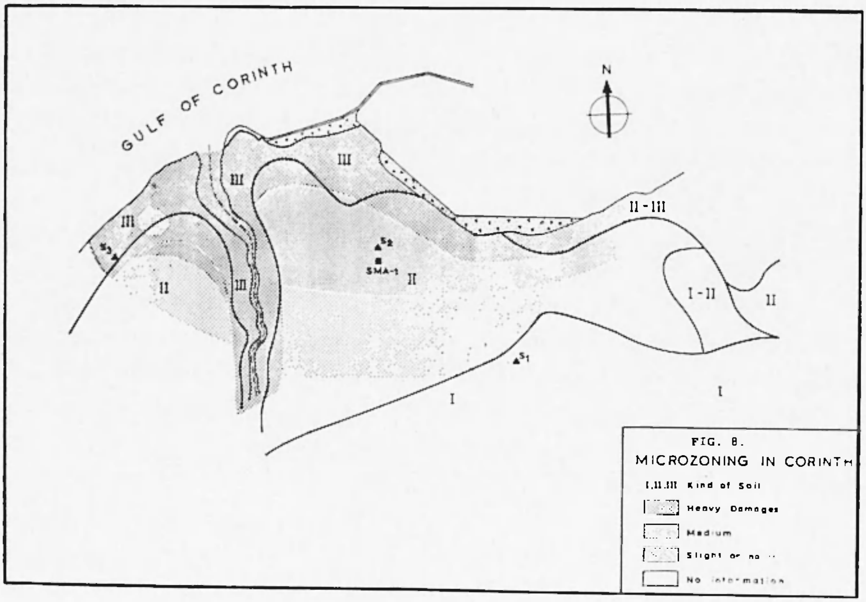
The measurements covered the populated area and also the outer part of the city of Corinth up to 3 km to different direction of the center of Corinth. In Corinth we carried out microtremor measurements in 70 points. Measurements of microtremors took place also at 35 points in the town of Loutraki, 8 points at the village of Perachora and 5 points in Kalamaki. The distance between two measuring points in Corinth and Loutraki was not larger than 200 m covering all the populated area.

All the measurements were finally recorded on the visigraph and 60 seconds from each record (the more representative of the site) were analyzed manually. Using the zero crossing method, period distribution curves were obtained for each point. Besides, largest amplitude (in means of displacement) of microtremors, mean period and largest period were calculated.

Two methods were applied for classification of seismic microzones in Corinth — Loutraki by microtremors technique. First based on the largest and mean period of microtremors, and the second based on the largest amplitude and the predominant period.

Finally the area of Corinth and Loutraki was classified into 3 main zones following the Japanese classification into kinds of soil. These zones are presented in fig. 8 and 9.

Typical examples of period — distribution curves for the three main zones are indicated in fig. 10 although we want to mention that almost in all points of the present study the corresponding curves are more complex (many peaks etc.). The nature of rather complicated period distribution curves is not peculiar for that study and has been observed and discussed by many authors.



GULF OF CORINTH
N
III
III
III
III
II - III
II
II
I - II
II
I
I
SMA-1
FIG. 8.
MICROZONING IN CORINTH
I, II, III Kind of Soil
Heavy Damages
Medium
Slight or no
No information

FIG. 8

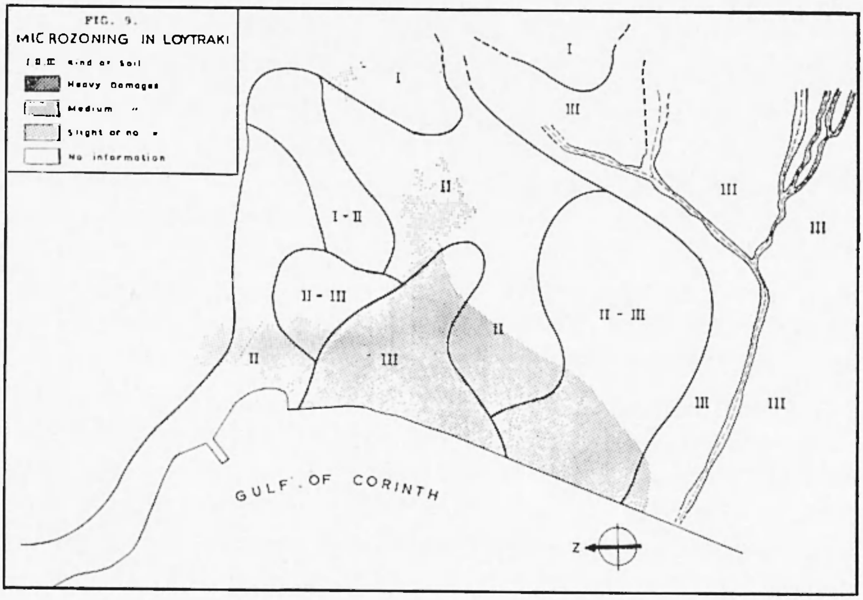


FIG. 9.
MICROZONING IN LOYTRAKI
I II III Kind of Soil
Heavy Damages
Medium
Slight or no
No information
I
I
III
II
I - II
II - III
III
II
II - III
III
III
III
III
II
GULF OF CORINTH
Z

FIG. 9

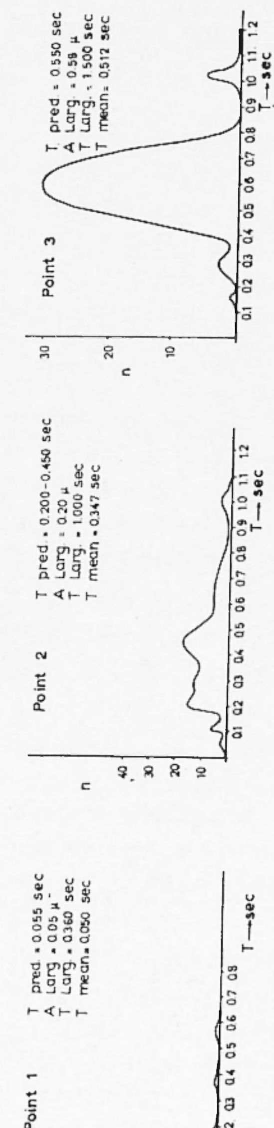


FIG. 10 - Typical examples of period - distribution curves for the three main zones in Corinth.

7. Comparison of the results with real shocks recorded in Corinth.

An attempt was also made to compare shocks recorded in Corinth with microtremors at the same sites. For that reason, 3 portable vertical component seismographs model MEQ 801 with smoked paper recording systems and characteristics almost equivalent to those of microtremors seismograph system were installed on each of the three different kinds of soil in the urban area of Corinth for the period of field work of microtremors (15 days).

We recorded 3 small shocks with epicentral distances from 15 to 140 km during the period of observation. Predominant periods corresponding to the first P, P with largest amplitude, S and S with largest amplitude have been calculated for one shock (D = 40 km) and the results are shown in the Table I.

From this table it is obvious that for all phases, the softer the soil the larger the corresponding predominant periods.

TABLE I

Recorded periods in sec. for different phases of the shock of 13.3.1976 and D = 40 km at 3 different soils.

Station	Kind of Soil	P	P Larg. ampl.	S	S Larg. ampl.
1	1	0.16	0.20	0.20	0.25
2	II	0.20	0.23	0.35	0.42
3	III	0.27	0.34	0.45	0.50

Since we operated the 3 seismographs in the same level of magnification, although the site noise was different (larger to site 3) it was possible to have a very rough estimation of the amplification at points 2 and 3, under the assumption that this amplification is equal to 1 for the site point 1. Dividing the largest amplitude of the above mentioned shock at the sites 2 and 3 with the corresponding at the site 1 we have:

$$\frac{S_3}{S_1} = 2.5 \quad ; \quad \frac{S_2}{S_1} - 1.6$$

We also compared in the three different zones the records of one local (D = 15 km) and one distant shock (D = 140 km), which were recorded on the three MEQ-801 portable seismographs. In the zone III for both shocks the motions were amplified. However, while the amplification for the zone III was about 2.8 for the local earthquake, it was only 1.5 for the distant shock. All these results must be considered as rather indicative until systematic data confirm them.

Since the stations were in a distance of 600-800 m in Corinth, it is obvious that the differences in motions recorded are due primarily to the effects of the soils rather than to differences in characteristics of the motions in the underlying rock.

There is also a strong motion accelerogram from a recent earthquake recorded in Corinth. The accelerogram of the October 12,1975 earthquake (H = 08: 23: 10,37,9° N, 23.1° E, M_L = 4.6) recorded on a SMA-1 seismograph at Corinth (37° 55′ N, 22° 55′ E). Maximum acceleration on the N 35° E component ca 0.25 g. Epicentral distance 16 km.

The site of the accelerograph is indicated in the map of fig. 8 and and the corresponding period distribution curve is illustrated in fig. 11.

From the Fourier Amplitude Spectrum of this earthquake in Corinth (N 35° E component), calculated by Carydis and Sbokos (fig. 12), it is obvious that the main amplitude appears in a period of 0.55 sec and two other max are in periods of 0.45 and 0.75 sec. So, we can say that the predominant period, at the site, for this shock and the N 35° E component is in a period of 0.55 sec, while large energy concentrations are in the 0.30

to 1.2 sec range, dropping off beyond that. The absence of energy concentrations in periods smaller than 0.3 sec may be attributed to the attenuation of the high — frequency components of earthquake ground motions.

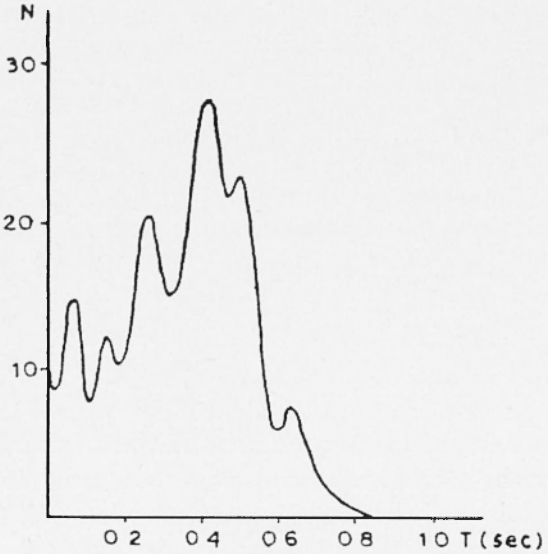


FIG. 11 - Period distribution curve at the site of SMA-1.

The comparison of the above observations from the strong motion record with the period distribution curve of microtremors at the same site and same component of accelerograph in Corinth (fig. 11) shows that the predominant period is almost the same although we observe generally in microtremors higher frequency content (large portion of very small periods $T < 0.4$ sec) while in the strong motion comparatively larger amplitudes in large periods e.g. $T > 0.4$ sec.

So for this case there is agreement when the comparison is restricted to predominant periods but it is difficult to support any strong correlation of accelerogram and microtremors when we examine the full frequency content.

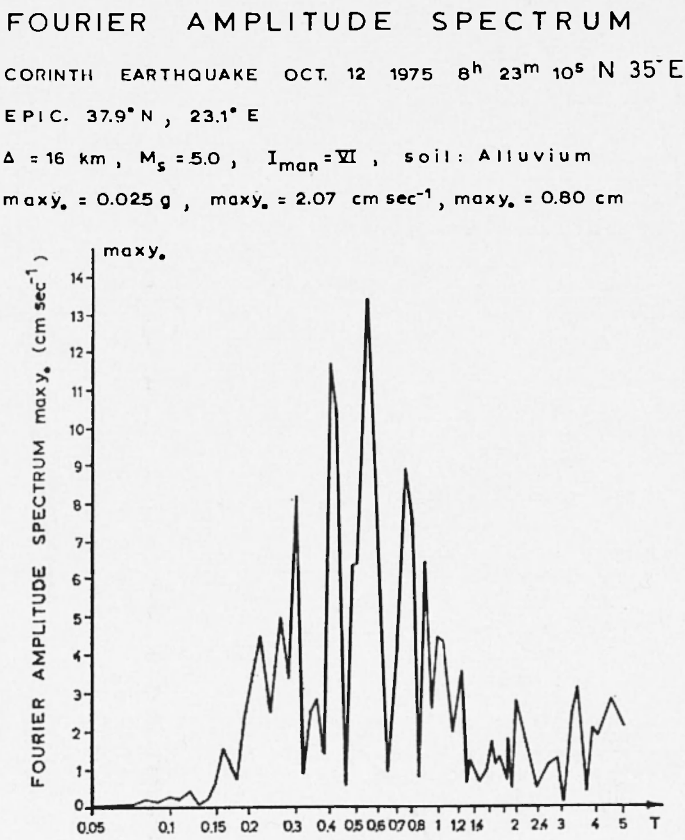

FOURIER AMPLITUDE SPECTRUM
CORINTH EARTHQUAKE OCT. 12 1975 8h 23m 10s N 35°E
EPIC. 37.9° N , 23.1° E
Δ = 16 km , Ms = 5.0 , Iman = VI , soil : Alluvium
maxÿ. = 0.025 g , maxẏ. = 2.07 cm sec-1 , maxy. = 0.80 cm
maxẏ.
FOURIER AMPLITUDE SPECTRUM maxẏ. (cm sec-1)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
0.05 0.1 0.15 0.2 0.3 0.4 0.5 0.6 0.7 0.8 1 1.2 1.6 2 2.4 3 4 5 T
UNDAMPED NATURAL PERIODS T (sec)

FIG. 12

8. The destructive earthquake of 1928.

Some information related to the 1928 shock and to its fore— and aftershock activity were given in a previous chapter of this report. In the isoseismal map of the 1928 earthquake (Sieberg) there is an elongation to the E-W only in the area enclosed by

Fig. 13

the isoseismal line 9 and it seems difficult to make any argument for the radiation pattern of that shock.

In the fig. 13 it is indicated by arrows the observed general direction of motion in buildings of some villages according to independent information of Roussopoulos and Tanakadate. The line EE' crossing the figure from WNW to ESE separates the area into two parts in each of which the average general motion indicated by damages is directed predominantly to the N and to the S. So by those macroseismic observations we can say that the epicenter was probably located between the triangle Corinth — Kalamaki — Loutraki and very near to the channel.

Another strong indication that the epicenter was very near to the channel is presented in fig. 14 where the predominant motion in the two guardhouses of the channel was horizontal twisting to opposite directions.

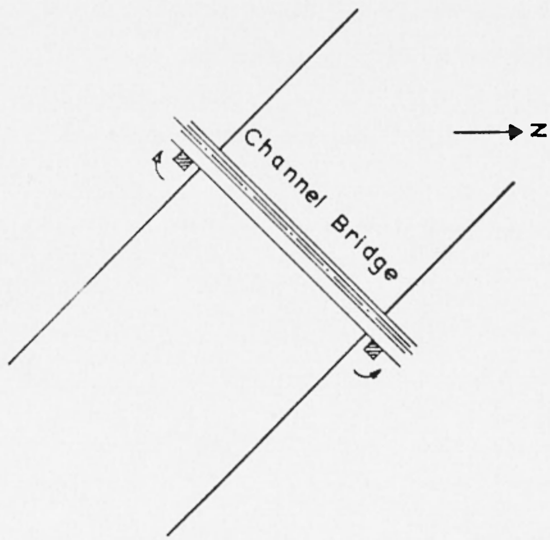


FIG. 14 - Predominant motion in the two guardhouses of the channel after 1928 earthquake.

The degree and portion of damage was higher in Corinth and Loutraki and this is due to the proximity of the epicenter and to unfavourable local soil conditions in some parts of both towns.

In the Table II the number of house with different degree of damage in villages and towns is indicated according to official reports of the responsible Ministry. The table is selfexplanatory if it will be compared with the map of fig. 14.

Most of the buildings were one or two story residential type. They were constructed predominantly of random stone masonry in mud mortar. Most of the village houses of mud or stone masonry had roofs supported on timber beams.

The damages in the area were extraordinary heavy in comparison with the magnitude of 1928 shock. Important factors for that high degree of damage are:

a) The shock was very shallow (5 km in the UNESCO catalogues);

b) Large area exist with unfavourable soil conditions;

c) Carelles constructions of houses.

It was observed that they used for building round stones which must be avoided and also the quality of plastering was not good.

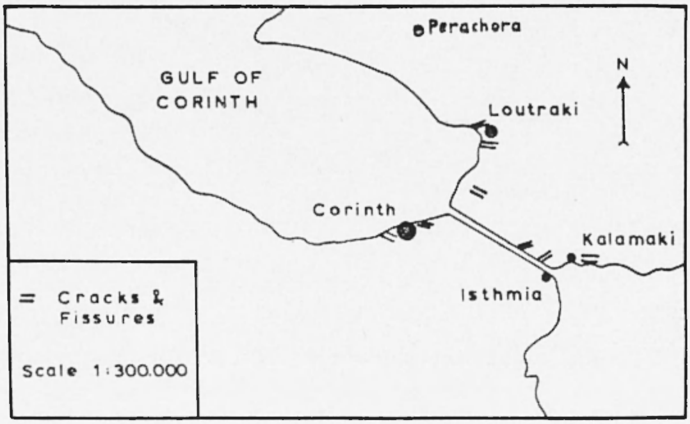


FIG. 15 - Cracks and fissures after 1928 earthquake.

Since the area under investigation consists in a large percentage of sandy deposits especially where damages were observed, we believe that during the 1928 earthquake — and in future shocks — the increament of ground saturation degree increased the liquefaction hazard and so the results of the shock were more extented to soil of sandy deposits.

TABLE II

Number of houses with different degree of damage in villages and towns after the 1928 earthquake according to official Governmental reports.

(1) Name of town or village	(2) Inspected or carefully examined	(3) Cracked*	(4) Slight to moderate damaged (may be repaired)	(5) Collapsed or seriously damaged (beyond repair)
Corinth	2200	2000	200	1800
Loutraki	402	352	51	185
Perachora	438	213	120	93
Schoenos	107	94	10	33
Bissia	110	107	23	65
Kalamaki	48	48	3	45
Isthmia	22	19	8	5
Posidonia	11	11	3	8
St.-Joannis	19	17	7	4
Azizi	56	56	21	13
Assos	172	172	83	89
St.-Theodoroe	152	94	77	17
Asprokampos	110	48	17	16
St.-Georges	203	194	63	17
Ano Dimenio	43	43	11	32
Athekia	302	120	23	21
Almyre	25	16	6	—
Vello	419	321	166	71
Vrachati	218	162	26	61
Vasilikon	29	29	8	21
Voivonda	45	10	6	4
Goelliniatica	10	10	1	9
Galataki	60	20	20	—
Evagelistria	44	44	11	33
Examillia	143	71	54	17
Zevgolatio	304	112	101	11
Heraklion	50	49	40	9
Heliaeika	4	4	3	1
Kyras Vryse	44	30	30	—
Kokkoni	140	140	31	109

(*) In the category of cracked are included not cracked houses but also both columns (4) and (5).

cont. Table II

Kouti	24	23	20	3
Katakali	35	15	15	—
Kato Dimenio	82	65	38	27
Kiaton	586	265	208	57
Krenae	98	73	64	9
Lechaeon	143	101	91	10
Limochorion	33	25	21	4
Bolati	83	52	37	15
Moulki	24	24	8	16
Melission	5	5	3	2
Botsika	97	23	11	12
Bokeika	10	5	5	—
Neratza	89	80	20	60
Xylokastron	25	25	7	18
Xylokeriza	53	12	12	—
Perighiali	113	128	125	3
Ancient Corinth	380	300	250	50
Poulitsa	60	59	56	3
Souli	90	19	8	11
Sykia	13	13	5	8
Stimaga	126	60	22	38
Soulinarion	75	22	22	—
Solomos	50	20	20	—
Sophikon	42	42	38	4
Tarsina	55	19	14	5
Chasanaga	139	120	45	75
Chiliomodion	178	73	57	16
Chalki	65	0	19	1

Another contributing factor to the localization of the damage is the presense of loose granular soils at the sites of heavy results from the shock of 1928. So maybe these soils have been compacted by the ground vibrations induced by the earthquake of 1928 resulting in settlements and differential settlements of the ground surface. This phenomenon multiplied the degree of damage only at sites with unfavourable soil conditions.

Very valuable information for the results of the shock of

1928, both damages in buildings and observed cracks on the earth surface, were taken mainly from Tanakadate, who visited the area 3 or 4 days after the event, from Roussopoulos, from many reports and newspapers and are the following:

8.1. Damages.

1. Corinth. The city is built up on the marine sand in northern half while the southern half on the tertiary sediments. The ground on which the city stands slopes slightly towards the sea. The main business district and the majority of residences in Corinth are situated on the topographically lower portion of the city which is underlain by relatively unconsolidated sediments with vertical variations in lithology. Many large houses and buildings were in the harbour street on the shore sand deposits, and they were almost completely destructed by the shock. The majority of the collapsed and very heavy damaged structures in Corinth were in the shore, in the zone around to Xirias river and to the western part of the town. One of the monuments in the Garden of the S. Paul Church is fallen towards West, while the other situated in front of the Church is displaced several centimeters to the SW direction.

Regarding the importance of construction of the buildings for earthquakes, there are several examples to mention: At the NW part of the city, there was a new school near the shore; it was a big and rigid building founded on sand bed. This building was only cracked on its wall, while the houses, east of this, were mostly destroyed. The French Consulate at the corner of the Central Park of the city was one of the strong buildings and it was only slightly damaged in spite of its two store height, while the houses around it were damaged very badly. Such difference in the destruction of houses maybe is related to the construction and the building materials.

The place Poseidonia at the channel opening and the houses by bridge on the channel were also badly damaged.

2. Loutraki and Perachora. The most part of the town of Loutraki is situated at the foot of a limestone hill, but the main street runs along the sea coast and on the shore sand. The newspaper accounts of 1928 earthquake and dr. Tanakadate mentioned that the houses in the principal streets were damaged completely, while the houses on the hillsides have escaped the catastroph.

According to the degree of damages the town of Loutraki can be separated into two sectors:

a) The NW and the uptown part of Loutraki where the soil conditions are relatively better and in this part small to medium damages were observed according to the quality of the structure.

b) The rest part of the town where the buildings were either collapsed or seriously damaged. The occurrence of more damage in areas with alluvial soils than in other parts of the town in Loutraki in structures of the same type, led us to believe that local subsoil conditions were the governing factor in the assesment of damage to structures.

From the cracks on the walls of some houses, it is sure that the main vibration of the shocks was SSE-NNW direction. This is confirmed by the fact that an unexpected jumping of a small statue happened from S to N e.g. from the roof of Isthmia to the roof of the neighbouring Hellas hotel in Loutraki (Roussopoulos, 1969).

Spotty distribution of damage was also observed in the village of Perachora, near to Loutraki. No damage was observed at the part of that village which is built on very hard mountainous subsoil.

3. Kalamaki. The foundation of the village is sand underlaid by the neogene sediments. The village consisted of 40 houses only, and they were completely damaged. This heavy disaster was caused mainly by the unstable foundation of the village. In order to examine the soil conditions in Kalamaki by Kanais' method, we measured microtremors at 5 points in

the village and the results showed that the kind of soil is III, in agreement with the heavy results of 1928 shock.

4. Isthmia. The foundation of the village is upper tertiary covered with thin alluvium in the part near the shore. The people say that the shocks came from NW and the movement was rather undulatory. The damage was very slight and only a few houses were cracked.

5. Ancient Corinth. The foundation is tertiary, the houses were cracked very badly and the stone fences were broken down to a great deal. From 280 houses in that village 50 collapsed or seriously damaged. In two rather good constructions which were used as museums, cracks were observed. Even the new rigid building of the school for classical study has been very badly cracked.

6. Perijali, Assos, Vrachati, Kohoni etc. Some houses were cracked and few damaged beyond repair.

7. — Vello, Neratza. It was reported that the villages of Vello and Neratza were very badly destroyed (see table II) by the earthquakes of the 22nd as well as that of the 29th April. The heavy damages in Neratza where almost all houses were built with bricks are partially due to the fact that this village stands on the unstable foundation of the shore sand.

8. Kiaton. The coastal part is built on the shore sand and only some houses were cracked on their wall very slightly and their tiles were fallen on the ground. They said that vibration of the arthquakes on 22nd was NNE-SSW and that of the shocks on the 29th was SEE-NWW.

9. The portion of damage to some other villages in the area is indicated in table II.

From the above mentioned and taking into consideration the table II, it is obvious that Corinth, Loutraki and Kalamaki were damaged at most by the shock of 1928 and the extension of damage is along the coastal zone. An important factor for that distribution of damages seems to be the unfavorable soil conditions in villages near the seaside .This is supported:

a) by the observed higher degree of damages, relatively to other villages with smaller epicentral distances, in a zone including the village of Neratza ,which stands on sand

b) the isolation of the area with collapsed buildings to different large parts with bad soil conditions in Corinth-Loutraki.

8.2. Influence of the Shock to the earth surface (landslides, cracks etc.).

Since the inclination of the bedrock in Corinth is not steep, the effect of landslides and rock falls was meaningless during the 1928 shock. So the damages were not influenced by landslides. Contrary to this, landslides of small scale and few rock falls as result of the main shock and one large aftershock (June 4, 1928) were observed near Loutraki where the slopes of Gerania mountain are relatively large. After that aftershock a large rock fallen near to the monastry of St. Patapios and rock falls were observed to the eastern side of Gerania mountain. Landslides of small scale as a result of the main shock were observed by Georgalas in Schoenos where the limestones of Gerania mountain have steep slopes.

According to Georgalas the quantity of the water in the hot springs of Loutraki was not influenced by the 1928 earthquake.

The cracks and fissures as a result of the shock were limited (fig. 15). In the City of Corinth, several cracks were observed in the shore near the S. Nicola Church. To the west of the Palmyra Hotel of Loutraki, just at the shore, there were some fissures on the alluvium parallel to the shore line. On the principal road between Loutraki and Corinth along the coast, some fissures took place along or across the road. Among these fissures one was about 15 meters long and run in the direction of N 70° W across the road. In Kalamaki, minor fractures occured on the shore just at the landing place of boats (Tanakadate, 1928).

In Isthmia, small cracks occured along the channel side, just at the junction between the channel wall and the mole, but they had no weight for the earthquake origins. A fissure will be noted here, found on the NE side of the channel just at the highest part of the hill, which the channel cuts across. This was a small fissure but it was about 50 meters long and ended to the wall of the channel; its direction was N 70° W and its continuation in the other side of the channel, coincides with a large fault line. Among the fissures mentioned above, this seems to be most important for the cause of the earthquake (Tanakadate, 1928).

9. A ROUGH MICROZONATION MAP BASED ON THE RESULTS OF 1928 EARTHQUAKE AND ITS COMPARISON WITH THE NEW MAP.

Immediately after the earthquake, in order to study the results of the shock, to repair the damage and for reconstruction of the towns (Corinth, Loutraki) and the villages, independed and valuable programmes of seismotectonics and engineering seismology investigations were elaborated (professors Georgalas, Ktenas, Roussopoulos, Paraskevopoulos and drs. Tanakadate, Papastamatiou and others) which in addition to the existing geological and seismological information covered the detailed study of the effect of the earthquake upon the structures. So at that time, they studied the damaged structures in Corinth and Loutraki and their scientific observations, the detailed descriptions and many special photos represent useful information for study in some degree microzoning and earthquake engineering problems.

The existing hotels at that period in Loutraki — rather good constructions — may be divided into 3 categories according to the degree of damage:

a) Hotels Palladion, Hermes and Aktaeon where no damages were observed.

b) Hotels Palas, Karellion, Melathron, England, Akte, and Byron: slight to medium damages were observed, may be repaired.

c) Hotels Eraeon, Isthmia, Palmyra, Hellas, Konstantinoupolis, Achillion, Stadion, Majestic, Panellinion and Posidonion were either collapsed or seriously damaged.

The degree of damage and the sites of the above hotels in Loutraki helped us — with other additional information — to have a very rough microzoning map for Loutraki based on the results of 1928 earthquake.

It must be underlined that there are detailed information and many photos of structures almost of the same type in different parts of Corinth and on different kind of soil.

In the microzone area near the seaside in a central part and western Corinth and southern Loutraki the estimated seismic intensity exceed 9 but was smaller than 10. So the most important damages had been suffered in both towns by those buildings placed in the district near the seaside, where marine deposits exist and the foundation soil is composed of sand and sandstones. Very heavy damages were also concentrated to both sides of Xirias river and especially to the western part of Corinth.

Throughout the second microzone the seismic intensity was rated 9 (major part of central and eastern Corinth and central part of Loutraki). In this second microzone, the foundation soil is represented almost entirely by gravel and sand with clay and it is a rather limited microzone and difficult to be defined by information of 1928 earthquake.

In the microzone where minor or no damages observed the rating was about 8 (NW and outer part of Loutraki and uptown Corinth). The soil conditions there, are better since this part of Loutraki is situated at the foot of a limestone hill and uptown Corinth stands on marls of good quality.

As it is obvious from the above, in the calculation of relative seismic intensity increases, the hard rock of Gerania mountain which is presented in Loutraki has been taken as the basic rock formation. The relative seismic intensity increase was half or one degree in slope deposits and 1-1.5 units on the marine deposits containing fine materials. In most of the points in Corinth and Loutraki the relative increase of intensity was 1 unit with respect to the base rock.

Higher intensities apparently correlate with areas of deeper alluvial fill, with sites near seaside, with less competent soil and with areas where ground water tables are near the surface. Prof. Roussopoulos estimated the accelerations in different parts of Corinth and Loutraki from macroseismic data and found values between (0.10 $\sim$ 0.15) g.

Many buildings in Corinth and Loutraki were classified according to the information for the importance of damages as follows:

1. Collapsed structures or very heavy damaged structures.
2. Heavy damaged or seriously cracked structures.
3. Structures with no or minor damage.

With this classification it was possible to have a very rough microzoning map for Corinth and Loutraki based on the results of 1928 earthquake. Figs. 8 and 9 present a very rough territorial behaviour of buildings damaged by the earthquake of 1928 in Corinth and Loutraki and there are similarities of the shading areas with different degree of damages and the new microzoning maps (same figures) compiled after the application of microtremors method.

Summary and conclusions.

Prediction of seismic shaking are critically dependent on local ground conditions, as it is indicated by the distribution of damage in many earthquakes. This was observed during 1928 earthquake in Corinth and the concept of microzoning was obvious from that times. The value of microzonation exist even in the official aseismic codes in Greece where practically we recognize that site conditions may alter seismic amplitudes.

It is very important, from seismotectonic point of view, that the region where Corinth and Loutraki belong is an area with an uplifting movement with amplitude of movement up to 100-500 m during Quaternary. From the seismogenetic map of Greece based on Geological criteria, the region of Corinth-Loutraki belongs to areas with possible occurrence of foci of strong earthquakes from both Tectonic and Neotectonic point of view.

In the region of Corinth-Loutraki-Kalamaki some faults originated or were reactivated during the Quaternary and since tectonic movements occur basically along recent faults, this area can be considered as a very dangerous one from geological point of view.

From seismicity studies it is concluded that the area in and around Corinth is very active and two times were suffered from destructive earthquakes during the last 130 years.

In the urban area of Corinth and Loutraki mainly we have coastal deposits plus Delta formations. The lithological character in both cities is formed of Neogene and Quaternary sediments which are divided into some lithological types.

In general, the water table is within 10 meters of the surface in those areas of Corinth and Loutraki suffering the largest damages during 1928 earthquake and this confirms the influence of the water table elevation to the macroseismic field.

The following general results of 1928 earthquake must be underlined:

1) The area most severely destroyed by the shock contains Corinth, Loutraki and Kalamaki. On this area almost all

house standing on the plain (not on locally rigid roks) damaged.

2) Such villages as Ancient Corinth, Vello, Neratza seem to be destroyed next to above area. As an average the soil conditions at that villages are not good but relatively better from Corinth and Kalamaky.

3) Perijali, Assos, Vrachati, Kokoni, Kiaton etc. were slightly damaged. The epicentral distances were larger.

4) There is a thick cover of alluvium in the whole area containing a layer or layers of water-saturated sand, which resulted in few surface displacements and fissures in 1928 earthquake. Landslides of small scale and rock falls were observed along steep slopes of Gerania mountain near Loutraki but were avoided in Corinth, Kalamaki generally by the absense of steep hill slopes.

5) Several small fissures and cracks on the earth surface occured in Corinth-Loutraki and Kalamaki. Two additional simple explanations of the localized damage during 1928 earthquake are that some soils in Corinth-Loutraki present a potential danger of liquefaction and also the ground vibrations induced by the earthquake probably resulted in settlements or differential settlements of the ground surface in few unfavourable sites. These phenomena probably multiplied the degree of damage only at sites with unfavourable soil conditions.

The microzoning map of Corinth and Loutraki compiled using the microtremors method are presented in figs 8 and 9. Few measurements of microtremors in Perachora and Kalamaki revealed kinds of soils I or II and III correspondingly in agreement with what we expected from the results of the 1928 earthquake.

It is of interest to say that the rough microzoning map of Corinth and Loutraki compiled on the basis of information of damaged buildings during 1928 earthquake is in a rather good agreement (in few cases we don't know the results of the shock in detail) with the new microzoning map based on microtremors technique and so we believe that local subsoil conditions in the area were the governing factor in the assessment of damage to structures.

It must be mentioned that to the southern part of the town of Corinth, in a height of 25-35 meters, there is a very broad step terrace of Quaternary formations. These formations consist of compact marls (solid). The kind of soil to that part of the town, where a large barrack exist today and the adjacent region it was found to be soil type I and seems the more convenient area from seismological point of view for the future expansion of Corinth, being not so sensible to earthquake damages. The seismic behaviour of the village Examillia to the shock of 1928 implies the same thing.

We recorded very well 3 small shocks by 3 portable seismographs operated in the three different kinds of soil in Corinth and the following observations must be mentioned.

a) For certain phases (constant distance and same magnitude of the shock) it was found that the softer the soil the larger the predominant periods.

b) Under the reasonable assumption that the amplification for hard rock (kind of soil I) is unit, the amplifications for the other two sites of portable seismographs (kinds of soil II and III correspondingly) were roughly estimated to be 1.6 and 2.5 for a shock with $D = 40$ km.

c) This kind of amplification changes for the same zone with the epicentral distance and the excitation level (magnitude). All the above observations must be considered observations must be considered as indicative until systematic data confirm them. However, the the recorded shocks in Corinth illustrate that soil conditions at a site can modify the ground surface motions by changing the amplitudes of the motions and also the frequency content.

There is a rough agreement when the comparison of one strong motion accelerogram and microtremors at the same site in Corinth is restricted to predominant periods but it is difficult to support any strong correlation when we examine the full frequency content. Practically we observed in microtremors relatively large portion of very small periods ($T < 0.4$ sec), while in strong motion comparatively larger amplitudes in large periods e.g. $T > 0.4$ sec.

It must be underlined here that methods developed from the studies of small earthquakes may have to be considered with caution as well as the case of microtremors because of nonlinear stress-strain characteristics of soils during strong earthquake shaking. So the predominant period of soil deposits may be quite different in different cases. Althouth there is this conservation, we believe that the systematic study of small earthquakes for such study as well as the application of microtremors technique, are useful tools for soil classification and microzonation.

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