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Warning Time Analysis for Emergency Response in Sumbawanga City for the Repeat of Magnitude 7.2 Earthquakes of 1919 Using Proposed Community Earthquake Early Warning System

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Abstract: ***Sumbawanga city, with population of about 90 thousand has experienced several damaging earthquakes from Kanda Fault System which is a seismically active fault in eastern side, encompassing Lake Rukwa and Lake Tanganyika basins. The magnitude 7.2 earthquake of July 1919 is one of the historical earthquakes from Kanda fault that generated damaging ground motions centered in Sumbawanga city while reaching several town/cities situated up to several kilometers from its epicenter. The historical earthquakes information of the region indicates that large earthquakes are expected in near future from the Kanda fault system. The Community Earthquake Early Warning System (CEEWS) are tools used to capture earthquakes onset time and ground motion levels in communities for emergency responses. To prepare for future emergency management of magnitude 7.2 earthquakes in Sumbawanga city, the study evaluates the warning times possible from the deployment of CEEWS in the city. Warning times calculated by simulating the event, indicates that Sumbawanga city will have approximately 8 second of warning times before the arrival of strong shaking if the processing and transmission delays are minimal. Warning times are meant to allow the appropriate emergency precautionary actions to be taken by the government officials, companies and individuals during the imminent earthquakes.***

Keywords: CEEWS, Community Earthquake early Warning System, Warning Times, Seismic wave velocities

1. Introduction

The Sumbawanga city in Rukwa region, South Western Tanzania (SWTZ), is situated at 7.97° South latitude, 31.62° East longitude and falls within Ufipa plateau between Lake Tanganyika and Lake Rukwa basins. The Ufipa Plateau is a tilted horst between the Tanganyika and Rukwa rift basins in the western branch of the East African Rift System [2], [3]. It is cut longitudinally by the 160 km-long Kanda fault system, the main active fault affecting the Sumbawanga city [2], [3].

A century ago, this region was hit by two large earthquakes, magnitude 7.4 earthquakes on December 13, 1910 and the magnitude 7.2 of July 8 1919 [3], [8]. The epicenter for the magnitude 7.2 earthquake of 1919 was located near Sumbawanga city, along the northern portion of the Kanda fault [3]. The seismic crisis due to the two events affected the Ufipa Plateau between Lakes Tanganyika and Rukwa and the Mbozi block, between Lakes Rukwa and Malawi [3]. Apart from that strong earthquake, there are other recently felt events in the region, which includes the Magnitude 6.8 earthquake of 2005, magnitude 5.8 of 1994, magnitude 5.7 of 1997, magnitude 6.6 of 2000, and magnitude 4.7 of 2009 [1], [8]. The seismicity data from historical and instrumental (far field and local networks) databases confirm that the Kanda fault is tectonically active [8].

Considering the magnitude 7.2 earthquakes of 1919 (Figure 1), the distribution of damage clearly indicates that the repetition of a similar event would now produce extensive destruction over a wide area, due to the current rapid urban development of the region. The cities/towns where the damage would be expected to be the highest, according to the location of the ruptured fault segment, includes Sumbawanga city, which is crossed by the fault; Tunduma (main gateway to Zambia), at its southern termination; and towns in the valley floor, including part of Mbeya city. Relatively new tools for reducing earthquake risks are community earthquake early warning systems that indicate that a large earthquake is actually happening, and estimated the time of arrival and level of ground shaking at user sites [1].

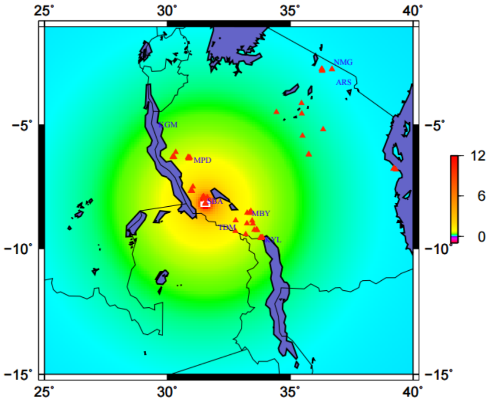

Figure 1. Simulated ground shaking of Magnitude 7.2 earthquake of July 1919. The area for strong shaking (red to yellow shades) extends to Mbeya city with Sumbawanga city (SBA) falling in most damaging area (red shading) zone

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2. COMMUNITY EARTHQUAKE EARLY WARNING SYSTEM MODEL

The CEEWS work by having a network of sensors near major fault zones and in the communities at risk. That is, CEEWS deploy MEMS accelerometers in community owned internet computers to capture seismic waves and provide warnings of upcoming danger by utilizing telecommunication networks that transmit information faster than seismic wave‘s propagation [1], [4]. The warning time is estimated as the difference between the alert time at the user site and the onset of p-waves at the nearest station or as the time interval between the detection of the P-waves by a sensor near the source and the arrival of S-waves at the user site [1], [9].

In this study, the available warning time analysis of likely upcoming magnitude 7.2 earthquake to the Sumbawanga city is investigated using the simulated P- wave arrival times at the proposed CEEWS sensor stations (Figure 2) from the event epicenter. The P- and S-wave velocities for the region is also estimated using the observed station P-wave arrival times as per ISC catalogue of events recorded in this region between 2002 and 2013. This study contributes valuable information to public and seismic hazard studies for Sumbawanga city and SWTZ region.

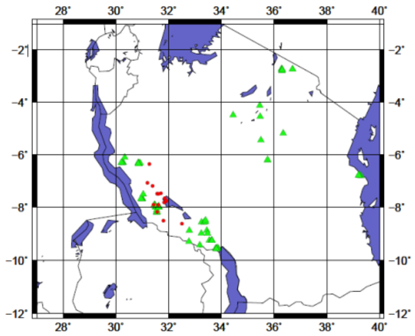


Figure.2. CEEWS Sensor Configuration. Green Triangles are CEEWS sensor stations and Red circles are earthquake epicenters. Only sensor stations along SWTZ are beneficial for capturing of earthquakes from Kanda fault system.

3. PREVIOUS WORK

The CEEWS are currently being deployed or working in several regions such as California, Japan and Taiwan [14] , [10], [6] , [11]. These CEEWS uses inexpensive MEMS strong motion sensors that are previously owned or supplied to community members at low cost [14], [8], [5]. These sensors report the sensed acceleration data to central server where algorithms are installed for analysis of data to pinpoint the source of an earthquake and send early warning alerts [8].

The possible warning times in current CEEWS are usually in the range of up to 70 seconds (in Mexico), depending on the distances between seismic source, seismic sensor and user sites [13], [7]. The warning time is estimated as the time difference between the alert time at the user site and the onset of p-waves at the nearest station or as the time interval between the detection of the P-waves by a sensor near the source and the arrival of S-waves at the user site [1], [12]. For personal protection, a few tens of seconds of warning time is enough for people to quickly move to safe-zones such as under sturdy table, or move away from hazards including falling bookshelves and windows. In Japan and Mexico, school children take about 5 seconds to get under their desks in response to audible warnings [13], [9].

4. METHODOLOGY

The warning time of an earthquake T_W, is defined in this study as the time interval between the detection of P-waves at the recording station and the arrival of energy carrying S-waves at the user site. For the epicentral distance R_S at the first detecting sensor, epicentral distance R_U of the user site and focal depth of earthquake Z, the warning time T_W is estimated as

$$T_W = \frac{\sqrt{(R_U^2+Z^2)}}{V_S} - \frac{\sqrt{(R_S^2+Z^2)}}{V_P} - t_{dec} - t_{tra} \qquad (1)$$

Or

$$T_W = T_S - T_P - t_{dec} - t_{tra} \qquad (2)$$

Where V_P and V_S are the P and S-wave average velocities, Ts and Tp are S- wave and P-wave arrival times, and t_{dec}, t_{tra}. are the time needed for decision making to alert or not and the time for data transmission, respectively.

The P and S-wave average velocities (Vp and Vs) are dependent on soil structure of earth. Through various methods, research findings indicates that the average P-wave velocity ranges between 5.9 km/s and 8 km/s while the velocity for S-wave ranges between 3.5 km/s and 4.8 km/s for the Kanda fault system and SWTZ region [2]. In this study, the observed seismic waves travel times between event epicenters along the Kanda fault system and recording stations situated across Tanzania, as well as the neighbouring countries for 36 earthquakes reported between 2002 and 2013 as per ISC database (Figure 3) were used to analyze the P and S-wave velocities. The seismic wave (P and S-wave) velocities across the region were evaluated by analyzing the observed seismic P-wave travel time from the event’s epicenter to recording station in SWTZ and their respective epicentral distances.

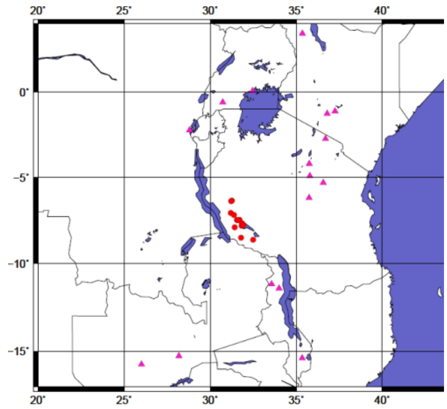


Figure 3. Stations Reporting Kanda fault earthquakes in ISC database between 2002 and 2013. While the event epicenters are shown in red circles, the triangles indicates the reporting stations

For the warning time (Tw) estimated as difference between the alert time (T_{Alert}) at the user site and the onset time (T_{p1}) of P-waves at the nearest recording site, equation (1) becomes

$$T_W = T_S - T_{Alert} \qquad (3)$$

Where

$$T_{Alert} = T_{P1} + t_{dec} + t_{tra} \qquad (4)$$

With the current seismic infrastructure that employs faster computer for faster packetization of seismic data, the processing time of seismic data are insignificant, but time set to record adequate data and process them into data for inferring the danger contributes into the time for decision making (t_{dec}) in many warning systems. These time includes: time used by the sensor to record the adequate data for trigger parameter identification by the computer (t_{id}), the time for trigger to reach third, fourth to fifth sensor site (t_{w3},t_{w4}, t_{w5}), and time for earthquake location and event magnitude estimation (less than 0.5 seconds). That is,

$$t_{dec} = t_{w3,4,5} + t_{id} \qquad (5)$$

In this study, simulation of magnitude 7.2 earthquake of July 1919 within the Kanda fault system using proposed CEEWS sensor station positions (Figure 2) and user site in Sumbawanga city (longitude 31.623, latitude -7.958, epicentral distance 24.823 km) were performed to estimate the t_{dec} time. The time used at each sensor to record adequate data (t_{id}) was set to 3 seconds, the time required to wait for three, four and five sensors in the network to be reached by the event (t_{w3}, t_{w4}, t_{w5}) were calculated using the P-wave velocity for the region and the epicentral distances to the third, fourth and fifth sensor station.
The transmission of data to the processing center is generally dependent on telecommunication infrastructure of the region, and can be less than 0.2 second in countries with faster telecommunication infrastructures and up to 10 seconds or more in countries with low communication infrastructure [7]. For the SWTZ region, time for transmission of seismic data from seismic stations in CEEWS is assumed to be 10 seconds. That is, the transmission delay (t_{tra}) for data recording in CEEWS to the server is fixed at 10 seconds in this study.
For the warning time (Tw) estimated as the time interval between the detection of the P-waves by a sensor near (Tp1) the source and the arrival of S-waves (T_S) at the user site, the warning time equation becomes

$$T_W = T_S - T_{p1} \qquad (6)$$

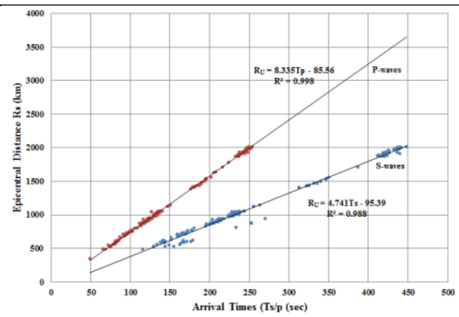
Where T_S is estimated by considering the S-wave velocity across the region and epicentral distance of the user site (R_U).

5. RESULTS

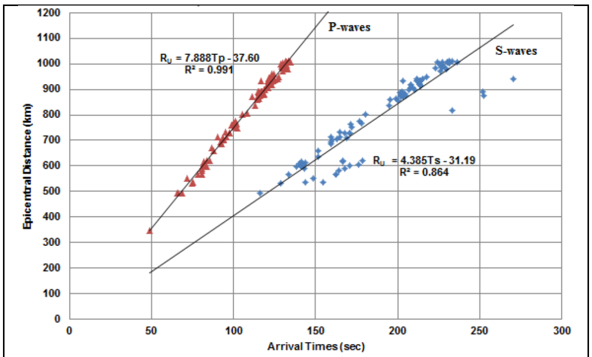
Results for estimated seismic velocities across the region using observed of seismic travel times from the event epicenter to recording stations are presented in this section. Also, the result of simulated earthquake warning times possible for repeat of magnitude 7.2 earthquake to Sumbawanga city by using proposed CEEWS are presented.

5.1: P and S-wave velocities across the SWTZ region

From the seismic phase stations arrivals data for earthquakes recorded from Kanda fault system, Figure 3, show the estimated velocities at various distance ranges of observing stations.



(a) Recording stations at distance range of 0 km to 2000 km



(b) Recording stations at distance range of 0 km to 1000 km

Figure 3: P and S-wave Arrival time versus epicentral distance of the observing station.

According to Figure 3, the seismic wave velocities are about 7.89 seconds to 8.33 seconds for P-waves and 4.38 seconds to 4.74 seconds for S-waves, giving the ratio of P/S wave velocities of 1.76 to 1.80.

Simulating the magnitude 7.2 earthquake of 1919 in Kanda fault system using the CEEWS sensor station positions, the P- and S-wave travel times to the target sites was as shown in Figure 4. According to Figure 4, the P-and S-wave velocities are 7.89 km and 4.38 km, respectively.

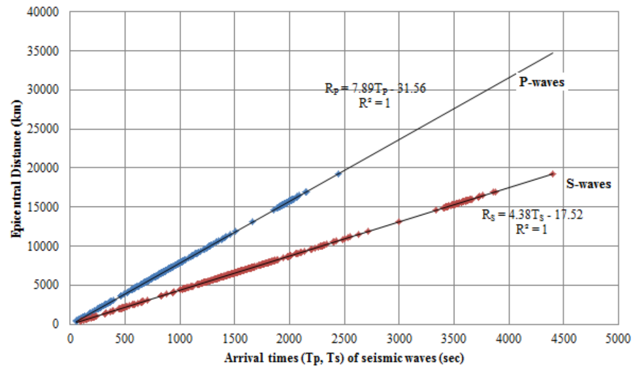


Figure 4. Simulated P- and S-wave Travel Times across SWTZ region for Magnitude 7.2 Earthquake of 1919. Simulated P- and S-wave velocities are shown as the slope of the line equation

5.2: Simulated Warning Times in Sumbawanga City

In this section warning time available for Sumbawanga city for the repeat of magnitude 7.2 earthquakes of 1919 using CEEWS configuration in SWTZ is explored. The results for warning times calculated using Eqn (2), Eqn (3) and Eqn (6). are shown in Figure 5.

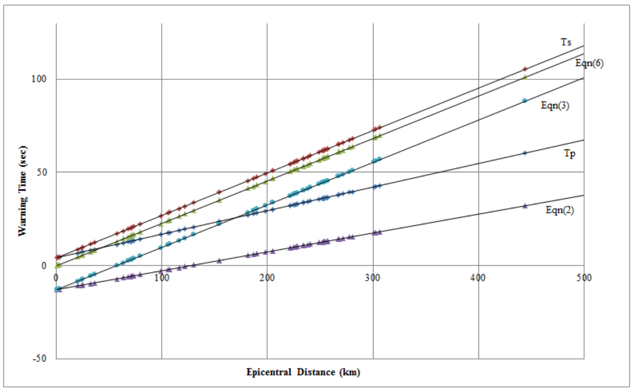


Figure 5. Simulated Warning Times across SWTZ Region for repeat of Magnitude 7.2 Earthquake. Arrival Times for S- wave (Ts) and P-waves (Tp) across the region are also shown

From Figure 5, cities at epicentral distances of 20 km, will have 4 seconds, -9 seconds, and -11 seconds of warning times using Equation (6), Equation (3) and Equation (2), respectively. Cities at about 80 km will have 18 seconds, 5 seconds, - 8 seconds of warnings time for Equation (6), Equation (3) and Equation (2), respectively. At an epicentral distances of 200 km, the warning times becomes 45 seconds, 33 seconds, and 8 seconds for Equation (6), Equation (3) and Equation (2), respectively. According to Figure 5, the warning times increases for all the cases with increase of epicentral distances.

Sumbawanga is at a distance of about 45 km from the epicenter of magnitude 7.2 earthquake of 1919. From Figure 5, the available warning times simulated using the proposed CEEWS are about 10 seconds, -4 seconds and -11 seconds for Equation (6), Equation (3) and Equation (2), respectively. That is, warning time of about 10 seconds for this event is possible in Sumbawanga city only when the warning time is calculated as the time interval between the detection of the P-waves (Tp1) by a sensor near the source and the arrival of S-waves (T_S) at the user site.

6. CONCLUSION

From the warning times result presented (Figure 5), the proposed CEEWS will provide adequate warning times for emergency response in Sumbawanga city for repeat of magnitude 7.2 earthquake of 1919 if the processing and telemetry time of seismic data is reduced. Therefore, local warning system where the warnings can be released automatically whenever acceleration level is exceeded at three nearby stations is recommended for Sumbawanga city. The delays introduced for propagation of seismic waves to the set of sensors deployed in Sumbawanga city and warning transmissions to a central location should be avoided.

7. FUTURE SCOPES

Because MEMS accelerometer sensors are currently embedded in communication devices like mobile phones widely used in communities and software for activation of these sensors is also available, utilization of smartphones in developing community earthquake warning systems for the SWTZ region will be explored in future works.

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