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RESEARCH ARTICLE

Instrumentation of the Nigeria network of seismological stations

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ABSTRACT

"Living in fear of Nigeria biggest Earthquake" is a sub-heading of the Punch daily newspaper of Nigeria, dated, 21st of August, 2016, reported the earthquake/tremor recently witnessed in the ancient town of Saki, accompanied by a series of aftershock events that lasted for about three (3) months (March/May, 2016) southwest Nigeria[1]. Similarly, roughly five (5) years later, another series of earthquakes/tremors occurred again in Saki town, which was reported by an online news vendor named "Ripples Nigeria" dated September 8, 2021, under the sub-heading of "earth tremor rocks Saki in Oyo state"[2]. However, these events were not captured nor recorded by any of the functional seismological stations in Nigeria. The nearest seismological station located at the Obafemi Awolowo University (OAU) Ile-Ife, also failed to capture the events. We therefore seek to examine the instrumentation of the Nigerian National Network of Seismographic Stations. This is necessary to understand the functionalities and the capabilities of the deployed seismometers in each of the seismic stations. Therefore, we evaluated the bandpass limit of the seismic wave frequency for the respective seismic stations in Nigeria through the computation of the amplitude-frequency response curve, phase response curve, and count to cm/sec.

Keywords: Nigerian seismological stations; Saki earthquake; Saki land tremor; OAU-Ife; Nigerian seismicity; Intraplate earthquakes; Nigeria

1. Introduction

The occurrence of earthquakes in the crust produces seismic waves. These seismic waves are of various kinds. The instrument that is used for earthquake recording is known as a seismograph while the time history

ARTICLE INFO
Received: 14 March 2024 | Accepted: 28 March 2024 | Available online: 7 May 2024

CITATION
Eluyemi AA, Adesope AP, Awoyemi MO, et al. Instrumentation of the Nigeria network of seismological stations. *Earthquake* 2024; 2(1): 1884. doi: 10.59429/ear.v2i1.1884

of the ground vibration recorded by it is known as a seismogram. Primarily, a seismologist takes the help of a seismogram to initiate the analysis. The quantitative analysis of seismic waves requires well-calibrated instruments, having proper instrument response, which could measure the true ground motion of the earth due to an earthquake. The instrument is designed in such a way that it must be able to detect the transient vibration within a moving reference frame (since the instrument moves with the earth as it shakes) and operate continuously with a very sensitive detection capability with absolute timing to get ground motion as a function of time[3]. The fundamental components of a seismograph are the sensor, recorder, timing system, and power supply[4]. All these constitute a seismic station. On the other hand, a combination of several seismic stations comprised of seismic network. There can be different types of seismic networks e.g., local networks, regional networks, and global networks[5].

It is quite obvious that the intraplate seismicity of Nigeria is not understood yet. A functional seismic network station in Nigeria would give crustal information about the Nigerian terrain as well as revelations of some seismogenic sources, which would ultimately consolidate on some recent seismological studies conducted by some researchers: Eluyemi and Baruah (2016); Eluyemi et al. (2019a); Eluyemi et al. (2019b); Eluyemi et al. (2020a) Eluyemi et al. (2020b); Eluyemi et al. (2022a); Eluyemi et al. (2022b)[6-12].

1.1. Nigerian national network of seismographic stations

Seismicity monitoring and investigation in Nigeria, The Center for Geodesy and Geodynamics under the National Space Research and Development Agency (NASRDA), has been operating the Nigerian National Network of Seismographic Stations (NNNSS) **Figure 1** since 2008 after it was handed over by the National Agency for Science and Engineering Infrastructure (NASENI). The NNNSS has five operational stations equipped with 24-bit 3-channel recorders (digitizer and data logger) and broadband seismometers. The recorders and seismometers were manufactured by Eentec Company USA. The Five operational stations in Nigeria are located in Kaduna, Nsukka, Ile-Ife, Awka, and Toro. Five other proposed stations in Oyo, Abuja, Minna, Ibadan, and Abakiliki have been constructed. However, seismic pieces of equipment are yet to be installed. The equipment at each station are DR-4000 data acquisition system, EP-105 broadband (30seconds period) seismometer, or SP-400 medium period (16 seconds period) seismometer, manufactured by Eentec. For further development and installation of seismic equipment in new stations, new sets of equipment have been procured: the DR-4050 data acquisition system, and EP-300 broadband sensor (100 seconds & 60 seconds period respectively). For time synchronization, the equipment at the stations is connected to a Global Positioning System (GPS), while solar panels and a 100 Ah battery are provided as a power source, at the remote stations. Efforts are being made to network all the remote stations (Kaduna, Ife, Awka, and Nsukka) to Toro Central station for real-time data transmission within Nigeria and robust sharing amongst neighboring countries and other international agencies[13]. In this study, we want to examine the five (5) known/pioneering functional seismic monitoring stations in Nigeria under the supervision of Center for Geodesy and Geodynamics (CGG) **Table 1**.

Table 1. Station parameters of the seismic stations of Nigeria along with seismometer and digitizer units.

Station name	Code	Site Geology	Latitude in Degree	Longitude in Degree	Elevation (m)	Seismometer	Digitizer	Start	End
Ife. SW	IFE	Gneiss	7.55	4.547	289	EP-105	DR4000	2009/06/06	2599/12/31
Nsuka SE	NSU	Sandstone	6.867	7.417	430	EP-105	DR4000	2009/03/22	2599/12/31
Kaduna NW	KAD	Granite	10.435	7.6414	668	EP-105	DR4000	2009/01/01	2599/12/31
Barga	TORO	Gneiss	10.055	9.12	882	EP-105	DR4000	2009/01/01	2599/12/31
SE2-Awka	AWK	Shale & Silt stone	6.243	7.112	50	EP-105	DR4000	2009/04/01	2599/12/31

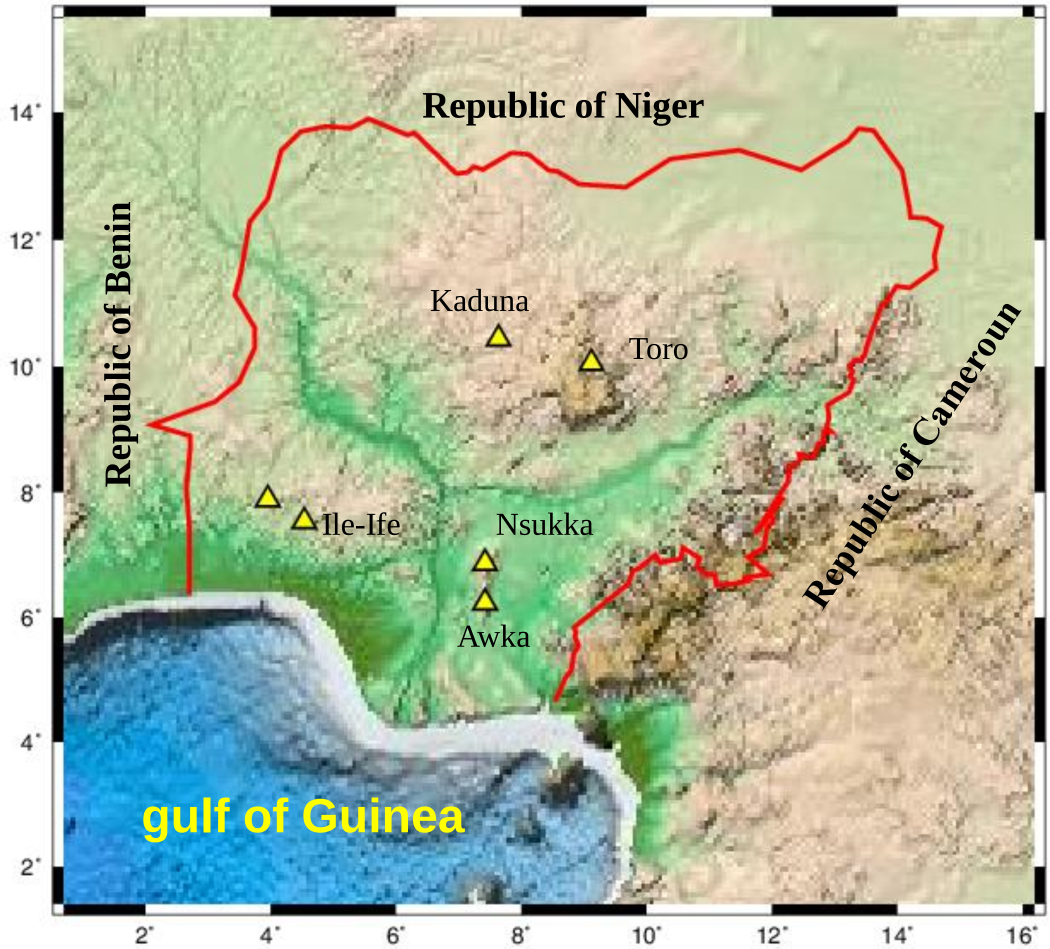

Figure 1. Map of Nigeria showing the Seismic Stations in Nigeria, operated by the Centre for Geodesy and Geodynamics, Toro Bauchi Nigeria (Indicated by a filled yellow triangle).

2. Methodology

2.1. Determination of amplitude frequency response curve

The frequency response curve describes the characteristics of seismic recording systems that deal with true ground motion[14]. The concept of the frequency response function is the Fourier transform of the output signal divided by the Fourier transform of the input signal. The modulus of the frequency response function is exactly the amount of magnification. In this study, the frequency response function is quantitatively determined which is used to ascertain ground motion amplitude from digital seismograms with necessary conversion [15]. Ground motion amplitudes are commonly calculated from digital seismograms by dividing the signal amplitudes in counts by the value of the amplitude of the displacement/velocity frequency response function (magnification curve) at a single frequency. In the determination of frequency response, it is assumed that the input signal is always harmonic. **Table 2** shows the lists of poles and zeros (transfer function) for different seismometers and recording systems whose data are used for estimation of amplitude and phase response curves in particular for necessary signal processing in the Nigerian National Network of Seismographic Stations. These transfer functions positions defined for a plane, are provided in a simple ASCII file ('poles-zeros file'), which is created by using a "text editor". In addition, an input signal free from any artificial noise, or earthquake (zero vibration condition) is provided. From the list of the poles and zeros correspondingly, the frequency response function is calculated. A complex multiplication of the frequency response function with the discrete Fourier spectrum of the input signal is performed. Finally, the inverse Fourier is calculated. The whole process is equivalent to convolving the input signal with the impulse response of the system. Evaluation of the impulse response function is made based on potential change in onset following[16]. Ultimately amplitude response is obtained. Determination of frequency response to the ground velocity first ascertains the true knowledge of passband frequency (**Table 3**) that is required for waveform processing in the Nigerian Network of Seismological Stations, **Figures 2** and **3** show the frequency Amplitude response curves for the studied seismological stations in Nigeria.

Table 2. Shows the values of poles and zeros for different seismometers for Nigerian seismic stations.

Seismometer	Vertical		Horizontal		Normalization Factor
	Poles (Hz)	Zeros (Hz)	Poles(Hz)	Zeros (Hz)	
EP-105	-0.024+0.024i	0.00	-0.024+0.024i	0.00	2304000
	-0.024-0.024i	0.00	-0.024-0.024i	0.00	
	-50	0.00	-50	0.00	
	-50	0.00	-50	0.00	
SP-400	-0.024+0.024i	0.00	-0.024+0.024i	0.00	2304000
	-0.024-0.024i	0.00	-0.024-0.024i	0.00	
	-50	0.00	-50	0.00	
	-100	0.00	-100	0.00	

Table 3. The table below presents the frequency band pass limit, seismometer sensitivity, digitizer sensitivity, and counts to m/s of the equipment of the seismic stations in Nigeria.

Seismometer	Digitizer	Passband Limit (Hz)	Seismometer sensitivity (V/m/s)	Digitizer sensitivity	Counts to m/sec
SP-400	DR4000	0.067-50	2000	2.384E-06	9.535E-12
EP-105	DR4000	0.033-50	2000	2.384E-06	9.535E-12

2.2. Determination of phase response curve

The phase response is the relationship between the phase of a sinusoidal input and the output signal passing through any device that accepts input and produces output signal. Seismometers are mainly characterized by their amplitude and/or phase response. As discussed above, amplitude response is the ratio of output amplitude to input, usually a function of frequency. Similarly, the phase response is the phase of output with the input reference. The input is defined as zero phase. A phase response is not always limited within 0^0 and 360^0, as a phase can accumulate in any amount of time.

The phase response of a seismometer is important because the recording of a seismogram is extremely sensitive to changes in phase. Detecting and processing the result of the phase relationship of a seismic source allows locating its direction and position with precision. **Figures 4** and **5.**

2.3. Conversion of Amplitude from Counts to cm / sec

In a digital recording seismograph, the output from the seismometer (voltage) is fed to an amplifier and amplified output is fed to a digital recorder, which records the ground motion in terms of digital counts converting voltage into counts. To obtain the actual ground motion, the amplitude counts for the velocity seismograms are converted to centimeters / second using instrument response. For instance, conversion of velocity seismogram recorded by a broadband station equipped with DR4000 (Entec make) sensor and SP-400 data acquisition system, related parameters are as follows: Data format =24 bit, Sampling rate = 100 SPS, Velocity sensitivity = 2000 V/m/s, Analogue to digital (A/D) conversion factor = 1.907E-06 Volts/counts, Preamplifier gain = 1.

Appropriate conversion is as follows:

Ground velocity = $\dfrac{Amplitude(counts)^{*} A/DConversionfactor(V/counts)}{preamplifiergain^{*} Sensitivity(V/m/s)}$

$$= Amplitude(counts)^{*} \frac{(1.907E-06V/counts)}{2000V/m/s}$$

Or Ground Velocity = $\left[(Amplitudecounts)*\dfrac{(1.907E-06)}{1*2000}\right]$ m/sec

Or ground velocity = $[(Amplitudecounts)*1.27E-7]$ cm / sec

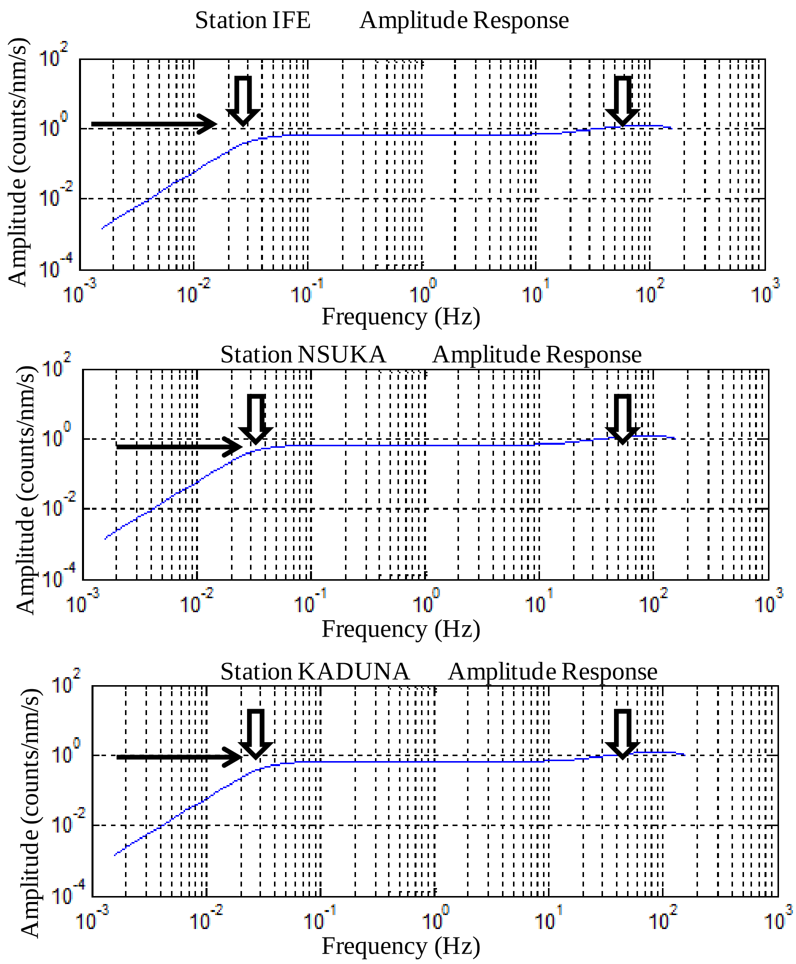

Figure 2. Figure above shows the amplitude versus frequency response curve to the ground velocity with known pole-zero distribution for (a) IFE, (b) NSUKA and (c) KADUNA seismic stations of Nigeria.

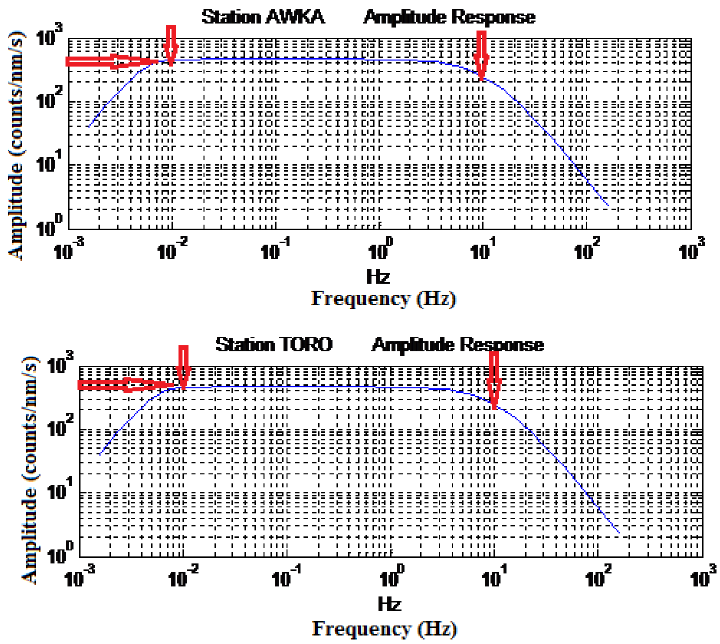

Figure 3. The above shows the amplitude versus frequency response curve to the ground velocity with known pole-zero distribution for (a) AWKA and (b) TORO seismic stations of Nigeria.

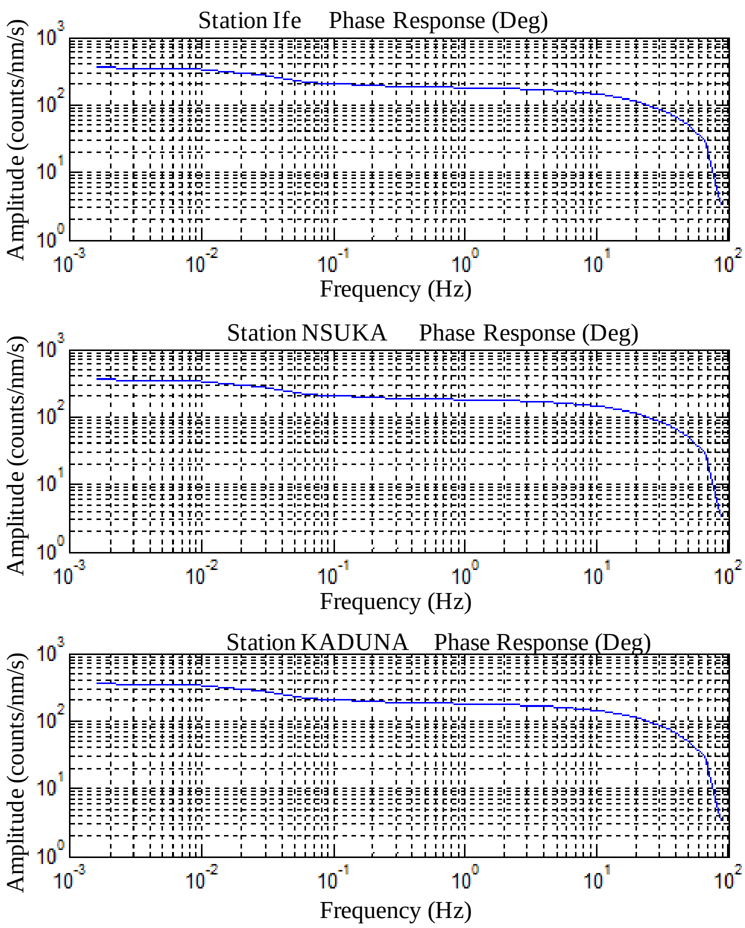

Figure 4. The above shows the phase response versus frequency curve to the ground velocity with known pole-zero distribution for (a) IFE, (b) NSUKA and (c) KADUNA seismographs-seismic stations in Nigeria.

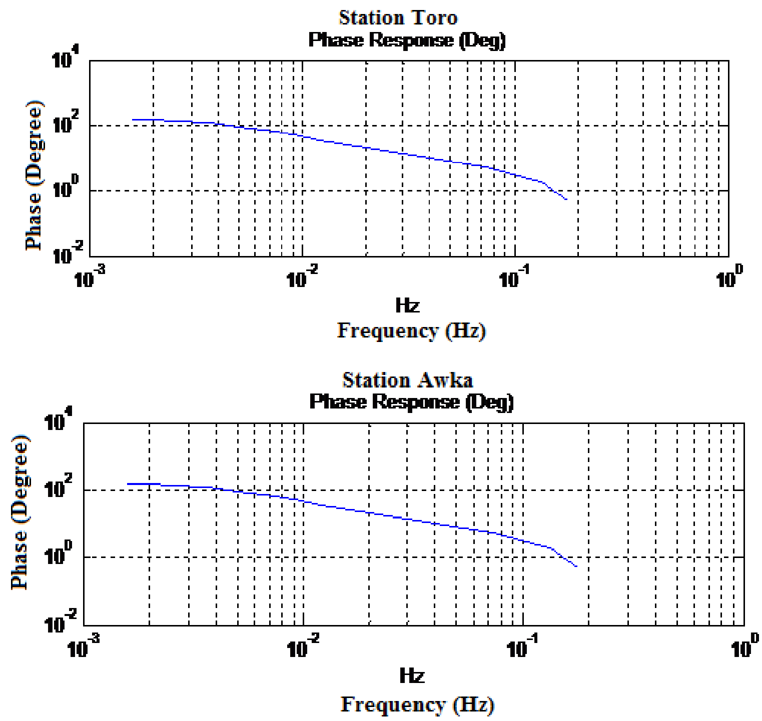

Figure 5. The above shows the phase response versus frequency curve to the ground velocity with known pole-zero distribution for (a) Toro and (b) Awka seismographs-seismic stations in Nigeria.

3. Results

The amplitude versus frequency response curve to the ground velocity with known pole-zero distribution for seismic stations in Nigeria shown in **Figures 2** and **3** represents two types of amplitude response curves for existing seismic stations in Nigeria, equipped with different seismographs. The amplitude-frequency response function decays rapidly outside the central frequency band, roughly below 0.067-50Hz and 0.033-50Hz respectively. Hence the signals outside this range are strongly attenuated while frequencies between 0.067-50Hz and 0.033Hz could be well recorded. These frequencies are the bandpass for the processing of waveform for the studied seismic stations in Nigeria while **Figures 4** and **5** show a phase response curve with frequency (Hz) along the X-axis and the amount of phase shift (in degree) along the Y-axis. From this figure, one can visualize that at high frequencies, the phase response of a seismometer (or any electronic circuit or system) turns negative, because the combined circuit elements behave as a series of low-pass filters. The rate of change of phase begins to increase rather rapidly above a frequency that is equivalent to $1/10^{th}$ of the turnover frequency of the combined filter network. Thus the behavior of the high-frequency phase response changes with the overall bandwidth of the system. Different phase response curves are obtained for different instrumentations as observed in **Figures 4** and **5** along with the amplitude response representing the true characteristic of the seismograph.

4. Discussion

The main objective of a seismologist is to measure the Earth's motion at a point concerning this same point undisturbed. The seismic sensor is the most critical element of a seismograph (seismometer and a recording unit). Seismic waves cause transient motions and this implies that there must be an acceleration. Velocity and displacement may be determined but an inertial seismometer cannot detect any continuous motion of them. The amplitude and frequency range of seismic signals is very large. So for good quality recording, the seismometers should be least cover the frequency band 0.01 to 100 Hz and Earth motions from 1nm to 10mm, considering the seismic wave bandpass limit for the Nigerian Seismological stations, as determined above.

It is obvious that events that occurred in the years 2016 and 2021 in the same zone in Saki ancient town of Nigeria was medium size earthquake magnitude, probably occurred at a shallow depth which brought about a conspicuous shaking intensity, the 2016 and 2021 episodes are suspected to be from the same source. However, the nearest seismological station located at the Obafemi Awolowo University (OAU), Ile–Ife, as well as the rest of the seismological stations located across the country, failed to capture these events due to a suspected malfunction of the seismic stations or the stations were not in operation at all as a result of power outages. Whereas, the 4.2Mw earthquake event that took place along the Lagos-Nigeria/Republic of Benin border was adequately captured by the three existing and functional seismological stations in Nigeria. This event was captured and recorded on the 11th of September, 2009.

5. Conclusion

The sensitivities of the Nigerian networks of seismological stations have been determined through the amplitude-frequency response and phase response, including counts to cm/sec conversion estimation for the Nigerian seismic instrumentations. This is necessary in the wake of the suspected reactivated fractured zones across the country. However, the phase response of a seismometer is important because the recording of a seismogram is extremely sensitive to changes in phase. Detecting and processing the result of the phase relationship of a seismic source permits the hypocentral determination, most especially, the longitude, and latitude (direction and position) with precision. This study revealed the amplitude response curves corresponding to the seismometers deployed in the existing seismic stations in Nigeria.

Considering the obtained curves, the amplitude-frequency response function decays rapidly outside the central frequency band, roughly below 0.067-50Hz. Hence the signals outside this range are strongly attenuated while frequencies between 0.067-50Hz could be well recorded. This frequency is the bandpass for the recording systems in Nigeria. Considering the frequency range of the deployed seismometers in Nigeria, for accurate and adequate seismicity monitoring, the country should deploy newer and more sophisticated seismometers for better performance and also increase the density of the seismic stations for ease of detection of very low-frequency wave signals.

Conflict of interest

Author declare no conflict of interest.

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