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EARTHQUAKE TRIANGLE

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ABSTRACT

The dimensions of the earthquake triangle have been studied in detail using relations involving only one measurable quantity called surface wave magnitude. These relations were derived by the elimination of subjective parameters (intensity and frequency) from known standard empirical relationships for the Horn of Africa and Ethiopian earthquakes. The results show that the foal depth lies in the range $16.41 \leq H_y \leq 41.79$ km representing 100% shallow focus earthquakes. This agrees well with 99% shallow earthquakes original observations made on macroscopic scale as compared to only 44% ($34.28 \leq H_o \leq 469.83$ km) obtained from analysis of teleseismic data carried out by previous investigators.

Keywords: earthquake(s), triangle, magnitude, teleseismic, focus.

INTRODUCTION

Earthquakes are ground motions due to the rupture and sudden movement of earth's crust and mantle. The breaking of the earth's crust results in its snapping into a new position, and in the course of this adjustment, it generates elastic energy or wave transmitted through the earth's crust. The point or area source of emanation of these waves within the earth's interior is called the focus (F). The vertical portion on the earth's surface directly above the focus is the epicenter (E). The separation between the epicenter and the reporting station is known as epicentral distance (Δ). The vertical distance between focus and epicenter is the focal depth (H), and the distance from the focus to station is the focal distance (R). The figure obtained by joining focus, epicenter and station is called earthquake triangle.

There are two useful parameters concerning the size of earthquakes, which are sometimes confused, these being the intensity and the magnitude. The macroseismic intensity of an earthquake in a locality can be measured by the extent to which shaking is perceptible to people, the degree of damage to structures, the deformation on the earth itself and the extent of animal reaction at a site or simply it is the measure of the effects of an earthquake. Thus, the intensity will vary with distance from the epicenter and will depend on local ground conditions. A large earthquake may occur far away from the inhabited areas and therefore cause little apparent damage. Ground conditions and quality of building constructions can have a considerable effect on subjective assessments of damage. The magnitude of an earthquake is related to the amount of energy released by the geological rupture causing it, and is therefore a measure of the absolute size of the earthquake, without reference to distance from epicenter.

Consequently, magnitude is not considered a subjective parameter. A workable definition of magnitude proposed by Richter (1958) as the logarithm to base 10 of the largest displacement of a standard seismograph situated at 100km from the focus.

Magnitude (M) –Intensity (I) relationships are no longer favoured for engineering purposes. A major factor affecting their unreliability is one of the length of the earthquake triangle, the focal depth. Shallow earthquakes, for example, Agadir in Morocco in 1960 with M=5.6 tend to be disproportionately more damaging because of the concentration of energy release and lack of dissipation (Smith, 1988). Therefore, the knowledge of earthquake triangle, in addition to magnitude intensity relationships is believed to prove more useful for the vulnerability of buildings to earthquake damage and to structures with different building standards or simply to create awareness and understanding of earthquakes among the general populace.

Okon et al., (2000) combined empirical relation of Karnick (1961) for European earthquakes and that of Sogade et al., (1994) for Ethiopian earthquakes and obtained a relation for the focal depth of earthquakes in the Horn of Africa and Ethiopia. However, they used the epicentral distance deduced by Sogade et al., (1994), which is dependent on intensity and frequency of events. They obtained frequency by counting the number of events with a certain or

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particular magnitude recorded in a year (Sogade, Yerima, Okon, 1994). The information on the events they considered were not all actually recorded by seismograph but information available to the author (Gouin, 1979) and as a result of counting the number of events per year, the frequency may vary from author to author. In this case, both frequency and intensity are considered subjective. It is worthy to note that the combination of empirical relations in terms of subjective parameters from different regions is not good enough to provide accurate focal depth. Therefore, in this study, relations involving only data from one region were used to derive expressions for calculating epicentral distance and focal depth in terms of surface wave magnitude, a measurable quantity. The results revealed that all the earthquakes (100%) are shallow focus agreeing well with the report of about 99% shallow focus (Gouin, 1979) as opposed to only 44% shallow focus (Okon and Nse, 2000).

Theory

Earthquakes are classified in terms of their depth of focus:

Earthquakes	**Focal depth**
Shallow focus	0-70km
Intermediate focus	70-300km
Deep focus	300-700km

Although the determination of the earthquake focus is not as precise as that of the epicenter on the surface of the earth, the determination of focal depth of an earthquake is of vital importance, for ground shaking may affect a site say a nuclear reactor or dam when the focus is at a depth of 10 rather than say 40 km. Duff (1993) reported that from the focus the intensity expressed in terms of acceleration theoretically decreases outwards inversely as the square of the distance. Thus, to first approximation the earthquake triangle becomes a right-angled triangle in which the focal distance is the hypotenuse as shown below.

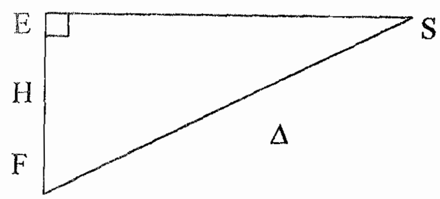

Fig. 1: The earthquake triangle, where all symbols have their usual meanings.

Applying Pythagoras theorem we have,

$$R=[\Delta^2+H^2]^{1/2} \qquad (1)$$

Gouin (1979) studied empirical relations relating earthquake parameters and reported a relation between intensity (I) and acceleration (a) for the Horn of Africa and Ethiopian earthquakes given by

$$I=3\log a+4.5 \qquad (2)$$

and

$$a=\frac{0.69e^{1.64M}}{\Delta^2+1.1e^{1.10M}} \qquad (3)$$

where M is the surface wave magnitude.

The general relation connecting the intensity (I), surface magnitude (M) and focal distance R of an earthquake (Smith, 1988) is given by

$$I=aM+b\log R+c \qquad (4)$$

where a, b and c are constants varying from place to place.

Substituting the expression of a from (3) in (2) and expanding in the of form (4), we have

$$I=4.92M-6\log R-0.48 \qquad (5)$$

where

$$R=[\Delta^2+1.1e^{1.10M}]^{1/2} \qquad (6)$$

$a=4.92$, $b=-6$, $c=-0.48$

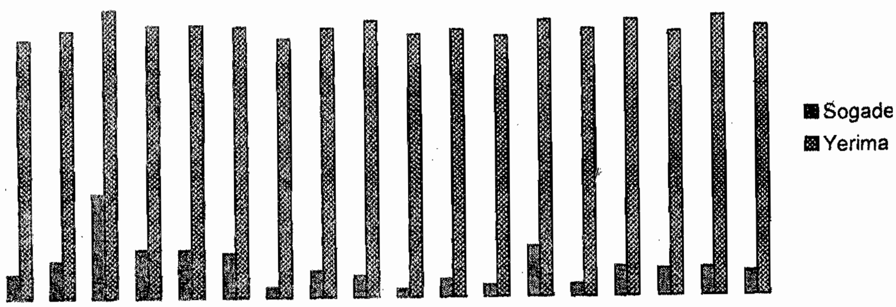

Fig. 2 Sogade and Yerima epicentral distance

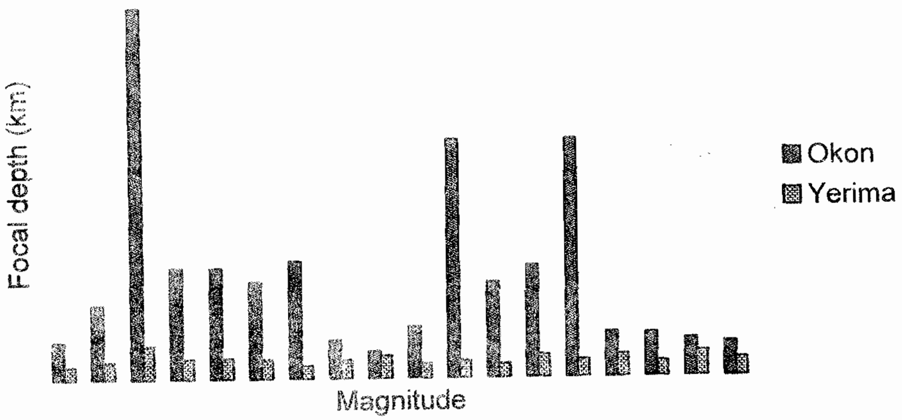

Fig. 3 Okon and Yerima focal depth

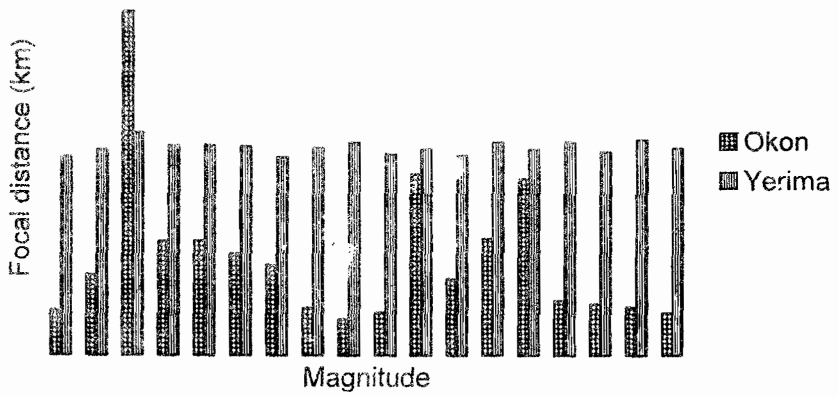

Fig. 4 Okon and Yerima focal distance

Comparing equations (1) and (6) yields

$$H=[1.1e^{1.10M}]^{1/2} \qquad (7)$$

Equation (7) gives the expression for focal depth for the Horn of Africa and Ethiopian earthquakes. Yerima (2000) derived a relationship between the surface wave magnitude (M) and the epicentral distance (Δ) as:

$$\Delta=23.77M+237.74 \qquad (8)$$

The values of R, H and Δ were calculated from (1 or 6), (7) and (8) respectively and the results recorded in Table 1.

RESULTS AND DISCUSSION

The letter S represents the reporting stations in Table 1. The reporting stations are abbreviated after name of author(s)*, acronym applied to agencies or sponsor country (organization). The reporting agencies are: Institute of Physics of the Earth, USSR (MOS), Rothe* a Briton (ROT), adopted epicenter parameters based on information available to the author (ZZZ), U.S. Coast and Geodetic Survey (CGS), Gutenburg* an American (GUT), Strasbourg (STR) and Fairhead and Girdler* joint epicenter determination (JED).

The sides of the earthquake triangle were calculated from empirical relations developed for Ethiopian earthquakes and compared with other values obtained from different methods as contained in table 1. The results show that the focal depth lies in the range $16.41 \leq H_y \leq 41.79$ km representing shallow focus earthquakes, which is in agreement with the report of Gouin (1979). Further, more than 99% of the events considered in this study are shallow focus earthquakes. Okon et al (2000) obtained the focal depth in the range $34.28 \leq H_0 \leq 469.83$ km showing all the three types of earthquake focus. Although Gouin (1979) did not give the numerical value of the focal depth of the events considered, the value he reported in percentage agrees well with the result of this study better than that of Okon et al (2000) and Sogade et al (1994). These discrepancies are illustrated in figures 1-3. The discrepancies may be due to the fact that the other investigators used empirical relations of different regions other

Table 1: Calculated values of the sides of earthquake triangle.

Date	M	Δ_S (km)	Δ_Y (km)	H_O (km)	H_Y (km)	R_O (km)	R_Y (km)	S
29/5/61	5.0	32.79	356.59	46.98	16.41	79.88	356.96	MOS
29/5/61	5.5	50.85	368.48	92.48	21.60	143.33	369.11	MOS
01/6/61	6.7	141.71	397.00	469.83	41.79	611.54	399.19	MOS
02/6/61	5.8	65.89	375.61	138.84	25.47	204.73	376.47	ROT
03/6/61	5.8	65.89	375.61	138.84	25.47	204.73	376.47	ROT
14/6/61	5.7	60.46	373.23	121.26	24.11	181.72	374.01	ZZZ
03/7/64	5.0	14.37	356.59	146.98	16.41	161.35	356.96	CGS
24/10/30	5.6	36.34	370.85	48.08	22.82	84.42	371.55	GUT
06/9/44	6.0	29.73	380.36	34.28	28.44	64.00	381.42	ZZZ
28/5/53	5.2	10.98	361.34	64.48	18.31	75.46	361.80	STR/ZZZ
11/11/62	5.5	24.78	368.48	300.61	21.60	325.39	369.11	ROT
07/6/65	5.1	16.14	358.97	119.67	17.33	135.81	359.39	CGS
29/3/69	6.0	68.32	380.36	139.92	28.44	208.24	381.42	JED
24/5/58	5.5	16.73	368.48	300.61	21.60	317.34	369.11	ROT
20/6/61	6.0	40.52	380.36	56.46	28.44	96.98	381.42	MOS
28/3/73	5.3	36.93	363.72	54.21	19.35	91.14	364.23	CGS
16/9/13	6.2	37.89	385.11	47.83	31.74	85.72	386.42	GUT
25/10/30	5.6	32.56	370.85	43.12	22.82	75.68	371.55	GUT

Key: subscripts y, o and y show respectively Sogade, Okon and Yerima calculated Values; S reporting station.

than those of the Horn of Africa and Ethiopia as well as subjective parameters in evaluating the dimensions of the earthquake triangle. It is believed that this work provides a basis for comparative studies and gives room for improvement, especially when one neglects the first approximation made and takes into account the curvature of the earth. In addition, to buttress this fact, most of the events considered were catastrophic (Gouin, 1979), for example, the village of Majete (N10.5^0, E39.9^0) was completely destroyed, most masonry houses collapsed at Kara Kore (N10.4^0, E39.9^0), rocksides and landslides observed, cracks as wide as 60 cm and as deep as 100-150 cm were opened. Bridges and culverts between kilometer posts 240 and 255 from Addis Ababa were destroyed, etc. due to concentration of energy release and lack of dissipation at shallow depth.

CONCLUSION

This work has provided a simple way of evaluating the dimensions of the earthquake triangle for comparative studies. The replacement of subjective quantities such as frequency and intensity with a quantitative parameter (surface wave magnitude) contributed largely in improving the results. However, there is room for further improvement especially when one thinks of the possibility of eliminating the effect of the curvature of the earth's surface. This method is cheaper and simpler since it does not involve cost of movement, and other inputs required in macroscopic measurements.

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