Evaluating Seismic Activity in Ethiopia

(A note for Architects and Engineers)

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The parameters used in evaluating the seismicity of a region are (a) the areal distribution of the seismic events, (b) their magnitude, (c) their frequency of occurrence, and (d) their focal depth. From the value of these four parameters, the strain and energy released is computed per unit area, usually per square degree, and then a seismic probability map is constructed from which seismic risks in a given sector can be assessed.

For Ethiopia, at present, a good quantity of instrumental data is available on the magnitude, epicentral distribution and frequency of occurrence of damaging earthquakes which have occurred since the beginning of this century. Sixty years of seismic history is an extremely short period of time and the analysis of these data, often incomplete, certainly does not yield an exhaustive picture of the present seismic conditions of a whole country, since it does not take into consideration the shifting in location of seismic centers with time nor the amplitude of their activity. It is known, for instance, that the western provinces were much more seismically active one century ago than they are today. Despite the short comings of our present knowledge, for engineering purposes one fact is certain: Ethiopia as a whole is a region where seismic activity often exceeds the threshold of damage. It is therefore pressing, in this present period of rapid development, to assess the magnitude of the problem and to take the elementary precautions necessary to minimize damage to lives and property.

Where do earthquakes happen in Ethiopia?

From figure 1 on which are plotted epicenters of earthquakes which could have produced damage within the borders of Ethiopia, it is apparent that most of the country is subject to seismic activity.

The greatest concentration of epicenters is found along the western escarpment of Afar and along the Ethiopian rift. This seismic belt of about 200 km in width runs parallel to the Asmara-Addis Ababa-Moyale highway. During the last century, centers of activity have moved along that zone: in 1842, the activity was located near Ankober and the then-capital of Shoa was completely destroyed (1); in 1853-1854, the epicenters had moved 3^0 to the north and left substantial fissures in the ground near lake Ashangui (2); in 1884, they were located off the coast of Massawa and the city was heavily damaged (3,4,5,6); in 1906, swarms of earthquakes shook the Shoa province at an epicentral distance of 75-100 km from Addis Ababa; (7,8,9); during June-July 1913, the epicenters were located North of Asmara; in 1921, Massawa was completely destroyed (10,11) and the people of Eritrea remember these years as ዘመን ድሌቀሌቀ ; in 1960, an earthquake of magnitude 6.3 hit a few kilometers west of Sheshamane near the dormant volcano Chabbi; in 1961, the seismic activity was centered in Wollo where Majete was 100% destroyed and Kara Kore heavily damaged; in 1964, Dessie was hit. When compared to the rest of Ethiopia, it is estimated that since 1906, about 75% of the total energy has been released along this seismic zone. By an unfortunate coincidence, this seismic belt corresponds to a zone of high population density.

At the latitude of Awash station, where the Ethiopian rift valley meets Afar, (see figure 1), a second seismic belt branches off the first one and crosses the Danakil desert in a NNE direction. This zone follows a line of silicic volcanic centers and reaches the shores of the Red Sea at the latitude of the Dubbi volcanic complex, near Edd. The recent disastrous earthquakes in Aussa, where Sardo is located, happened in this seismic zone.

The south-eastern region of Ethiopia, referred to in geology as the Somali plateau, is much less seismically active. Apart from the series of shocks which occurred in Hararghe in 1953 (12) and caused damage both in Harar and Dire Dawa, no other seismic event has ever been reported. Ogaden seems to be practically inactive.

How large are the earthquakes in Ethiopia?

There are two ways of expressing the "strength" of an earthquake: either by giving the **Magnitude** of the energy-release at the focus, or by indicating the **Intensity** of the damage produced by this release of energy.

Engineers, in general, are used to speaking in terms of damage caused to man-made structures: they refer to intensity scales such as the Mercalli Modified or the Rossi-Forel scales, which they usually identify as the 12-or the 10 grade scales. Since the damage is an effect of acceleration, ground displacement, etc. . . caused by a release of energy at a given focal point or along a fault line, seismologists prefer to speak in terms of quantity of energy or strain released. The scale they use is the Richter energy-scale or Magnitude (M) scale. Knowing the quantity of energy, the depth of the focus, its distance from a given site, the geology of the region, and the soil and sub-soil conditions, it is easier to compute such factors as attenuation of

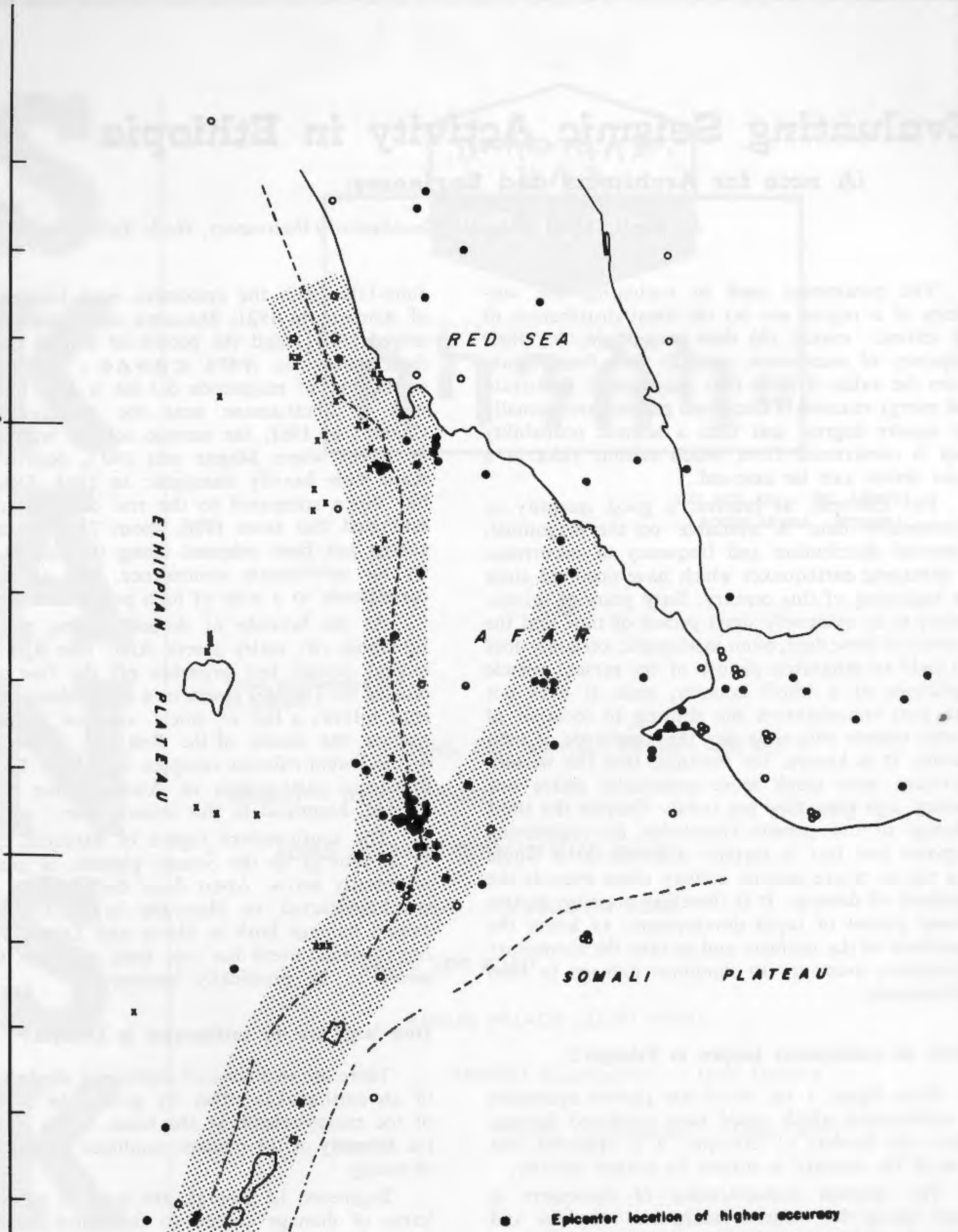

Figure 1. Location of epicenters in Ethiopia and neighbouring regions. The outer margins of Afar and of the Ethiopian rift valley are marked by dotted lines.

energy with distance, dispersion of frequencies, acceleration, earth displacement vectors, that is, all the parameters essential for the assessing of seismic risks at a particular site and therefore forecasting eventual damage to a given type of structure.

The magnitude (M) scale is a quantitative evaluation of the strength of an earthquake, while the intensity (I) scale gives a qualitative estimation of the damage produced, provided that, in the epicentral region, there be "something" to be damaged! Gutenberg and Richter have formulated the quantity of energy released as follows:

$$\mathrm{Log}_{10} E \text{ (ergs)} = a + b M$$

where M is the magnitude of the event, "a" and "b" are constants to be determined for each region. For the total globe, 11.4 and 1.5 are the values used for "a" and "b" respectively. To give an example, a seismic event of $M = 0$ yields 2.5×10^{11} ergs while an event of $M = 8.9$ yields 5.6×10^{24} ergs. The other ratios are distributed logarithmically between these two extremes. The strain release is equal to $E^{1/2}$.

Basing this analysis on instrumental data going back as far as 1906, the estimated maximum magnitude recorded for an event having taken place in Ethiopia is 6.75 Under standard geological conditions, an event of this magnitude occurring at normal depth (30-35 km) would produce at the epicenter, that is, a point on the surface of the earth directly above the focal point, damage of intensity VIII-IX on the Mercalli scale and about IX on the Rossi-Forel scale.

How often do earthquakes happen in Ethiopia?

During seismically quiet years, the Geophysical Observatory has recorded since 1959 an average of 1.5-1.6 seismic events per day originating within a radius of 1000 km from Addis Ababa. Since there is only one seismic station in the country, events happening beyond a maximum epicentral distance corresponding to their magnitude are naturally eliminated from these statistics.

In the years of higher seismic activity, the daily count reached 350 at Addis Ababa in May 1961 (13).In Asmara, between June 6 and July 16, 1913, 141 shocks were recorded on the very low sensitivity equipment temporarily installed in the city (14); 457 shocks were also reported felt at the same place between May and June 1921 when swarms of earthquakes destroyed Massawa (11). Historical documents often report that tremors were felt for months and months and even years, especially in Tigré, after a large earthquake.

All the recorded earth tremors are not necessarily reported felt or destructive. The instruments at present used at the Observatory have a dynamic amplication factor of x50K at periods of 0.8-0.9 seconds; this would mean that 95% at least of the tremors recorded are not reported felt. The recording of such micro-seismic activity would be of primary importance in mapping the active fault-zones in Ethiopia if the location of each individual event could be accurately pinpointed. With one station, an accurate epicentral distance can be calculated but the determination of an accurate azimuth requires a minimum of a tripartite array, a network that we do not have at the moment,.

The analysis of the frequency of earthquakes as a function of their magnitude gives for Ethiopia the following mean statistic ratios:

Table I

ESTIMATED FREQUENCY OF EVENTS ABOVE A GIVEN M_0» 4.5

Magnitude M_0	Nnmber of events per year
6.5	0.165
6.0	0.4
5.5	1.1
5.0	2.8
4.5	6

These figures are valid for Ethiopia as a whole and for a period of sixty years. The values to be attributed to different sectors of the country are still to be computed.

How deep are the foci in Ethiopia?

In estimating the seismic risks, the focal depth of a shock is important since it is a primary factor controlling the energy radiation pattern. A good example of the importance of focal depth to the degree of damage for shocks of similar magnitudes are the result of earthquakes of Kara Kore and Sardo. During the Kara Kore quakes of 1961 damage was observed as far as 250 km from the epicentral region: among other instances, in Addis Ababa partition walls of a well designed modern building were detached from their reinforced concrete frame. The focal depth of the Kara Kore quakes reached 57 kilometers. In Sardo, this year, damage was extremely heavy but restricted to very small areas: the village of Sardo and a particular fault-line. The only damage to houses outside of Sardo was the collapse of an an adobe brick house in Dubti, about 40 km away. Most of the shocks had a focal depth of 4-5 kilometers only. The smaller the focal depth, the higher the absorption of radiated energy with distance, the higher the damage in a restricted zone near the epicenter.

All earthquakes happening in Ethiopia are classified as "shallow"; the focal depths range between 4 and 60 kilometers.

What causes earthquakes in Ethiopia?

There are two types of shallow earthquakes: tectonic and volcanic. By an earthquake of tectonic origin is meant a release of energy due to the readjustment of forces within the earth's crust or the upper mantle. Earth tremors of volcanic origin are those which often accompany volcanic eruptions.

In Ethiopia, there are some active and some dormant volcanoes, most of them in the Danakil desert. Historical documents narrate volcanic eruptions accompanied by destructive earth tremors: for instacne, in 1628 during the eruption of a certain volcano Waraba, in Aussa, the tremors destroyed a nearby village presumably killing 50 people (15); in May 1861, during the eruption of the Dubbi volcano, over 100 people were killed (4, 16, 17).

Most of the earthquakes, in Ethiopia, however, are of tectonic origin. It is my personal opinion that those earthquakes along the western escarpment of Afar and those of the rift valley and central Afar are not caused by the same mechanism within the crust of the earth (18). Along the western escarpment of Afar, earthquakes seem to be caused by an isostatic readjustment of the Ethiopian plateau. The gravity surveys conducted by the Observatory show that the Ethiopian highland above 1600-1700 meters (above sea level) is isostatically overcompensated; in other words, the mass of the Ethiopian plateau is held higher up than it should be. The differential force-vector is mainly vertical and reaches the magnitude of -80 milligals at the mean elevation of 2560 meters. The Ethiopian plateau therefore tends to sink relatively to the rest of the country which is isostatically balanced. The weakest zone in the earth's crust along which the isostatic readjustment takes place is the heavily faulted zone along the western escarpment of Afar.

On the contrary, along the axis of the rift and in central Afar, the earthquakes are due to horizontal tension. It is well known that the Arabian peninsula is moving away north-eastward from the African continent. The Red Sea trough widens at an average rate of 1 cm per year while the Gulf of Aden opens at the average rate of 2 cm per year (19). Different mechanisms of crustal plate movement have been suggested to explain such movements. Although, at present, no theory is satisfactory, the fact remains that an opening in the earth's crust cannot develop without causing horizontal tensions in the surrounding regions. In the case of the Red Sea and Gulf of Aden, the line where the tensional readjustments occur seems to be the Wonji Fault belt running axial to the Ethiopian rift and its prolongation through central Afar. The epicentral distribution in the Gulf of Tadjura and at the Western end of the Gulf of Aden also indicates a zone of horizontal tensions.

Conclusion.

History shows that Ethiopia has always suffered from seismic activity. When a country is mostly agricultural, damage due to earthquakes is very low; when the same country modernizes and moves towards industrialization, the common facilities are much more sophisticated and the evaluation of damage from a shock of the same magnitude soars up proportionally. A fracture in the ground across a sandy village path passes unnoticed; the same fracture across a paved city street under which lie electric and telephone wires, water supply and sewage pipes, etc...... causes damage estimated in millions of dollars.

Other countries are in a worst seismic situation than Ethiopia and they live with it. Nowadays there are engineering techniques developed to minimize the damage due to seismic tremors. The initial increase in cost in designing a "seismic shock proof" building might be some 5-10% higher than for an ordinary building; 5-10% at the beginning is much less a price to pay than total destruction.

Constructions in Ethiopia are going up everywhere. It is my sincere hope that our Association of Architects and Engineers will be instrumental in the enforcement by the Ethiopian Government of a security building code to protect civilian lives and property.

Acknowledgment.

This research was fully sponsored by Haile Sellassie I University.

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