TOWARDS SEISMIC HAZARD ASSESSMENT OF SUDAN

J. A. Abdalia, Y. E-A. Mohamedzein and A. AbdelWahab

Department of Civil Engineering, University of Khartoum
P. O. Box 321, Khartoum, SUDAN

ABSTRACT

This paper presents seismic hazard assessment of Sudan based on probabilistic approach. A relationship between earthquake magnitude and earthquake frequency is established for each source. The attenuation of intensities is presented as a function of magnitude and epicenteral distance. The paper makes use of historical as well as instrumental earthquake catalogue of Sudan from 700 to 1994. Seismic sources, known rifts and active faults, are modeled and seismic hazard assessment are carried out. The paper shows several seismic hazard maps of Sudan based on probable peak ground acceleration for return periods of 50, 100 and 200 years. Other maps are also shown such as a map showing active faults and earthquake sources and a map showing distribution of epicenters for historical and instrumental earthquakes of Sudan. The results of this study provides design engineers and architects with information about earthquake prone areas and seismic risk potentials. It helps them in determining the design earthquake, in selecting sites for large structural projects and in planning for land use for urban and regional development.

KEYWORD

Seismic hazard; Sudan; East Africa rift; Red Sea; peak ground acceleration.

INTRODUCTION

Sudan is considered a country with a low to moderate seismic activity. However, recent medium to large earthquakes struck different portions of the country. e.g. the May 20, 1990 earthquake of magnitude 7.4 in Southern Sudan (Gaulon 1992), and the August 1, 1993 and November 15, 1993 earthquakes in Northern
Kordofan state with respective magnitudes of 5.5 and 4.3. The seismic activity of Sudan is not limited to these two regions; several other parts of Sudan are seismically active such as the Red Sea Area.

Regardless of the increasing seismic activities in Sudan, most of the existing buildings and infrastructures in Sudan are not designed to resist earthquake loading. In few cases where the earthquake loading were accounted for, arbitrary values were assumed for seismic design parameters. Realistic estimation of these parameters can best be made through evaluation of seismic hazard of Sudan. This is the objective of this study.

**TECTONIC FEATURES OF SUDAN**

Sudan, the largest country in Africa, is located on the northeast portion of the African plate. Figure 1. shows the major rifts in Sudan. Earthquakes in Sudan are associated with:

1. The East African rift with its several branches,
2. Red Sea rift,
3. Central Sudan intraplate region,
4. Seismicity associated with volcanic centers, e.g., volcanic center of Jebel Marra in Western Sudan and
5. Induced-seismicity in Lake Nassir in Southern Egypt.

The East African rift includes the active zone of Southern Sudan and extends northeast into Ethiopia and Afar depression in Eritrea and terminates at the Red Sea rift. Both the East African and Red Sea rifts are considered parts of the Afro-Arabian rifts (Browne and Fairhead 1983, Browne et al. 1985, McKenzie et al. 1970). These two rifts are very active. The intraplate zone of the Central Sudan, an area of about 2000 km2, shows low and scattered seismic activities (Fairhead 1988, Schandelmeier et al. 1990). Tectonic features of the region are not well studied, however, limited results have shown the presence of Abu Gabra rift also known as southern Sudan rift in Western and Southern Sudan and Bara shear zone that covers Central and Northern portions of Kordofan, in addition to White Nile, Blue Nile and Atbara rifts (Grass Files, Browne and Fairhead, 1983). The other sources (Jebel Marra and Lake Nassir) have also shown low seismic activities. The former is associated with volcanic activities and its effect are limited to the Darfur region in Western Sudan. The induced seismicity of Lake Nassir was felt as south as Khartoum (Ambraseys and Adams 1986).

**EARTHQUAKE HISTORY IN SUDAN**

Earthquakes in Sudan and neighboring countries have been reported since 700 (Abraseys et. al. 1994, Fairhead and Stuart 1982). Modern instrumental events were recorded starting in 1964. Two catalogues
were prepared for Sudan. The first attempt was made by (Abraseys and Adams 1986).

In this catalogue data has been extracted from files of the East African Meteorological Department of Tanganyika, Kenya, and Uganda and the Geological Survey Departments of East Africa and Sudan. The second Catalogue is developed in the present study and is based on a recent and comprehensive data gathered by the newly established Eastern and Southern Africa Regional Seismology Working Group (ESARSWG). Data was gathered by this group from different sources, but mainly from the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce (Abdalla et al. 1995). The data covers the period from 700 to 1993 and all the regions of Eastern and Southern Africa, including Sudan.

About 900 events were extracted from ESARSWG Catalogue and they represent events in Sudan and Neighboring countries. The results presents in this paper are based on this catalogue which is considered inclusive of the earlier catalogue prepared by (Abraseys and Adams 1986).
The catalogue was revised for completeness. All magnitudes were converted to local magnitude following the general recommendations of ESARSWG. All felt events whose magnitude was not reported was assigned a magnitude of 4.

**REGIONAL DISTRIBUTION OF EARTHQUAKES**

Figure 2. shows the distribution of epicenters of reported events from 700 to 1993. Eight regions were identified to affect Sudan. The regions included portions of the neighboring countries. Since accurate relationships between faults and rifts and earthquake events in Sudan are not well established, these regions are considered tentative until more accurate relationships are established. The regions selected covered most events in Sudan and those near the borders.

![Map of Africa showing earthquake epicenters](image)

**RECURRENCE MODEL**

Recurrence model for each region was estimated based on the classical Gutenberg-Richter relation, i.e.,

\[
\log N = a - bM
\]  
(1)
The parameters \( a \) and \( b \) for each region were determined using least square techniques. The values of these parameters are generally within the values obtained for some portions of East Africa. The values of "\( a \)" found to range from 3.10 to 4.96 and that of "\( b \)" varied from 0.36 to 0.75.

**ATTENUATION RELATION**

A valid attenuation relation for Sudan is not available at this time because of the low seismicity and instrumental centers. An approximate relation, however, can be derived based on proposed attenuation laws for neighboring countries (e.g. Saudi Arabia, Ethiopia and Egypt). The following, well-known and widely used, attenuation law is proposed for all regions.

\[
a = C_1 e^{C_2 M} (R + C_3)^{C_4}
\]

(2)

Where the constants are taken as: \( C_1 = 5759 \), \( C_2 = 0.71 \), \( C_3 = 40 \) and \( C_4 = -1.6 \) (El Hassan 1994).

**SEISMIC HAZARD MAP OF SUDAN**

Seismic hazard assessment has been studied by several researchers (Cornell 1968, McGuire 1976, Karnik 1977 and Chiang 1984). In this study probabilistic seismic hazard analysis for the regions was performed using the computer code EQRISK (McGuire, 1976). The whole study area was subdivided into a grid of approximately 60x60 km. The output of the program was the peak ground acceleration (PGA) for a risk level of 0.02, 0.01 and 0.005 as shown in Figures 3, 4 and 5. The figures show maximum PGA in the Southern Sudan, near the Eastern border of Sudan in Ethiopia and Eritrea, and the Red Sea. Maximum PGA for a risk level of 0.02, i.e., 50 years return period, is about 100 cm/sec\(^2\) in Southern Sudan and 80 cm/sec\(^2\) along the Red Sea Coast (see Figure 3). For the rest of the country the PGA ranged from 20 to 60 cm/sec\(^2\). For a risk level of 0.01, i.e., 100 years return period, the maximum PGA was found to be about 160 cm/sec\(^2\) in Southern Sudan and 100 cm/sec\(^2\) along the Red Sea Coast (see Figure 4). The remaining areas of the Sudan showed PGA in the range of 20 to 60 cm/sec\(^2\). For a risk level of 0.005, i.e., 200 years return period, the maximum PGA was 220 cm/sec\(^2\) in Southern Sudan and 140 cm/sec\(^2\) along the Red Sea Coast (see Figure 5).
CONCLUSION

The Southern region and the Red Sea Coast are the most seismically active parts of Sudan. The PGA in these regions can reach up to 220 cm/sec$^2$ for low risk level. This amount of PGA can cause major structural damage to key structures and lifeline systems. Therefore, it is advisable that, in design of major structures in these regions earthquake effects should be taken into consideration. Since there is no earthquake code written or adopted for Sudan, it is high time to consider this goal and provide engineers with provisions and guidelines for earthquake resistant design. This paper is the first step towards achieving that goal.

REFERENCE


