MACROSEISMIC OBSERVATIONS FROM SOME RECENT EARTHQUAKES

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The field study of ten recent earthquakes in the Mediterranean area shows that intensity as defined by any of the current scales cannot be assessed rigorously nor when assessed can it be used for design purposes. Also, that proximity to a fault-break is not a criterion of heavier damage and that serious exception should be taken with empirical formulae connecting properties of the ground and ground movement with intensity.

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Introduction

During the period 1965-1967 ten earthquakes in Jugoslavia, Greece and Turkey destroyed over 30,000 houses and damaged another 30,000, killing at least 2,600 people. Each of these earthquakes had its own characteristic and some of these shocks showed interesting and unusual features. The study of these earthquakes also showed that the engineer's ideas about earthquake resistant design and on seismicity in general need basic revision and that a new outlook to the problem is needed if progress in this field is to be made.

In what follows we give a brief description of the effects of these ten earthquakes, and a discussion of their main features.

The earthquake of Alonisos (Greece) of 9 March 1965

This earthquake caused considerable damage to the islands of Alonisos and Skopelos in the Aegean Sea, Figure 1. It destroyed 170 and damaged beyond repair about 1,000 local houses killing two people. Reinforced concrete structures suffered absolutely no damage. In the islands, villages are built on steep slopes of flysch and sandstone formations and many of them were involved in landslides. Local houses are mainly of dry rubble or stone masonry laid in lime mortar and are covered with heavy slate roofs. In the villages, houses are clustered together and the damage they suffered was not apparent at first sight. Although only 170 houses collapsed, about 1,000 houses were shattered by the shock but were left standing with disintegrated walls. When the islands were visited, most of the damaged houses had been replastered with only slight repairs. Many of them collapsed later on, during the rainy season. An attempt to grout damaged lime-mortar masonry walls with cement slurry was found to be ineffective. The grout would not adhere to the lime-mortar. Grouting was more effective in dry rubble walls but this was found to be very expensive for the local economy.

A year earlier, on Feburary 23, 1964, a strong earthquake had caused considerable damage to these islands. So that when the islands were visited after the 1965 earthquake it was found practically impossible to separate the effects of these two earthquakes, and consequently impossible to assess the local intensity. A rather subjective estimate would be VII (MM) which was based mainly on the behaviour of reinforced concrete structures and on the response of various other undamaged structures. No abnormal fluctuations of the sea level were noticed on tide-gauge records in the Aegean Sea. (Ambraseys 1965, Panagiotidi 1965)

The earthquakes of 1965-1966 in Southern Greece

Between March 1965 and September 1966 four strong earthquakes occurred in southern Greece and caused considerable damage. Two of these shocks, those of March and July 1965, were of normal depth and occurred about 100 kilometres north of the other two earthquakes which were shallow (numbers 2, 3, 4 and 7 in Table I), Figure 1. Their cumulative effects were considerable and difficult to separate. In many cases structures withstood the first shock but became progressively damaged by the earthquake that followed. These four earthquakes killed

27 and wounded 200 people, destroying 6,500 houses and damaging more than 16,000. Landslides and slumping of the ground, initiated by one of these shocks, was aggravated by the shocks that followed.

The average house in Southern Greece is a two to three storey stone masonry construction laid in lime mortar or in clay. Over 80% of these houses have suffered considerable damage in the past through heavy rains, slides, earthquakes, but mainly due to neglect and lack of repairs. New houses, mostly built after 1945 have brick walls and reinforced concrete columns and they are covered with cast in situ concrete slabs. Many villages in the affected areas are situated on unstable ground which under normal conditions and without the assistance of earthquakes slide every year, particularly after the rainy seasons.

Successive shocks activated previously unstable sites and also produced new ones. The damage caused by slides triggered by the earthquakes of 1965-1966 accounted for over 70% of the houses that were destroyed and over 30% of the houses that were damaged beyond repair.

With the exception of the last earthquake of the series, the other three did not produce violent ground movements. Well-designed reinforced concrete structures throughout the region, and properly constructed rural houses suffered little or no damage. Stone masonry houses which had been recently renovated or tampered with, suffered most. Some of them showed signs of unintentional weakening caused by the installation of new electricity and water conduits in old masonry walls, or by improper repairs. Houses on sliding areas when not damaged by foundation failures showed no signs of vibrational damage, and many of them were found in perfect condition.

The last shock of the series, of September 1, 1966 was of smaller magnitude and the shaking lasted only a few seconds. It produced, however, far more intense ground movements than the previous shocks and these were confined within a comparatively small area. People were thrown to the ground and pack animals staggered. Heavy objects slid on the ground and water sloshed from cisterns. Nevertheless, this earthquake caused comparatively little damage. An SR-100 Wilmot seismoscope in the area of severe shaking showed a response amplitude of just over 60 millimetres or, a maximum velocity response of about 2 feet/second, Figure 2. The direction of the maximum displacement of the pendulum was at right angles to the direction of the major fault that bounds the Megalopolis graben, which is believed to be associated with this earthquake, and which is located 3 kilometres from the location of the instrument. A search for surface fault movements, however, did not disclose any conclusive evidence and the validity of fissures in alluvium near the wall of the graben as evidence of surface faulting is questionable.

Intensities within the epicentral region of these earthquakes was very difficult to assess. The maximum intensity assessed by the Seismological Institute of Athens for the shock of April 5, 1965 is X on the Medvedev-Sponheuer-Karnik (MSK) scale. This intensity we found to be in excess by two degrees at least from what we deduced from field observations using the Modified Mercalli (MM) scale. The difference between the Institute's assessments and ours was found to decrease with decreasing intensity, the assessments becoming almost identical for intensities smaller than VI (MM). This difference was found to be mainly due to the fact that ground effects such as slides and cracks in the ground had been used by the Institute as criteria indicating high intensity irrespective of the pre-earthquake stability of the ground, and also because all rural houses were considered to be of similar strength. Differences in their resistance which resulted from ageing and from damage caused by previous shocks had been disregarded, (Ambraseys 1967, National Observatory 1966, Vinken 1965).

The Kremasta earthquake of February 5, 1966, in Greece

This earthquake occurred in one of the least seismic regions of Greece where, according to the seismic regionalization map of the country earthquakes of medium to low intensity are rare. As a matter of fact, no earthquakes of magnitude greater than 5¼ have ever been registered in this region and earthquake damage in this region was unknown. The earthquake of February 5, 1966 was preceded and followed by an abnormally large number of shocks which began soon after the Kremasta lake was impounded. Over 700 foreshocks and about 2,500 aftershocks of magnitude between 2.0 and 5.6 were recorded during the period August 1965 to the end of 1966.

Many of these foreshocks were damaging and triggered numerous slides over a wide area around the lake. Throughout the foreshock period damage to villages neighbouring the lake increased progressively; some of this damage was due to the shocks but also due to landslides, Figure 3. The main shock of February 5, 1966 destroyed about 500 and damaged beyond repair 1,200 houses, most of them damaged already by previous shocks. The Kremasta dam, a 450-foot high rock-fill dam was not damaged, Figure 4. Leakage, however, through outcropping conglomerates along the rim of the reservoir near the left abutment of the dam was noticed reaching values, soon after the earthquake, of a few cubic metres per second, Figure 5. Hot sulphur springs which had been sealed off before the construction of the dam near its foundation reappeared, and fresh-water springs in the region dried out. No water waves were noticed in the reservoir during the earthquake, though intensive "bubbling" of the water accompanied by noise was reported.

The ground movements throughout the epicentral region were not very intense. Well designed houses suffered little damage. The Kremasta colony, the rest house and other reinforced concrete structures near the dam were not damaged.

The question of whether the impounding of the lake triggered this exceptionally long and intense seismic activity has not yet been settled, (Galanopoulos 1966, Papazachos et al 1967).

The earthquake of 19 August 1966, in Varto (Turkey)

The Varto earthquake of August 19, 1966, occurred at the extreme east end of the Anatolian fault zone in Turkey, very near where an earlier, less intense earthquake had caused damage twenty years earlier. The 1966 earthquake was preceded by a number of damaging foreshocks and the main shock was associated with faulting along a zone about 30 kilometres long. The total number of people killed by this earthquake is well over 2,500. The number of houses destroyed was difficult to assess but at least 19,000 were completely destroyed making homeless over 100,000 people.

The average house in eastern Anatolia is single storey adobe or mud-brick construction. The roof is usually supported by timber beams and it is convered with a thick layer of tamped earth; there are very few other types of construction. With non-traditional building materials, such as reinforced concrete and brick-work, the standard of workmanship is far below average and accounted for the complete collapse of most of the more modern constructions.

Throughout the epicentral region, damage was very erratic. The widely different resistance that the various types of local construction could offer and the damage caused to them by the foreshocks produced a haphazard distribution of damage. The cumulative effects of the foreshocks and of the main shock were almost impossible to separate as houses damaged by the foreshocks collapsed during the main earthquake. Damage was found to bear no relation whatsoever with proximity to the rupture zone.

Within an area of about 5 acres in the town of Varto a complex of reinforced concrete structures designed to resist earthquake forces collapsed completely. Within the same area, hybrid brick masonry structures were damaged, most of them beyond repair while ordinary local houses as well as a 20-metre high chimney suffered absolutely no damage. An inspection of the area showed that the main cause for the collapse of the reinforced concrete structures was dirty and badly graded aggregates. Column-girder junctions contained little concrete as the space between bars was too small to allow the aggregates to pass through and bond the bars. Most of the destroyed structures were built on very shallow footings on made ground, and some of them had suffered some damage prior to the earthquake from excessive differential settlements. During the earthquake footings of the heavier structures were forced to move laterally by as much as 50 centimetres, and heavy walls punched into the ground by 30 centimetres.

Because of the strong foreshocks and the damage they caused, it was found practically impossible to assess the intensity distribution of the main shock. It was found that an intensity VII (MM) or greater will cause such heavy damage to adobe houses that no distinction can be made between heavy damage and complete destruction. Consequently, from the behaviour of this type of construction alone intensities greater than VII cannot be assessed.

For the case of the Varto earthquake, the epicentral intensity, based on vibrational effects did not exceed IX (MM). The use of the (MSK) scale was found to be totally impracticable, (Wallace 1968, Ambraseys and Zatopek 1968).

The Acarnanian earthquake of October 29, 1966, in Greece

This earthquake is in fact a strong aftershock of the Kremasta earthquake of February 5. It caused considerable damage to rural districts that had already been damaged by previous shocks and many villages situated on the plains or near the coast suffered heavy damage caused by slumping of the ground and sliding. The shaking was not severe, and the damage to reinforced concrete houses was negligible. A series of cracks in the ground, about 2 kilometres long associated with slumping of the coast appeared on the beach of Amphilochia. The main road from Athens where it crosses the valley was damaged and a causeway spread laterally disrupting the communications, Figure 6. Houses near the destroyed causeway founded on solid ground, suffered absolutely no damage.

Three SR-100 Wilmot seismoscopes of the National Observatory in Athens installed in Mesolonghi, Agrinion and Lefkas showed response amplitudes of 30, 6 and 9 millimetres respectively. The town of Mesolonghi is built on very soft deposits near the coast about 60 kilometres south-southeast of the epicentral area, and the shock was felt there with an intensity which did no exceed V(MM). Agrinion is situated in a valley about 40 kilometres southeas of the epicentral area and the intensity there was perhaps less than V (MM). In Lefkas, which is 30 kilometres west of the epicentre, the intensity was only IV (MM). No explanation can be suggested for this anomaly in the response of the seismoscopes.

The Mudurnu Valley earthquake of July 22, 1967 in Turkey

The earthquake of the Mudurnu Valley of July 22, 1967, is but the most recent shock of a series that since 1939 has devastated Anatolia. The earthquake occurred not far from where an earlier shock occurred ten years earlier. The Mudurnu earthquake destroyed about 4,000 houses and killed 86 people. This shock was associated with 80 kilometres of fresh faulting, part of which occurred in a zone ruptured in 1957. The sense of movement along the fault is right lateral with maximum relative displacement of 190 centimetres, and a throw to the north of 120 centimetres.

Almost all houses in the epicentral zone are of timber frame construction with light timber walls, infilled with clay and straw, adobe, or covered with wood sheathing. There are few adobe unbraced houses and these were totally destroyed; nearby timber frame houses suffered very little damage.

The ground movements in the fault zone were very severe. People and animals were thrown to the ground and cobbles were thrown out of their sockets into the air. Boulders embedded into the ground were jostled and displaced tens of centimetres from their seats. Nevertheless, timber framed houses at some distance from or straddling the fault break were found distorted but still standing. Houses of similar construction next to the fault suffered comparatively little damage, while adobe, wherever found, was totally destroyed. Brick masonry houses suffered various degrees of damage, while elevated barns on stilts 5 to 10 feet high suffered absolutely no damage. There were no reinforced concrete structures in the fault zone nor were there any other important engineering structures.

Structural damage to houses in the fault zone and also further away, was surprisingly small for an earthquake with such extensive surface rupture and large magnitude. Variations in damage were found to be closely related to the quality of the building materials and the method of construction rather than to the proximity of the fault break.

Estimates of intensity in the epicentral region were so variable that isoseismals could not be traced on the map. It was found that proximity to the fault break was an unjustified criterion for higher intensities. Damage in the immediate vicinity of the fault was equal to but more often less than at some distance away, the controlling factors being the stability of the foundations and the type of construction rather than proximity to the fault break, (Ambraseys et al 1967).

The earthquake of Debar of November 30, 1967

This earthquake occurred on the border between Albania and Jugoslavia. A strong foreshock warned the people who had time to flee in the open. Nevertheless, 19 people were killed and 180 wounded. Over 500 houses were destroyed and at least 3,300 were damaged beyond repair on either side of the border. These figures, however, are approximate as it was not possible to visit the epicentral region in Albania.

The average house in Debar is a two storey stone masonry construction with timber bracing and timber roof covered with tiles. The country is mountainous and many villages are situated on steep slopes where numerous slides triggered by the earthquake caused additional damage. Unreinforced masonry accounted for thebulk of the damage. Timber-braced houses with adobe infilled walls suffered less. In Debar, there were only four reinforced concrete skeleton structures which had been designed to resist 6%g laterally; they suffered only minor structural damage. Minor damage was noticed on the abutments of two bridges and on retaining walls. A long crack was also noticed on the upstream slope of the Globocica dam, a rockfill dam about 25 kilometres from the epicentre.

Numerous aftershocks were recorded in Skopje and some of them were strong enough to trigger a SMAC strong motion accelerograph which was installed in Debar immediately after the main shock. One of the strongest aftershocks, on February 2, 1968 at 1345 hours, triggered the instrument which recorded a maximum ground acceleration of 9%g; the corresponding Intensity was V (MM). According to the information supplied by the Seismological Institute of Skopje, the maximum ground acceleration of the main shock was about 40%g. The local Intensity did not exceed VIII (MM), (Hadzievski 1968).

Discussion

The question of a less elusive definition for Intensity has long been of interest to the engineer. The criteria incorporated in intensity scales are obviously open to criticism, but even if they were exact, the estimates of the epicentral intensities of a strong earthquake are so variable that any agreement between two independently assessed Intensities for the same locality suggests more of coincidence rather than a convincing demonstration of the reliability of the Intensity scale used. No two intensity maps of a strong earthquake drawn by two different observers look alike.

The assessment of Intensities for most of the earthquakes discussed earlier led to subjective interpretations of the (MM) or of the (MSK) scales. For the same locality, Intensities assessed by different observers varied by as much as four degrees, depending on the particular criteria of the scale that each observer considered to be most suitable for the occasion. Factors such as the weakening of man-made structures by earlier shocks, the different resistance that rural houses of different construction can offer to lateral loading, the duration of shaking and the manner in which earthquake damage is interpreted by seismologists and other scientists with no training in engineering, make it practically impossible to assess Intensities with any degree of reasonable accuracy. Not only what is damaged by a strong earthquake should be studied but also what is not, and one should distinguish between damage caused by vibrations from that caused through foundation failures. Disregard of the effect of strong foreshock activity to structures has lead systematically to an overestimation of the Intensities of the main shock. The use of fissures and of landslides as criteria that help to determine higher intensities usually add to this overestimate of intensity. Within the epicentral region of a strong earthquake, the writer doubts the existance of isoseismals and the value of intensity for engineering purposes.

From the field study of the ten earthquakes discussed here, it was found that the (MM) scale is inadequate for the description of the vibrational effects on structures and on the ground itself. This scale allows, however, enough flexibility for an experienced observer to use his own judgement and arrive at homogeneous assessments of Intensity. In contrast, the use of the newly proposed (MSK) scale (Sponheuer 1965) was found to be impracticable. This scale makes an effort to distinguish the effects of earthquakes between structures of different resistance, by classifying them into a number of categories. But it is difficult to see how one can ever expect to classify the resistance of structures after they have been damaged, without knowing their pre-earthquake condition, the way in which these structures have been loaded by the earthquake and the duration of shaking. Each structure is a special case and to classify its earthquake resistance in one of the four categories proposed in the (MSK) scale is not only impracticable but it can also be misleading. In short, the ratings in the (MSK) scale are so rigidly defined for criteria which are in reality so variable that the very base of this scale becomes untenable.

The question of changing from the (MM) scale to the (MSK) scale has been raised on a number of occasions, and some of the earthquakes dealt with here have been studied by local seismologists using the (MSK) scale. The writer looked into this problem, and in all cases he assessed epicentral intensities using both scales. He could find no advantages in the (MSK) scale, from either the seismological or the engineering point of view that warrant changing a well established, though unsatisfactory scale.

Thus, Intensity as defined by any of the current scales cannot be assessed rigorously, nor when assessed can it be used for design purposes. In the Mudurnu earthquake, the fact that "objects were thrown into the air and lines of sight and level were distorted" implies an Intensity XII (MM).

Yet, on purely vibrational criteria, which are the criteria needed for dynamic design, the stressing of structures was very low.

A number of empirical conversion formulae have been suggested in the past through which intensity can be converted into acceleration. It is difficult to see how such a loosely defined quantity as Intensity can be related uniquely to say, maximum ground acceleration. Apart from the fact that for design purposes the maximum ground acceleration alone tells us little useful, such a relation should not and cannot be uniquely defined. It is not surprising therefore that accelerations recorded for a particular Intensity range over two orders of magnitude (Ambraseys 1969). The scatter is, as it should be, too large to allow the assumption of any definite quantitative correlation between intensity and acceleration; an observation already made by Hershberger in 1956.

As in the case of the Buyin-Zara earthquake of 1962 (Ambraseys 1963) the Mudurnu Valley earthquake of 1967 showed that proximity to the fault-break was not necessarily associated with heavier damage. This feature was investigated more precisely, in a qualitative way in the following manner. The percentage (D) of the total number of houses destroyed in each village was calculated for the whole epicentral region of the Mudurnu Valley earthquake which covers 7,000 square kilometres. Also the number of villages (N) that suffered damage equal to or greater than (D) was calculated as a percentage of the total number of villages. A damage distribution plot was then constructed, shown in Figure 7, in which the abscissa is the percentage of the villages that suffered damage equal to or greater than (D), while (D) is the corresponding ordinate. Distribution (A) in this Figure refers to the whole epicentral region, while distribution (B) shows the damage distribution within the fault-zone, taken as a zone 4 kilometres wide and about 100 kilometres long following the fault-breaks. On such a plot, a significant increase of damage in the fault-zone, should have lead to much higher values of (N) in the (B)-distribution. Instead, there is a conspicuous similarity between distributions (A) and (B) that shows that the damage in the fault-zone which covers an area of only 400 square kilometres is a representative sample of the whole area and consequently almost independent of its proximity to the fault-break. Thus, proximity to a fault is not a criterion of heavier damage, and the displacements that can be noted on fresh fault-breaks a few hours or days after an earthquake are not necessarily those produced during the earthquake. Observable displacements contain a considerable component due to creep.

As a result of the earthquakes described earlier, the seismic regionalization maps of Jugoslavia and Turkey must be altered considerably. Considering the state of development of instrumental seismology and of its interpretation, these cases show that it is inadequate and perhaps misleading to attempt the assessment of seismicity of a region without due consideration to its earthquake history and tectonics. Moreover, the Kremasta earthquakes show that additional factors must be taken into consideration, such as the reservoir loading and perhaps other types of loading or unloading of the upper crust that may trigger earthquakes. If we assume that earthquakes can be triggered say, by reservoir loading, the available data shows that this is more likely to occur in a relatively quiescent rather than in a seismically active region. Preliminary data from the study of twelve sites where reservoir loading has been shown to be associated with abnormal increase in seismicity show that none of these sites is located in an actively seismic region. For instance, the sites of Marathon and of Kremasta in Greece are located in the least seismic regions of the country. The same applies to Koyna in India, Kariba in Rhodesia, Boulder in the USA, Contra dam in Switzerland, and to a number of other dam sites in Italy and France. In contrast, reservoir areas in seismic regions, such as for instance the Benmore site in New Zealand and other sites in Japan, Pakistan and India, have shown no conspicuous increase of seismicity with impounding. This suggests that the stress changes required to trigger an earthquake in an actively seismic region should be greater than those needed to trigger a shock in a quiescent region. It seems that the stress changes that are brought about by frequest past earthquakes in a seismic region are larger than those associated with reservoir impounding.

The use of microtremor data for regionalisation purposes has been used in a number of cases in the Soviet Union, in Japan and in Jugoslavia. The value of the microtremor work for the delineation of regions where strong ground movements may be expected during future earthquakes, is questionable. Strong ground movements can be transmitted to structures only through strong ground. As the shear strength of a foundation material decreases so does its capacity to transmit intense ground movements. It is not difficult to show that the amount of kinetic energy per unit time per unit area that can be transmitted in shear through a real foundation material to a structure standing on it decreases with decreasing strength of the material. This implies that damage due to vibrational effects should be smaller to structures on very poor foundation materials. There is evidence to show that where structures on such materials were damaged, the damage was almost entirely due to foundation failure, ground settlements and distortions. In Niigata, it appears that little, if any, of the damage to buildings was the direct result of the earthquake shock. In many instances little or no structural damage to houses occurred in the Peloponnesus as the direct result of the earthquake shocks of 1965 and 1966; most of the damage was due to differential settlements aggravated by the shocks that followed. Such damage as did occur in Varto , appears to be the result of the failure of ground support, rather than of severe shaking. Overall damage to structures on very poor ground may be heavier not because shaking is more severe but because of secondary effects associated with excessive settlement, slumping, tilting or even liquefaction. It is rather difficult to see how microtremor data can be of use to predict vibrational damage. Microtremors reflect the behaviour of soil deposits at very low stress levels and extrapolation to stresses corresponding to strong earthquakes is obviously untenable.

Serious exception could also be taken with empirical formulae connecting elastic properties of foundation materials and other quantities such as Intensity. One of these formulae is due to Medvedev (1962). The formula

$$\Delta I = 1.67 \log (P_{o}\rho_{o} / P_{n}\rho_{n}) + \exp [-0.04\, h^{2}]$$

gives the increase in intensity ΔI as a function of the P-wave velocities P_o and P_n in the bedrock and overburden respectively and the depth of the ground water table, h. This formula has been derived from the change of momentum in the bedrock and overburden due to compressional impulses assuming perfectly elastic behaviour of the two materials. In deriving this formula the effect of shear has been disregarded and the formula does not take into account the fact that for higher intensities the use of elastic theory for soils is not justifiable. Thus, this formula cannot distinguish between the effects of shaking on a loose saturated sand deposit on the verge of liquefaction and on a stiff clay. In the case of the Skopje earthquake of 1963 the intensity changes that can be predicted by this formula fall short of the actual conditions.

The engineer has adopted ideas and methods used by the seismologist who rarely deals with strong motion problems and for whom linear theory solutions are adequate. During strong earthquakes very few structures and foundation materials will behave elastically and the fitting of linear theory to non-elastic models may lead to unrealistic results. In conclusion, it can be said that we need more research and more instrumental data and less attempts at standardising intensity scales or at producing new empirical formulae. It is not so much that the (MM) scale is unsatisfactory or that formulae connecting various earthquake quantities are inadequate, but rather that we have not as yet formulated the problem we want to solve for real materials and real strong earthquake conditions.

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TABLE I

	Date	Hour	Epicentre	M	I	h	A	DD	D	K	W
1	1965 Mar. 9	1757	39.1-24.0	6.2	(VII)	-	30	170	1,000	1	2
2	1965 Mar. 31	0947	38.4-22.2	6.8	VII+	100	60	100	900	6	17
3	1965 Apr. 5	0312	37.4-21.9	6.0	VIII	34(11)	30	6,100	13,000	20	160
4	1965 Jul. 6	0318	38.4-22.3	6.6	VIII	50	50	70	1,000	1	6
5	1966 Feb. 5	0201	39.1-21.6	6.1	VIII	15	17	480	1,200	1	60
6	1966 Aug. 19	1222	39.2-41.6	6.8	IX	50(10)	30	19,000	5,500	2,500	1,400
7	1966 Sep. 1	1422	37.4-22.1	5.5	VIII	17(10)	25	180	1,500	0	25
8	1966 Oct. 29	0239	28.8-21.0	5.8	VII	20	8	25	1,000	1	43
9	1967 Jul. 22	1656	40.6-31.0	7.1	(IX)	10	45	4,000	2,400	86	330
10	1967 Nov. 30	0723	41.5-20.5	6.4	IX	25(10)	20	500	3,300	19	180

M = Magnitude
I = Epicentral Instensity (MM)
h = Focal depth in km; (h) = macroseismic depth in km.
A = Area of perceptibility in 10,000 km^2
DD = Number of houses destroyed
D = Number of houses damaged
K = Number of people killed
W = Number of people wounded.

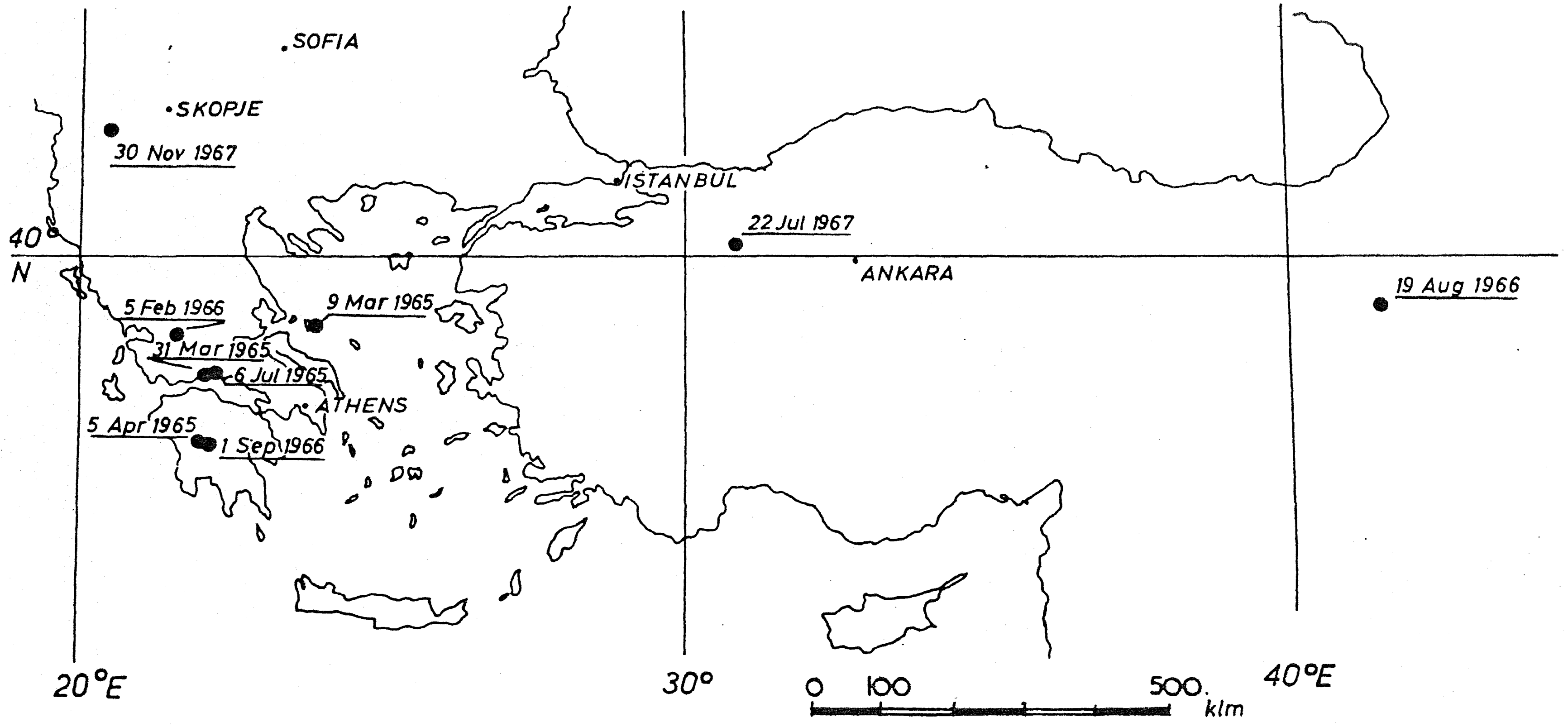

Figure 1. Area map.

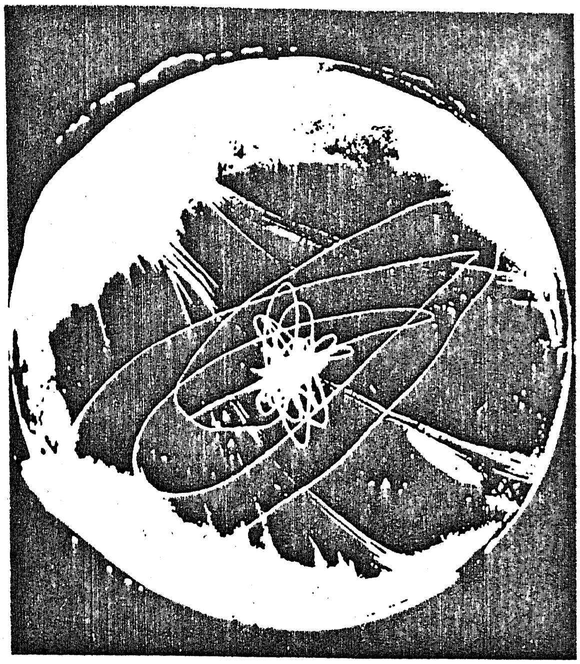

Figure 2. Megalopolis seismoscope record for the earthquake of September 1, 1966.
(Up on sheet is north from station)

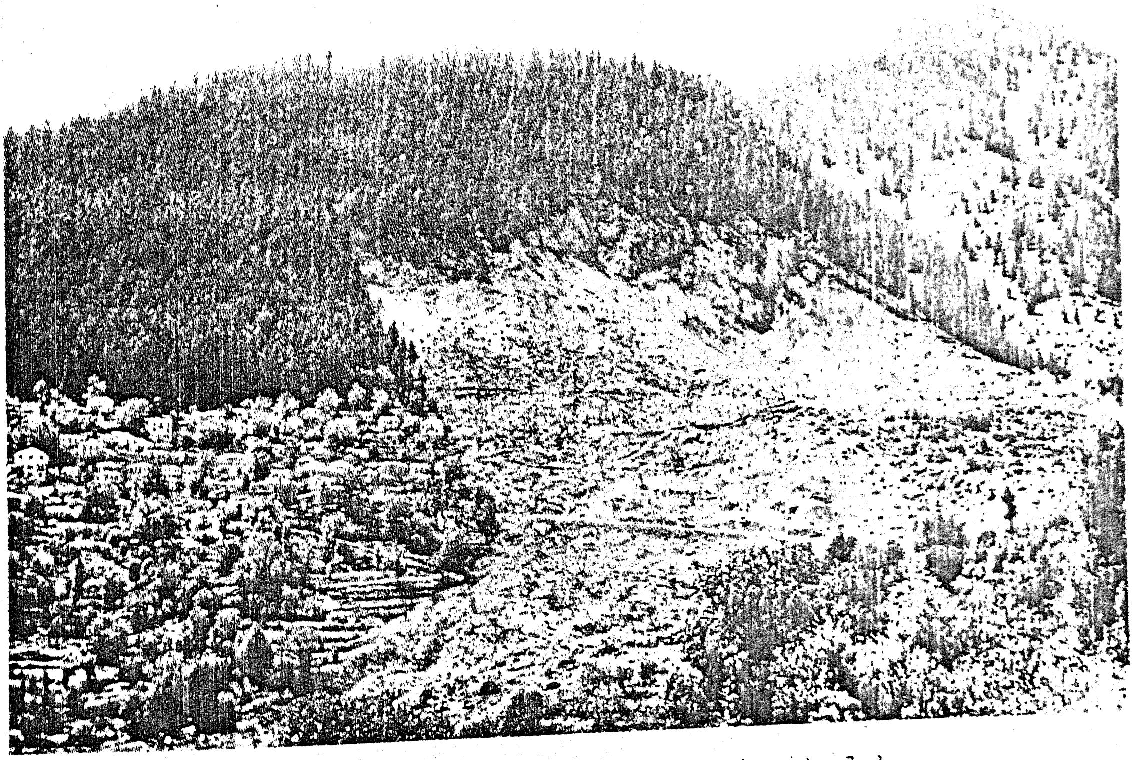

Figure 3. Slide at Mikron Khorion, east of Kremasta lake.

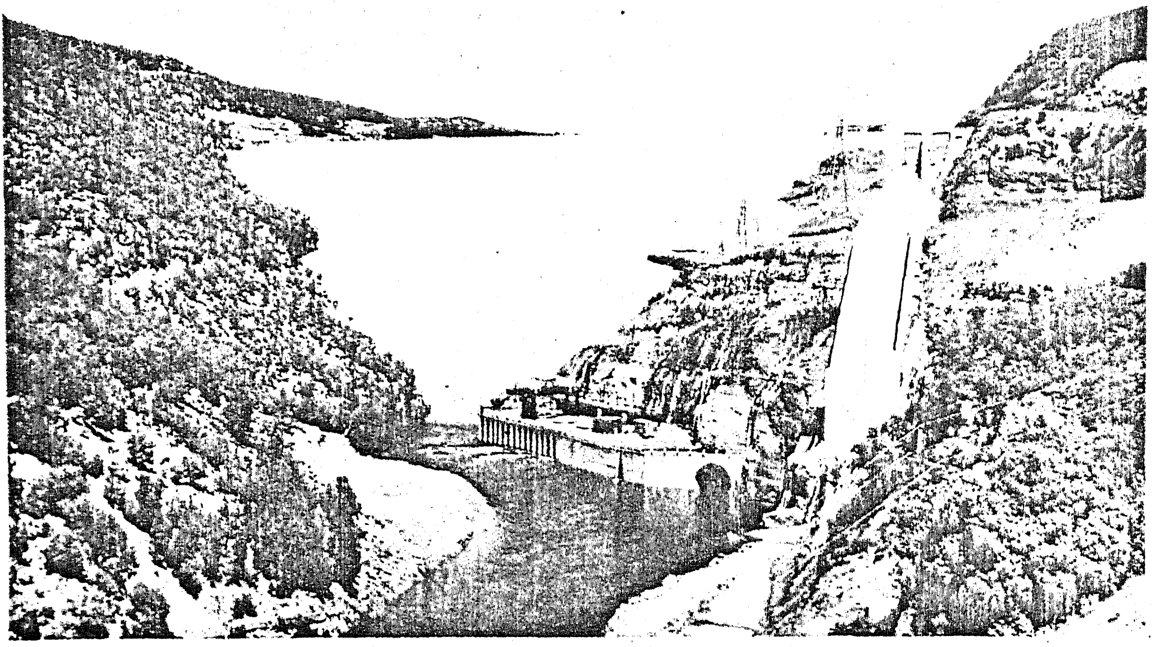

Figure 4. View of Kremasta dam; leakage on left abutment over power house.

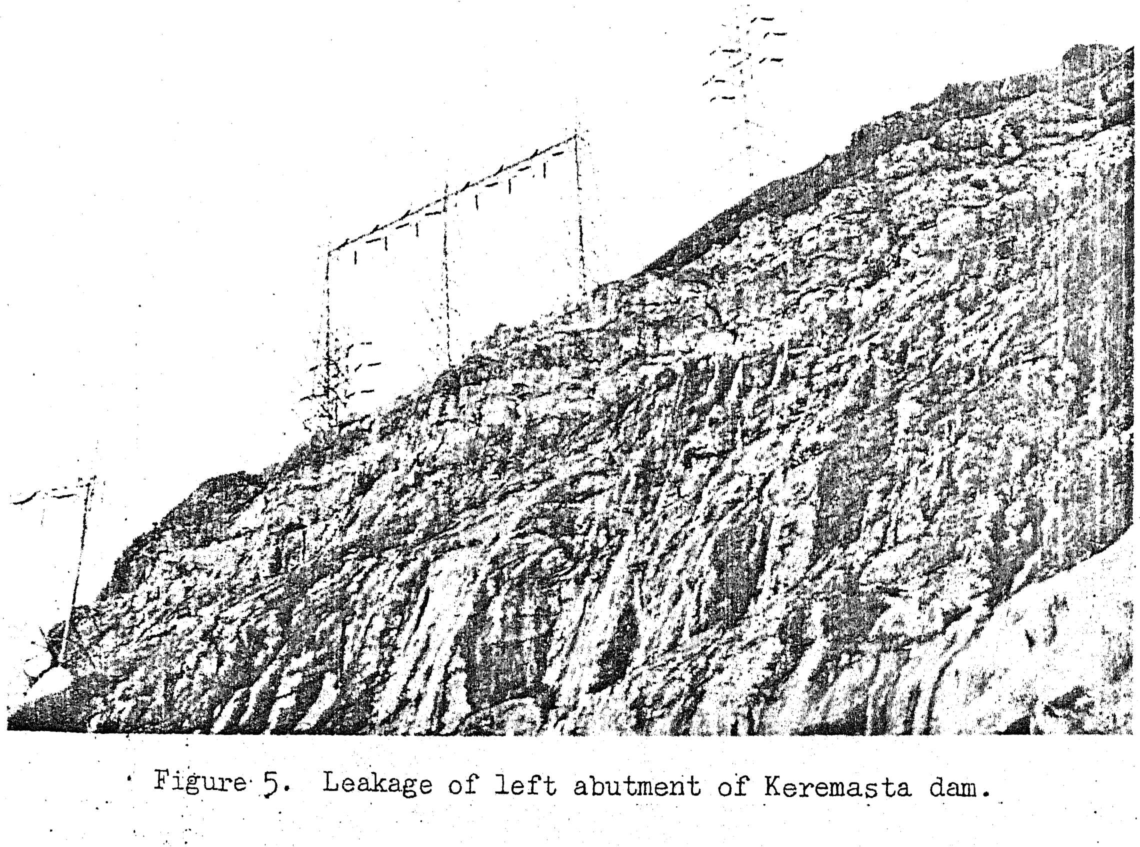

Figure 5. Leakage of left abutment of Keremasta dam.

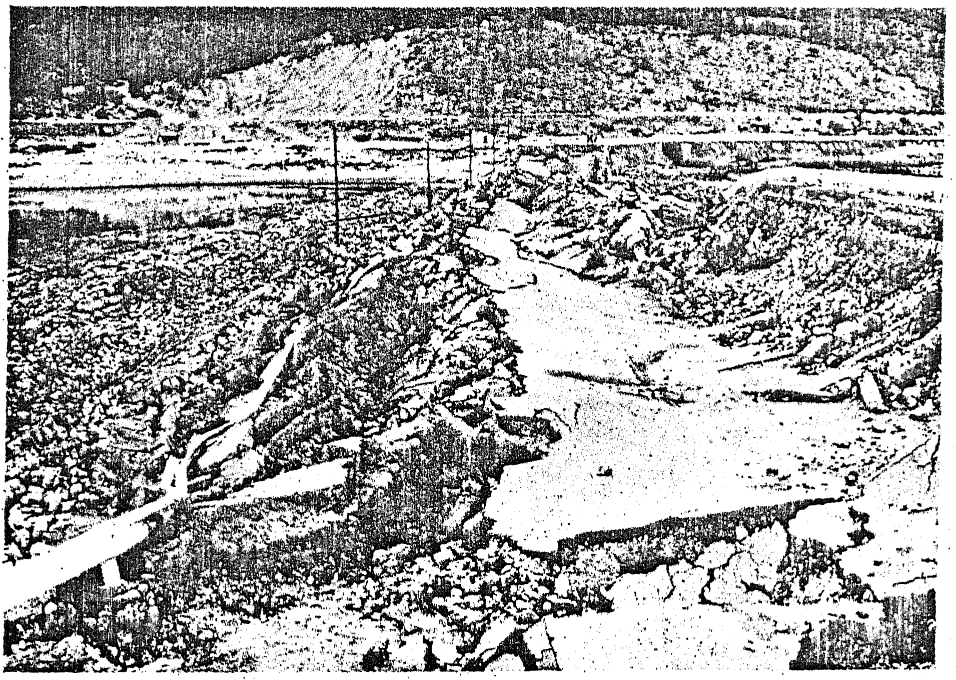

Figure 6. Slumping of causeway near Amphilochia.

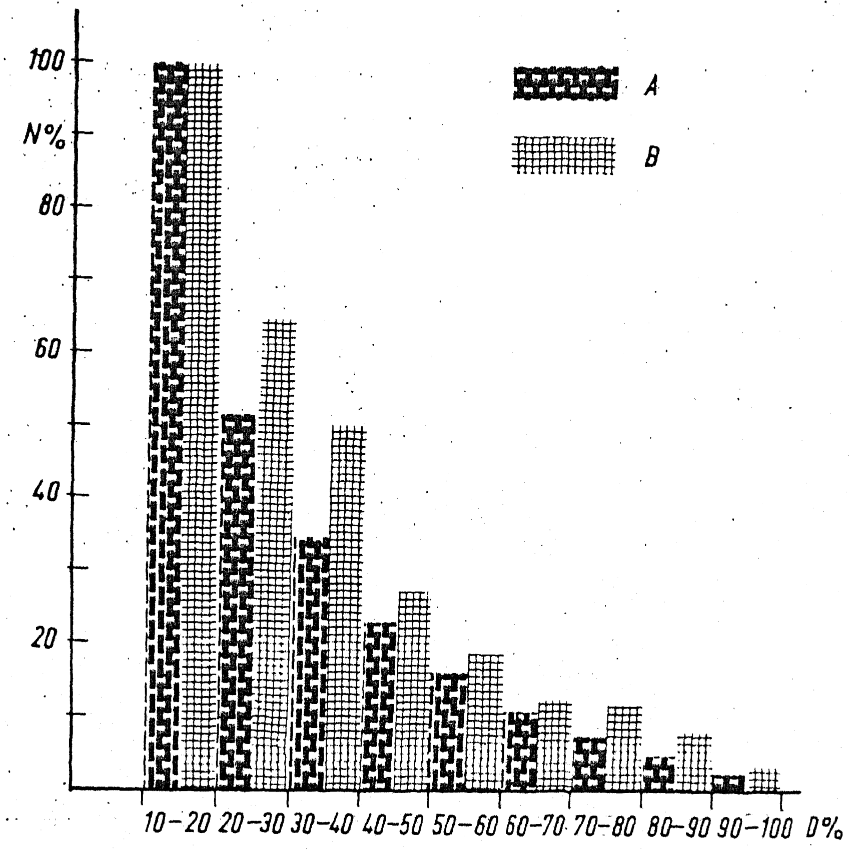

Figure 7. Damage distribution, Mudurnu Valley earthquake 1967