AN EARTHQUAKE ENGINEERING VIEWPOINT OF THE SKOPJE EARTHQUAKE 26th JULY, 1963.

BY N.N. AMBRASEYS *

General Characteristics of the Skopje Earthquake.

The Skopje valley has a rather long history of minor seismicity with a number of damaging local earthquakes. The earliest earthquake, in 518 AD, caused considerable damage to Skupi (old Skopje) and perhaps accounted for its desertion in 519 AD. The accounts of this earthquake are rather confused and in all probability grossly exaggerated (4). In 1555 another earthquake shook Skopje with some damage. Strong earthquakes occurred in 1890 and 1921 as well.

In spite of the fact that the early seismic history of the Skopje valley is not very well known, the available information shows that extremely shallow earthquakes of medium magnitude (5 - 6½) were common.

On July 26, at 0517 time, (local), North Macedonia was shaken by a severe earthquake. It killed 1,070 and injured over 3,000 people. The shock destroyed or damaged beyond repair 40% of the houses in Skopje and about 2% of the houses in the neighbouring settlements (Table 1).

The characteristics of the main shock are summarised on Table II. Many accounts of the effects of the earthquake have been published in a number of papers and reports. Those that have come to my attention are given in the Appendix.

The earthquake was felt with an intensity equal to, or greater than III on the Modified Mercalli Intensity Scale (MM) over an area of about 50,000 square miles. The maximum intensity of the shock, assessed on a statistical basis by the writer, did not exceed IX (MM).

The Skopje earthquake was a medium magnitude (M=6) surface shock of the kind that in a sparsely populated region might have caused little concern. Unfortunately, it occurred in a densely populated area and it had appalling consequences. It literally destroyed more than 30% of the houses in Skopje without causing their collapse. From the ground, some distance away, or from the air, it was practically impossible to detect any damage to the city.

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Like the Agadir earthquake of 1960, the unique characteristics of the Skopje earthquake was the extreme localisation of destruction which was concentrated within an area of not more than 5 km^2, typical feature of a shallow, medium magnitude shock that happened to occur very close to a city; most of this area was occupied by Skopje. As a matter of fact, the effects of the earthquake could not be seen for a radius of more than four miles around the city.

There is little doubt that the destructive movement of the ground was, ror all practical purposes, of a shock type directed in most cases from ESE to WNW, and that this was confined within a limited area which included the largest part of Skopje. So far, the results of the field studies show that the predominant ground acceleration, on the average, was very high and of a very brief duration. Preliminary results show ground accelerations of about 30% which lasted not more than 1/3 of a second.

The destructive part of the ground motion being very violent but of very short duration, subsided before there was time to produce total collapse of the majority of the damaged structures which, after the earthquake, whose total duration did not exceed 5 seconds, were left shattered on the verge of collapse but still standing. It may be argued perhaps that a building left standing on the verge of collapse does not necessarily mean a shaking of short duration, since it takes different amounts of time to shake down buildings of different types. But in Skopje we have the case of more than 1,000 buildings of widely different types, which were shattered and brought on the verge of collapse, and even weaker ones, were left standing.

A careful, but no exhaustive search in the epicentral region did not disclose any definite case of faulting. It is questionable whether the existence of fissures in alluvial ground in a number of places in the city, as well as some kilometres north and northeast of Skopje, provided evidence of faulting.

Water spouts, fissuring and minor land-slides were noticed in some places but these were confined within area where, either the water table was very near the surface or where artesian pressures were known to exist.

The foundation strata in Skopje consist of alluvial deposits underlain by marls. The alluvium is generally gravel with sand and silts, and it is very well compacted. With a very few exceptions, Skopje had no foundation problems, its superficial geology being, for all practical purposes quite uniform. The thickness of the alluvium within the limits of the city varies from a few feet to hundreds of feet, in some areas the gradients being very steep. The ground water level is about 6 to 30 feet below the surface and it varies seasonally, responding quickly to river fluctuations.

The analysis of the available seismological, geotectonic and damage data suggests that during the earthquake the city with its surroundings underwent a sudden mass movement, perhaps of considerable irreversible displacement, and that the destruction was brought about by a sudden re-adjustment of a number of tectonic blocks of the mosaic structure of the Vardar zone on a part of which Skopje stands. Apparently, a number of blocks underwent a tilting to the NNE and a simultaneous abrupt sliding to the northwest. Neighbouring blocks slid to other directions.

I believe that the greatest part of the released seismic energy was spent in displacements of the ground in a powerful unidirectional shock of extremely brief duration. While it cannot be said that subsequent oscillatory movements of the ground were of no consequence, it remains true that these, so far as severe damage is concerned, were of secondary importance. Also minor movements of the ground in other directions accompanying the destructive part of the shock are not precluded. Since the damaging part of the ground movements was not a sustained oscillatory one, but a short pulse, its brief duration did not allow damping in structures to become fully effective. This type of ground movement produced striking anomalies; what one would expect to see damaged remained, when another was destroyed.

Tall reinforced concrete skeleton structures, modern engineering constructions such as factories, mills, bridges, dams, underground installations, highway embankments, railways, all of which had not been designed to resist earthquake forces, but had been well designed and constructed for normal operation conditions, suffered little damage. Two concrete dams near Skopje suffered absolutely no damage.

A few pipes of the water distribution system in the city and some underground telephone cables were damaged by the fallen buildings or by heavy debris. In other places only slight leaks were found, and in one place only a subsidiary main water pipe was damaged by the relative movement of its supporting structure where it crossed a ravine.

Buildings in Skopje may be divided into four categories: Old adobe construction with or without timber bracing. Load bearing brick wall construction supporting reinforced concrete or wood floors supported partly by masonry walls and partly by reinforced concrete columns and beams. Reinforced concrete skeleton buildings with and without concrete shear walls. There was also one roof structure of prestressed concrete and a few isolated cases where use of prefabricated prestressed or ordinary elements was made. There were no steel skeleton buildings in the city of any sort, with the exception of the new steel mill in the outskirts of Skopje.

Brick wall structures suffered more than any other type and accounted for the larger number of deaths. Mixed construction suffered considerably and although many of these buildings did not collapse they were left completely shattered, beyond repair. Old adobe construction, particularly those with timber bracing, resisted the shock with some damage but behaved far better than the brick or the hybrid construction. Reinforced concrete skeleton structures suffered comparatively little damage and only two small structures of this type collapsed. Perhaps, tall skeleton structures, up to 15 storeys, performed far better because they were flexible but also because, being important engineering undertakings in SR Macedonia they were constructed with more care and in some cases wind forces were considered in the design. Finally, the prestressed construction was totally destroyed after its supporting columns collapsed. The steel mill, which at the time was under construction, suffered only minor damage.

In general, the subsoil conditions at Skopje are adequate and cannot be held responsible for the damage that the city suffered. Also, the design of modern structures, with the exception of the brick wall bearing houses, was in general adequate, although in some cases little undersigned and with considerable improper detailing. What was detrimental is that these modern methods of design were not followed up by equally advanced methods of construction and materials. The extremely variable quality in the building materials and in the methods of construction were found to be more important than the lack of earthquake resistant design. Considering that structures were designed for static conditions and that the building materials and the methods of construction were admittedly below average reinforced skeleton buildings performed rather well.

There is an interesting point that emerged from the study of the distribution of damage in Skopje, though not as yet fully explained. The area of the most severe damage correlates surprisingly well with the part of the city that was flooded in November 1962, just nine months before the earthquakes. A number of plausible explanations for the observed correlation have been suggested (2,4,5,6).

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TABLE I

Damage	Flats %		Net Area%		Per Capital %
Structural collapse	8.2	....	7.0	....	8.5
Heavily damaged (condemned)	33.6	....	29.9	....	36.4
Damaged (repairable)	36.6	....	39.9	....	30.6
Slightly damaged	19.0	....	19.8	....	20.3
Not damaged	2.6	....	3.4	....	4.2

TABLE II

Date	: 26 July, 1963.
Origin Time	: 041711 (GMT)
Epicentre Microseismic	: 42 00.5'N – 21° 27.3'E
Macroseismic	: 42 10 N – 21° 26' E
Magnitude	: 6.0
Focal depth	: 4 km ± 2km
Epicentral Intensity	: VIII – IX
Area of Max. Intensity	: 30 km^2

PLATES AND FIGURES

PLATE 1: Building opposite Post Office, Zeleznicha Street. Ground floor sheared, columns leaning to the vertical; upper floors slightly damaged. Torsional effects observed at ground floor. Arrow indicates direction of ground movement. Building structurally condemned. Plates (1a) - (1e): Details of same building.

PLATE 2: Mladic Klub (under construction). Partition wall with concrete tie-beam on concrete floor sheared along second course of brick-work; displaced along longitudinal axis by 2.5" (d). Arrow shows direction of shock (N70W).

PLATE 3: Guro Djakovich Str. One of the load-bearing brick-wall buildings that had only their ground floor destroyed and crushed reducing the height by one floor. Note similar cases in Agadir.

PLATE 4: Mladic Klub. Partition wall of hollow bricks orientated E-W sheared along first course of brick-work which was partly crushed (cde); second line of failure just below tie-beam (ab). Perpendicular wall leaning. Arrow indicates direction of ground movement. Walls rest on concrete floor.

PLATE 5: New Town Hotel (under construction) opposite Mladic Klub. Another partition wall sheared along its base. Concrete tie beam acting like battering ram damaged column on the other side of the wall.

PLATE 5a: Another brick wallsheared along (abcde) at the Youth Hostel. The acceleration of the concrete floor in this case should have been very high with a considerable vertical (downwards) component.

PLATE 6: A pair of rigid-flexible houses overlooking Tourist Hotel. Plastic joints developed in columns (circles). No sign of pounding; tiles that fell into the gap were not crushed. Upper storeys of skeleton building slightly damaged.

PLATE 7: Karposh district. Eastmost part of brick-wall blocks of flats destroyed. Chimneys (c) fell to the east.

PLATE 8: Six-storey building on Zeleznicha Street, (looking up). Shear combined with torsion.

PLATE 9: Karposh district. (Kula Brj. 1). 15-storey reinforced concrete skeleton building with central concrete core designed to withstand wind forces suffered minor damage.

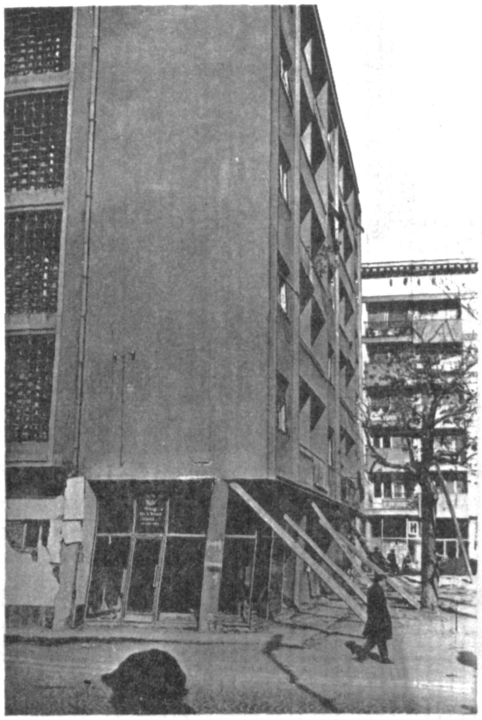


PLATE 1

PLATE 1A

PLATE 1B

PLATE 1C

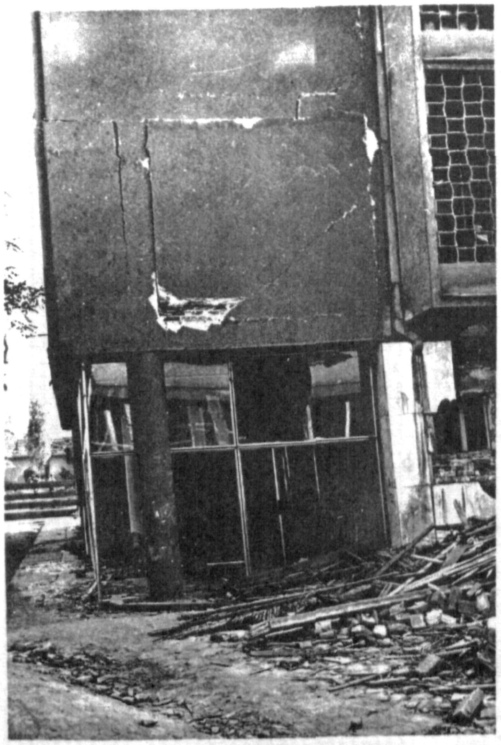


PLATE 1D

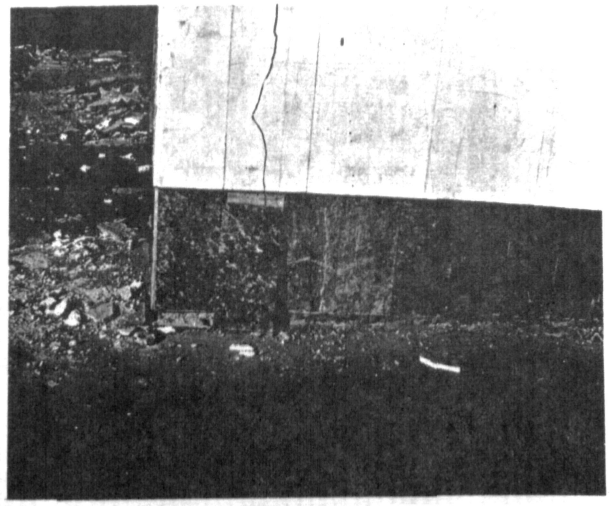
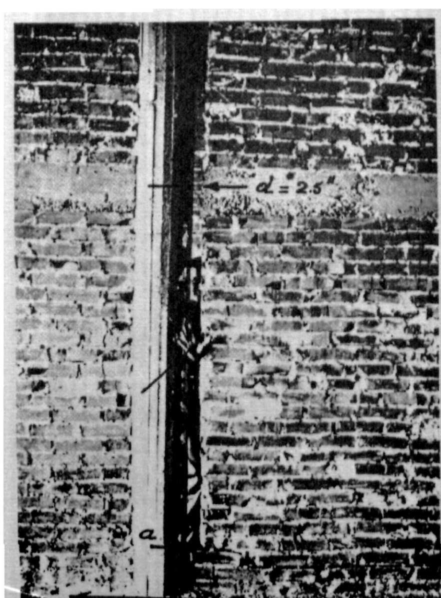
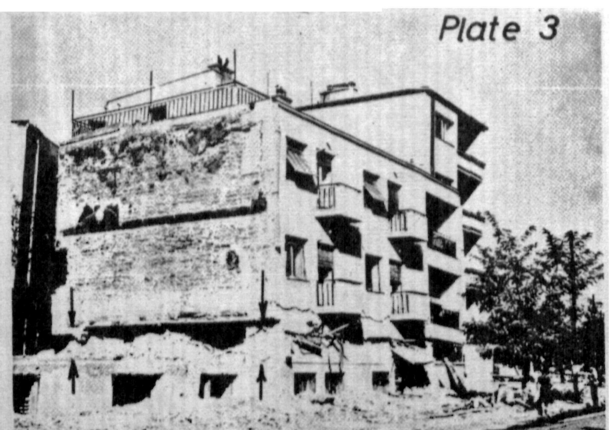


PLATE 1E





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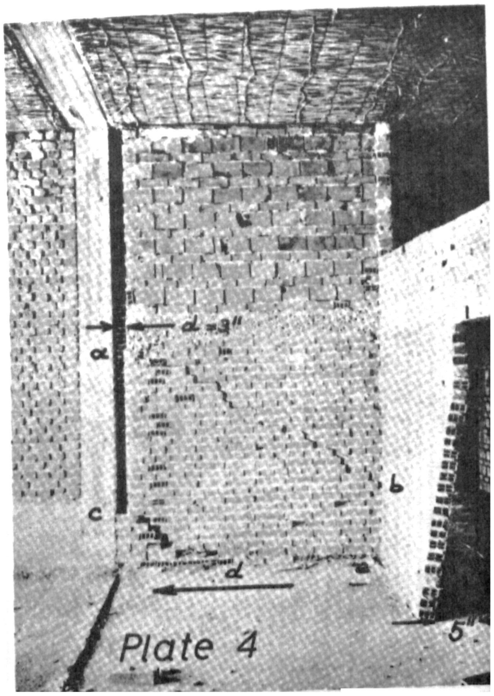

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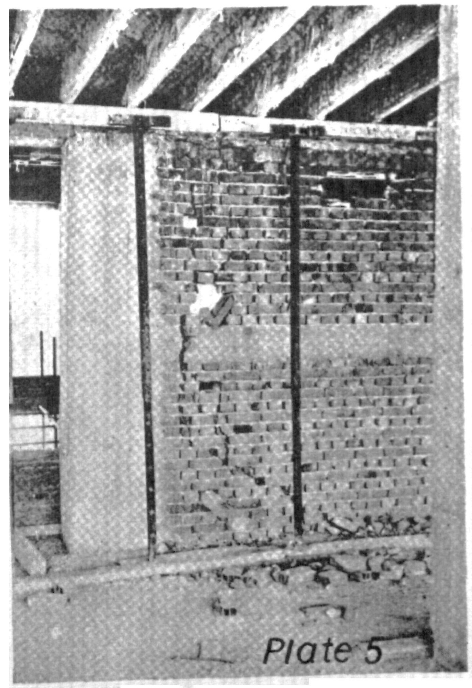
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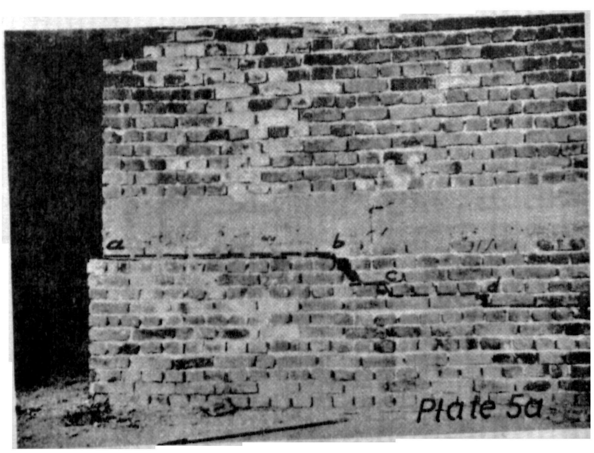

Plate 5a

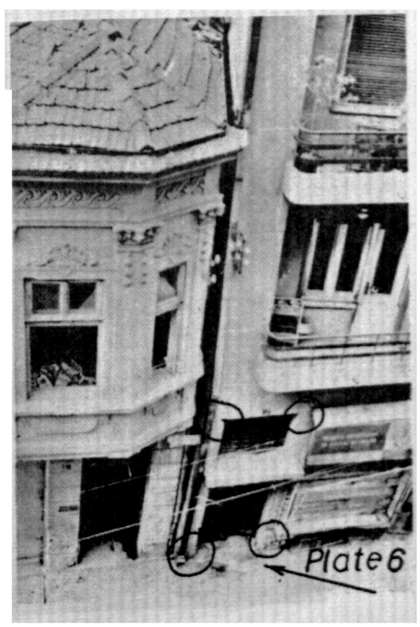
Plate 6

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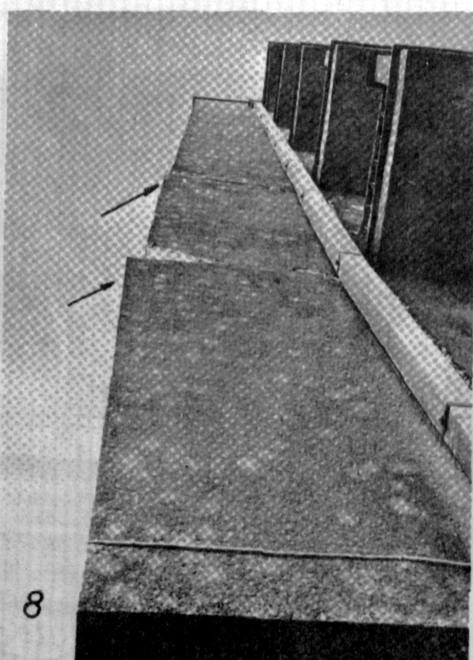
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AN EARTHQUAKE ENGINEERING VIEWPOINT OF THE SKOPJE EARTHQUAKE

26th JULY, 1963

BY N.N. AMBRASEYS

QUESTION BY: G.V. BERG - U.S.A.

Mr. Ambraseys mentioned the focal depth of the Skopje earthquake as determined by instrument being 25 km and as determined by damage observations being 4 km. What accuracy would Mr. Ambraseys attribute to the latter figure?

AUTHOR'S REPLY: The microseismic focal depth of the Skopje Earthquake determined by the USCGS was 33 km. This value is nominal, merely indicating that the focus was located in the upper crust. It is of interest to note that both Strasbourg and Moscow calculated the focal depth to be zero kilometres.

The focal depth of 4 km $\pm$ 2 km that I determined on the basis of macroseismic data using Kövesligethy's method agreed very well with the values obtained from Gassman's and Sponheuer's methods, with which the seismologist is very well acquainted.

Professor Berg asks what accuracy I would attribute to this figure. Instead of answering his question I would like to remark that the definition of the focus as a point, and its distance from the ground surface as the focal depth, includes a vagueness with respect to the actual dimensions of the fracture. The focal depth I obtained for Skopje shows that the earthquake involved somewhat deeper structures than the Agadir Earthquake, and much shallower structures than the Iran Earthquake. Such macroseismic determinations of the focal depth are of value mainly for comparative studies.

QUESTION BY: N.M. NEWMARK - U.S.A.

The velocity consistent with Dr. Ambraseys' estimate of 0.45 *g* and 1/3 sec. duration with $\frac{1}{2}$ sine wave pulse shape corresponds to about 4 to 5ft./sec. velocity, which seems extremely large. The basis of the estimate requires detailed examination. Has this basis been published or will it be available?

AUTHOR'S REPLY: My estimate of 0.45 g and 1/3 sec. duration refers to the extreme values of the ground acceleration and of the duration of the shocks, respectively. These values do not refer to the same pulse.

The average pulse calculated from the distortion of a small number of simple structures was found to give velocities between 1.5 - 2.0 ft./sec.

For instance, preliminary results for the structure shown on the following four figures gave v = 1.7 ft./sec.

The analysis was based on the response to a simple ground pulse of a one-degree of freedom oscillator with a non-linear restoring element.

Structures with flexible ground storeys distorted excessively by the shock wave chosen for the analysis and their equivalent restoring element was calculated on the basis of their actual dimensions and strength properties. These structures usually suffered no damage above the first floor level, and the response of a number of objects in the 1st and 2nd floors was incorporated in the response analysis.

A detailed account of the analysis will be published at a latter date, though to those interested I would be pleased to communicate beforehand some of the pertinent facts and results.