

Crust-upper Mantle Structure and Seismic Hazards Studies for National Planning and Development in Nigeria

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Abstract

This work is aimed at assessing critical issues on sites response and earthquakes prediction, improve earthquakes location and better seismic hazards assessment for planning in Nigeria. Firstly, sediment depths in the Lower Benue Trough were collected; resonance frequency (Fo) and shear-wave velocities (Vs) were then computed. Secondly, average velocities were estimated from cross-correlation along stations' paths in Nigeria. Thirdly, the Moho depths beneath Ife, Kaduna and Nsukka stations were estimated, and Vp/Vs ratio beneath Ife station. Finally, Statistical and Probabilistic Seismic Hazard Assessment (PSHA) were used to compute seismic hazard parameters for Nigeria and environs. The results showed Moho depths of 39km, 38km and 28km beneath the stations, and average Vp, Vs and Vp/Vs beneath Ife station to be 5.8, 3.8 and 1.7 respectively. Vs beneath the stations were found to be 288m/s, 101.9m/s, 940.6m/s and 255.02m/s respectively. Results from PSHA indicated high probability of yearly occurrence of magnitudes 2.0-3.5 in Nigeria, but low for magnitudes 4.0-6.0. The expected maximum magnitude would likely not exceed 6.5 within the 1-1000 years covered. The computed Peak Ground Accelerations ranged from 0.01-0.08g, and would be useful for engineering design and as baseline parameters for the establishment of seismic building codes for Nigeria.

Introduction

Nigeria is not located in seismically active regions
 ■ However, historical earthquakes had been observed within the country in the past 70 years (Akpan and Yakubu, 2010; Afegbua et al., 2011; Eze et al., 2011)
 ■ Evidences that earthquakes would continue to occur in Nigeria (Adepelumi, 2009; Olurufemi et al, 1986; Olujide et al, 1989; Adepelumi et al, 2008; Anifowose et al, 2010)

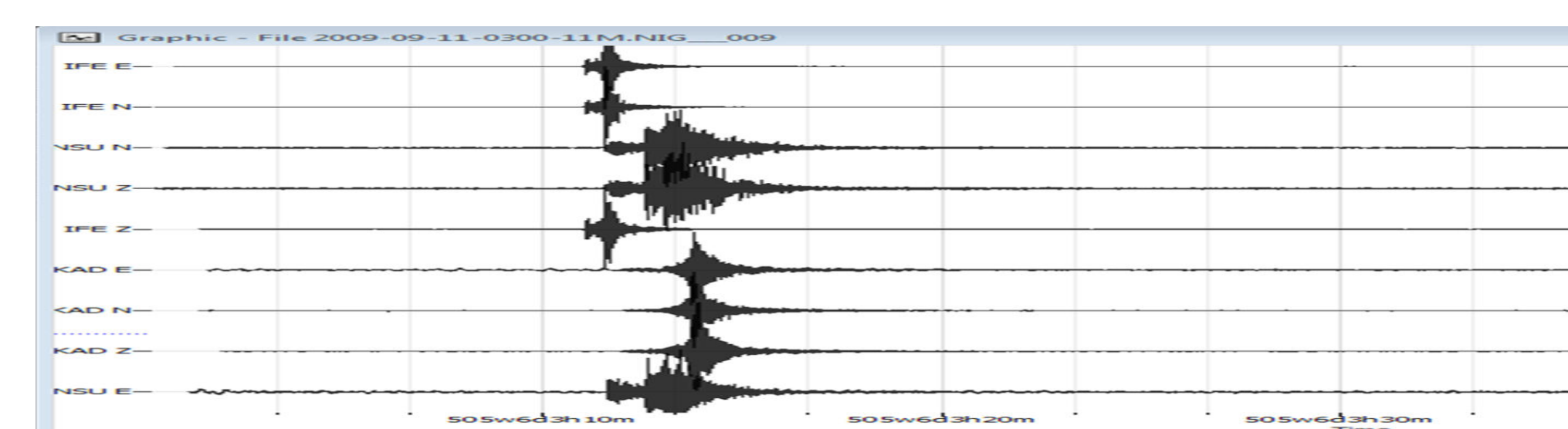


Fig. 1: September 2009 earthquake recorded in Nigeria at IFE, NSUKKA and KADUNA stations respectively

■ Three earthquakes occurred in Kwoi, Kaduna State, Nigeria on 11th and 12th, September, 2016

■ Multiple events earlier observed in Shaki, in Oyo State and Bayelsa/Rivers border in Nigeria

■ Buildings and other Structures were affected

■ Causes of earthquakes in Nigeria are natural (tectonics, volcanic etc.); and man-made (oil

Materials & Methods

Methods

DATA

■ Active sources: Earthquakes in Nigeria and neighbouring regions, Nigerian Seismic stations, Historical, USGS, ISC, ANSS, IRIS, GFZ, Ghana, Cameroon, etc **Spanned (1816 to 2014)**

■ Passive sources: Noise data from Nigerian Seismic Stations and from field work (2013-2015)

Methods

■ Computation of Resonance Frequency, Thickness of Sediments, and Shear-wave Velocities using H/V technique

■ Moho depth determination, P-wave and S-wave velocities, Vp/Vs ratio using Pyrocko algorithm and Global crust model (crust2loc)

■ Probabilistic Seismic Hazard Assessment (PSHA) adopting model in (Kijko and Smit, 2012) that addresses incomplete earthquake catalogues scenario

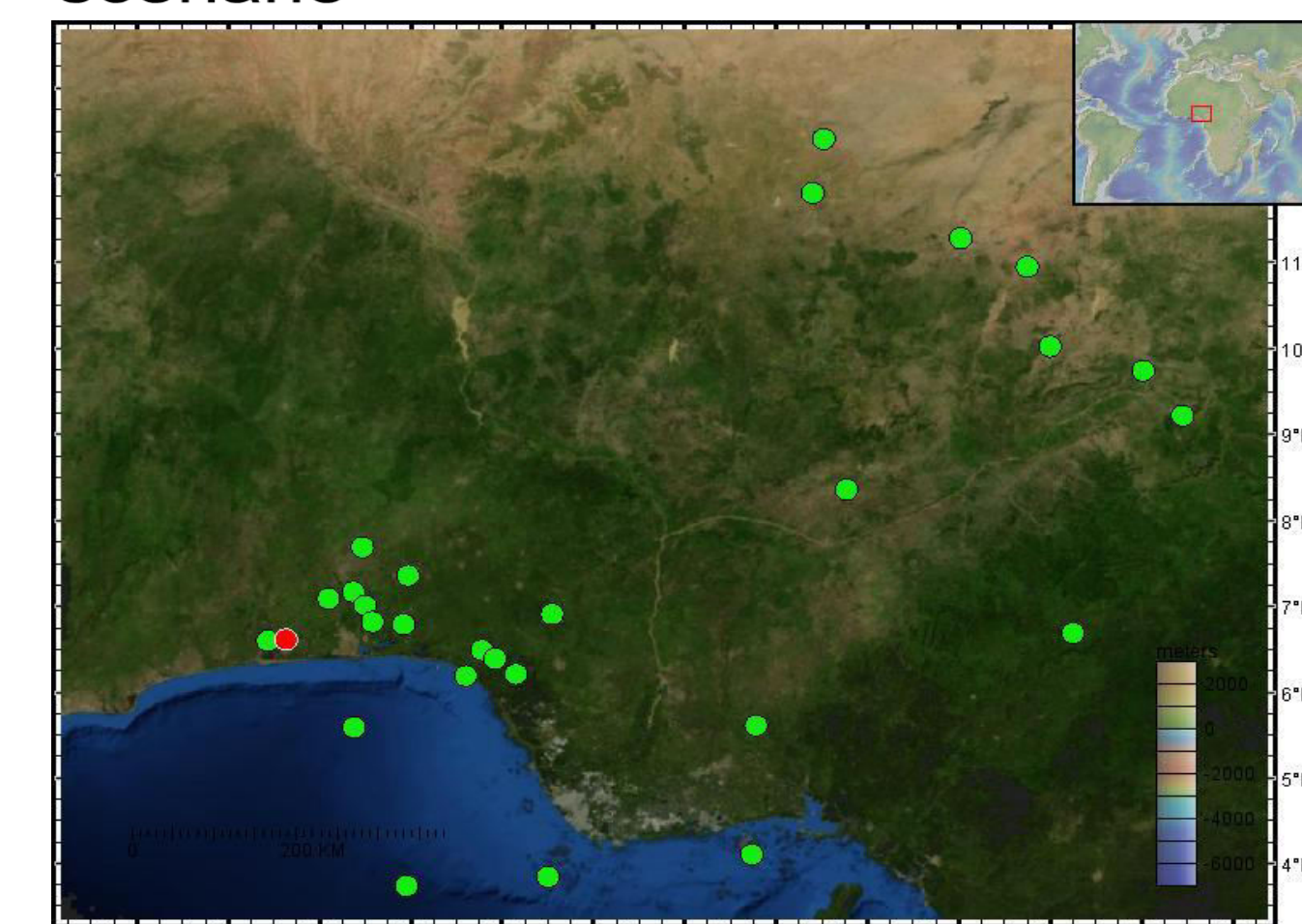


Fig. 2: Seismicity map of Nigeria (Red dot=2009 earthquake in Nigeria, blue dots=historically observed events)

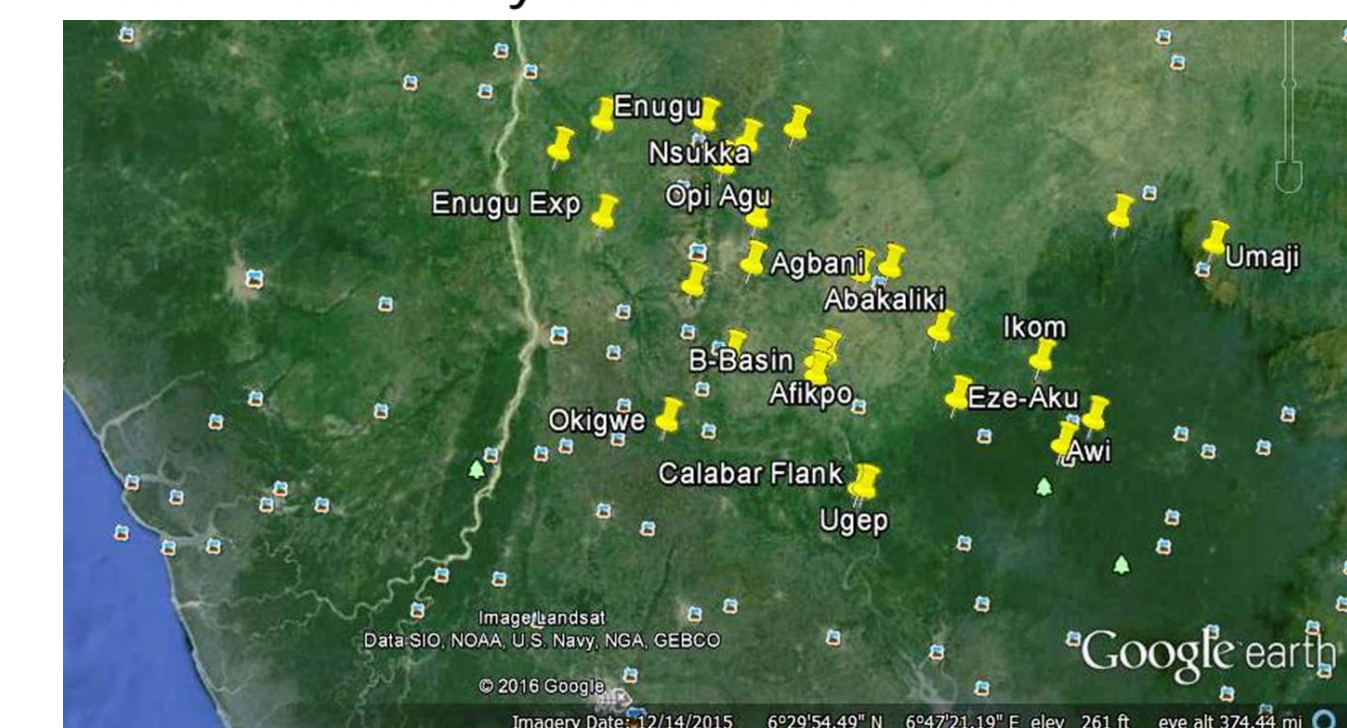


Fig. 3: Yellow pins indicate points where noise data were acquired on the Lower Benue Trough (Courtesy: Google earth)

Results and Discussion

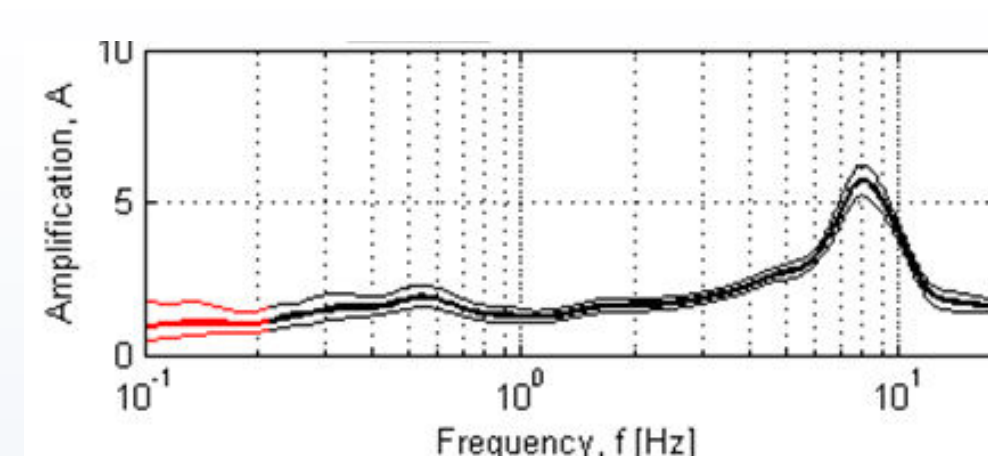


Fig. 4: Resonance frequency beneath basement complex of IFE seismic station, Nigeria

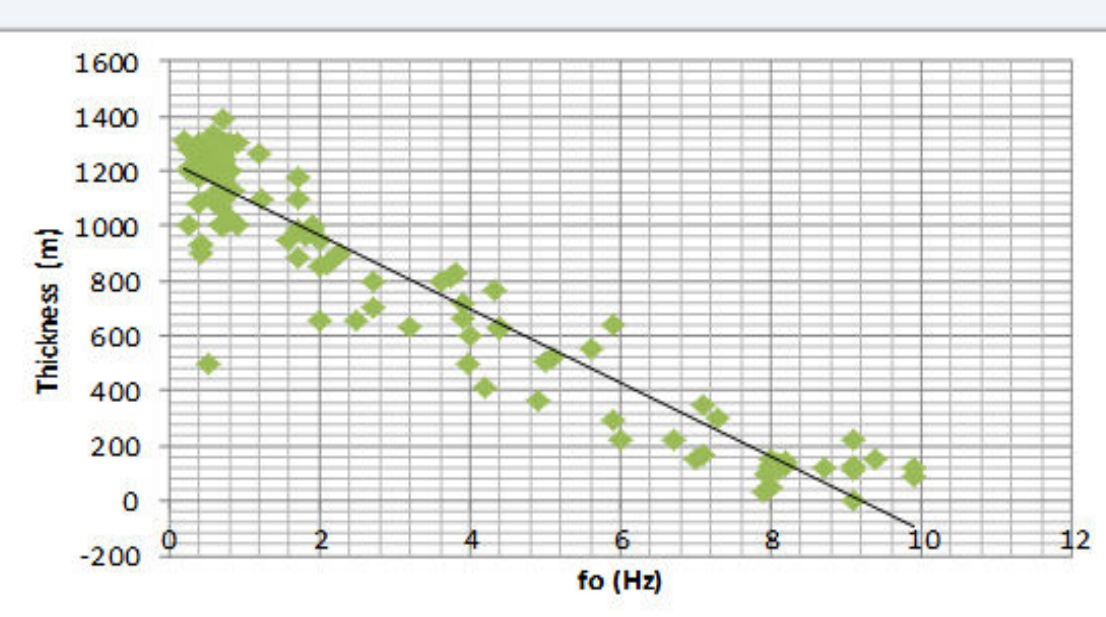


Fig. 6: Line fit plot of sediments thickness versus resonance frequency from noise data acquired in the Anambra Basin.

Resonance frequency values shift towards lower frequency region with increasing sediment thickness as

Presented in Table 2 from the Global modeling algorithm, are results of slowness of the phases from where the velocities were computed; distances covered by P and S waves (100-300km) from the surface beneath the Ife station; and the time taken for the P and S phases to cover the distances respectively. The knowledge of the conversions of phases at different boundaries within the earth were utilized to determine the depths of the discontinuities

Table 2: Arrival times of the phases=p, s and covering horizon distance 100:300km

slow (s/km)	dist (km)	time (s)	inci (deg)	effi (deg)	spre (%)	phase used
0.17142	100.0	17.314	95.3	83.8	100	100 p (p)
0.28735	100.0	29.023	95.3	83.8	100	100 s (s)
0.17204	200.0	34.497	92.0	86.2	100	99.9 p (p)
0.28839	200.0	57.828	92.0	86.2	100	99.9 s (s)
0.17213	300.0	51.708	90.6	86.7	100	99.4 p (p)
0.28855	300.0	86.677	90.6	86.7	100	99.4 s (s)

❖ Results of Vp, Vs and their ratios are presented in table 3.

Table 3: Computed Vp/Vs ratios beneath the Ife station in the Southwestern Nigeria region where the 2009 earthquake occurred and recorded

Dp(km)	Ds(km)	Slow(s/km) P,S	Vp (Km/s)	Vs(Km/s)	Vp/Vs
100	100	0.171 0.287 42 35	5.83	3.48	1.68
200	200	0.172 0.288 04 39	5.81	3.47	1.68
300	300	0.172 0.288 13 55	5.81	3.47	1.67

$$h = 99fr^{-1.631} \quad (1.0)$$

Equation 1 was established using data in figure 6. The model would be useful for future sediment determination

Findings

- Clear imaging of the structural heterogeneities within the Nigerian crust from 0km to 300km depths, and computation of Vp/Vs ratio for South-West Nigeria using active source. Determination of moho depths beneath three stations in Nigeria using the 2009 earthquake in Nigeria.
- Natural Frequency of the sediment covers (less than 30m and above 1000m) in the South Eastern Nigeria and beneath seismic stations in Nigeria have been successfully assessed for the first time in Nigeria from seismic noise data.
- Shear-wave velocity (Vs) profile was successfully determined from sediment thickness in the Southeastern Nigeria and beneath Nigerian seismic stations sited on parts of sedimentary basin.
- An earthquake in Nigeria, depending on the magnitude and epicenter, could produce a ground shaking up to 0.8 g
- The PSHA conducted using incomplete earthquake catalog in Nigeria indicated the probability of occurrence of large magnitude earthquakes in Nigeria is very low in short-term.

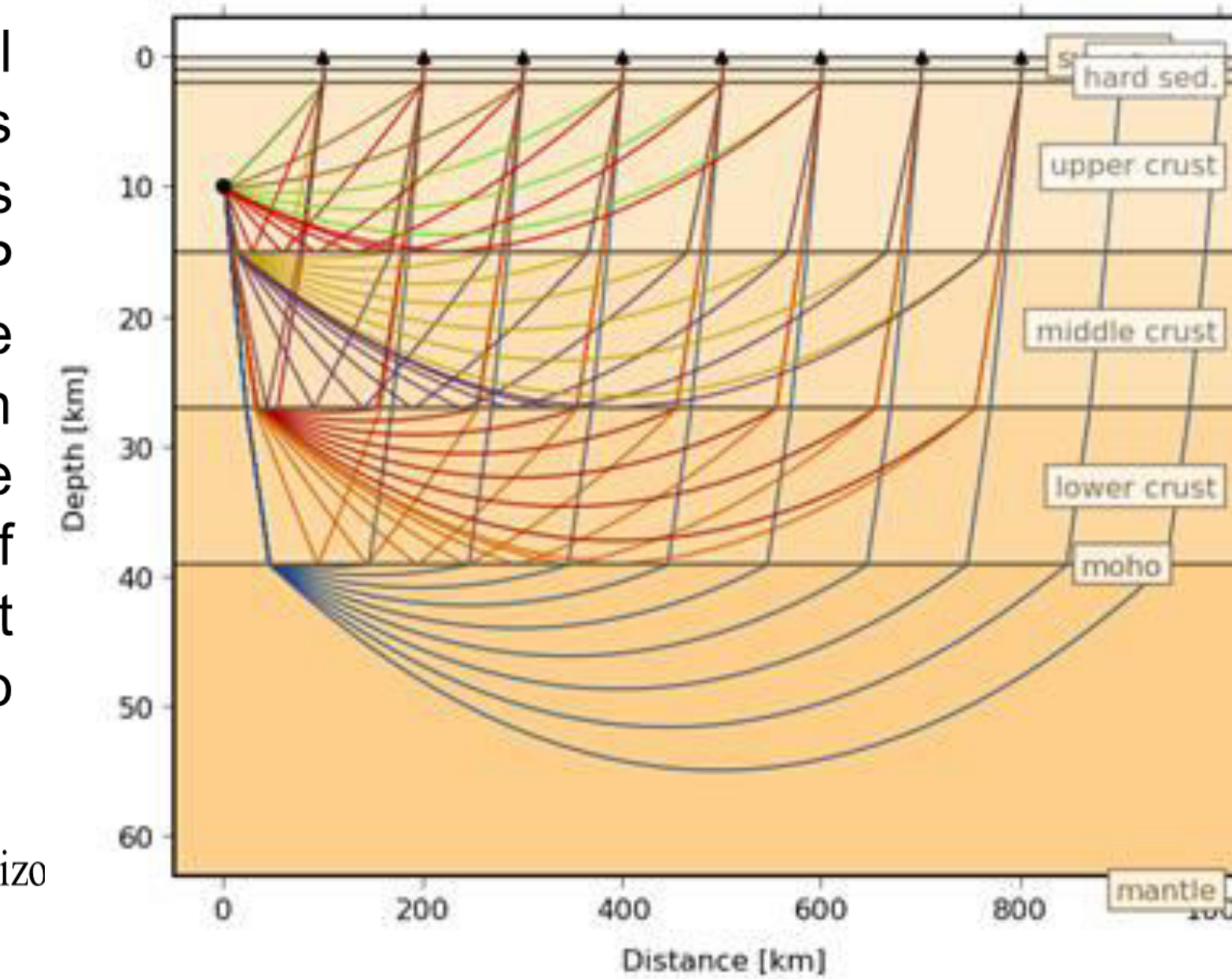


Fig. 6: Moho depth beneath the IFE station using the 2009 event in Nigeria

Using the P and S phases from the 2009 earthquake, the global crust model (crust2loc), the moho depths beneath the Ife, Kaduna and Nsukka stations were estimated as 39km, 38km and 28km respectively.

Conclusion

■ This work was able to address some critical questions bothering on crust-mantle structures and seismic hazard investigation for holistic planning purposes in Nigeria.

□ The results showed the following:

- Low resonance frequency corresponding to thick sediments and vice versa on the Lower Benue Trough
- Shear wave velocity (Vs) ranged from 174 to 1515m/sec for sites in Southeastern Nigeria; and 288, 1019, 940.6 and 255.02m/s beneath Ife, Nsukka, Kaduna, Awka and Abakaliki stations respectively.
- Large magnitude earthquake in Nigeria, would like cause more damages in S-E region due to soil amplification. It is expected also that intra-crustal earthquakes would continue to occur in Nigeria with earthquake of 6.4 magnitude or less expected in the next 100-1000 years.

Acknowledgements

Results for PSHA

The Table 4 and Figs. 7-9 presented the earthquake recurrent parameters in Nigeria from the seismic hazard assessment.

Table 4: Earthquake parameters for Nigeria within the period (1933-2009)

Mag	Lambda	RP	Prob(T=1)	50	100	1000 years
2.0	2.6365e+000	3.79e-001	0.91288	1.00000	1.00000	1.00000
2.1	2.4538e+000	4.08e-001	0.89801	1.00000	1.00000	1.00000
2.2	2.2837e+000	4.38e-001	0.88172	1.00000	1.00000	1.00000
2.4	1.9778e+000	5.06e-001	0.84507	1.00000	1.00000	1.00000
2.5	1.8404e+000	5.34e-001	0.82483	1.00000	1.00000	1.00000
2.6	1.7123e+000	5.84e-001	0.80343	1.00000	1.00000	1.00000
2.8	1.4816e+000	6.75e-001	0.75756	1.00000	1.00000	1.00000
2.9	1.3778e+000	7.26e-001	0.73331	1.00000	1.00000	1.00000
3.0	1.2809e+000	7.81e-001	0.70836	1.00000	1.00000	1.00000
3.1	1.1905e+000	8.48e-001	0.68282	1.00000	1.00000	1.00000
3.2	1.1061e+000	9.04e-001	0.65684	1.00000	1.00000	1.00000
3.3	1.0273e+000	9.73e-001	0.63052	1.00000	1.00000	1.00000
3.4	9.5369e-001	1.05e+000	0.60400	1.00000	1.00000	1.00000
3.5	8.8491e-001	1.13e+000	0.57739	1.00000	1.00000	1.00000
3.8	7.0438e-001	1.42e+000	0.49808	1.00000	1.00000	1.00000
4.2	5.1362e-001	1.95e+000	0.39682	1.00000	1.00000	1.00000
4.4	4.3555e-001	2.30e+000	0.34931	1.00000	1.00000	1.00000
4.5	4.0018e-001	2.50e+000	0.32650	1.00000	1.00000	1.00000
4.6	3.6705e-001	2.72e+000	0.30484	1.00000	1.00000	1.00000
4.7	3.3599e-001	2.98e+000	0.28288	1.00000	1.00000	1.00000
4.9	2.7958e-001	3.58e+000	0.24207	0.99996	1.00000	1.00000
5.0	2.5398e-001	3.94e+000	0.22274	0.99991	1.00000	1.00000
5.1	2.2996e-001	4.35e+000	0.20413	0.99983	1.00000	1.00000
5.2	2.0742e-001	4.82e+000	0.18624	0.99966	1.00000	1.00000
5.3	1.8627e-001	5.37e+000	0.16906	0.99935	1.00000	1.00000
5.4	1.6641e-001	6.01e+000	0.15257	0.99877	0.99999	1.00000
5.5	1.4776e-001	6.77e+000	0.13678	0.99770	0.99997	1.00000
5.6	1.3025e-001	7.68e+000	0.12166	0.99576	0.99993	1.00000
5.7	1.1380e-001	8.79e+000	0.10720	0.99231	0.99982	1.00000
5.8	9.8338e-002	1.02e+001	0.09338	0.98626	0.99953	1.00000
5.9	8.3898e-002	1.13e+001	0.08019	0.97581	0.99882	1.00000
6.0	7.0148e-002	1.43e+001	0.06760	0.95805	0.99702	1.00000
6.1	5.7303e-002	1.75e+001	0.05560	0.92833	0.99254	1.00000
6.2	4.5223e-002	2.21e+001	0.04415	0.87937	0.98137	1.00000
6.3	3.3859e-002	2.95e+001	0.03326	0.79996	0.95364	1.00000
6.4	2.3167e-002	4.32e+001	0.02288	0.67318	0.88509	1.00000
6.5	1.3104e-002	7.63e+001	0.01301	0.47384	0.71621	0.99993
6.6	3.6319e-003	2.75e+002	0.00362	0.16521	0.30171	0.96211

The earthquake recurrence parameters in Nigeria using earthquakes covering the period 1933 to 2009 are:

BETA = 0.68 ± 0.00; (b = 0.29 ± 0.00);
 LAMBDA = 2.636 ± 0.685 (for Mmin = 2.00)
 Mmax = 6.64 ± 0.29 (for Mmax obs. = 6.50 ± 0.25).

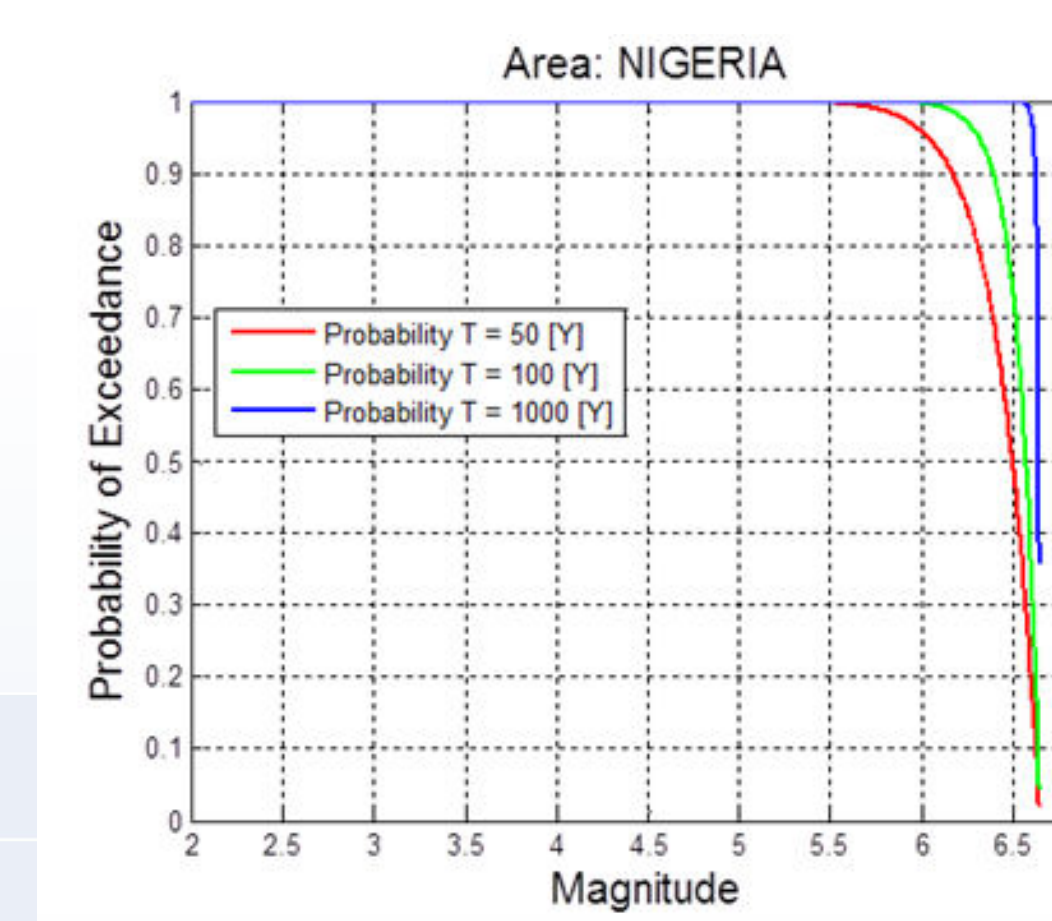


Fig. 7: Magnitudes and probability of Exceedance in Nigeria (1933-2009), given 50, 100, and 1000 years projection

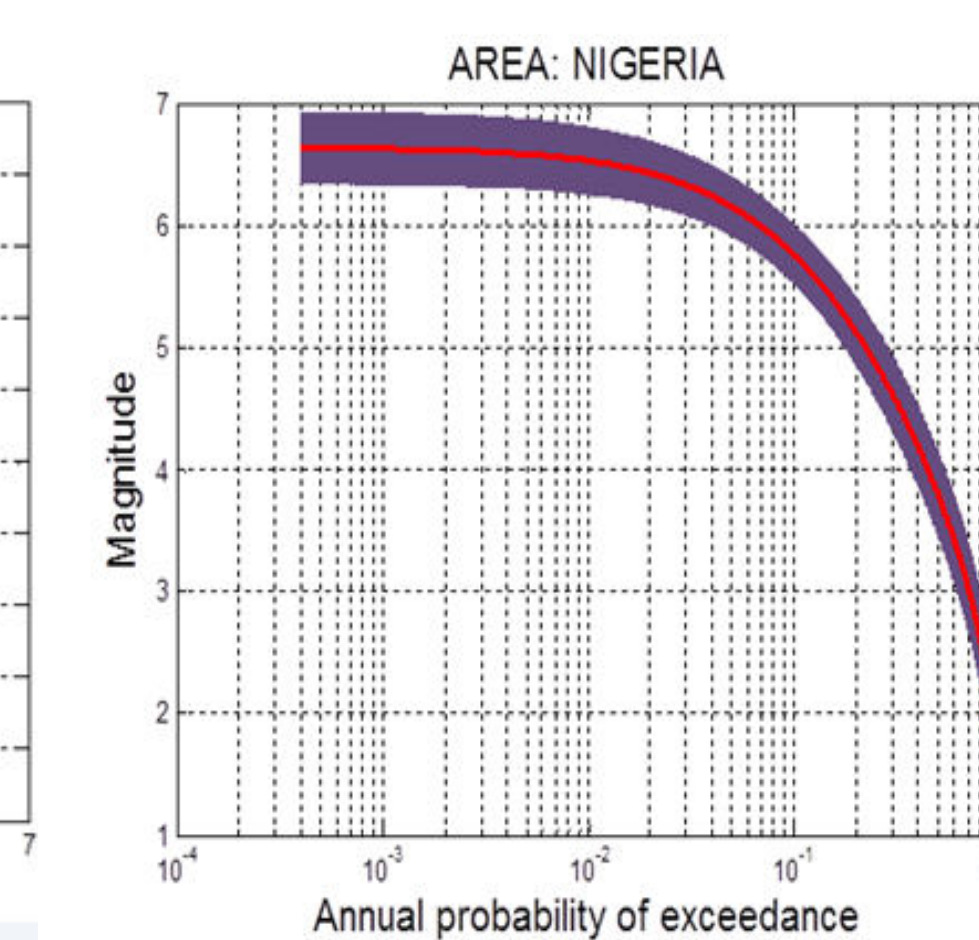


Fig. 8: Magnitudes and Annual Probability of Exceedance for Nigeria (1933-2009) projection

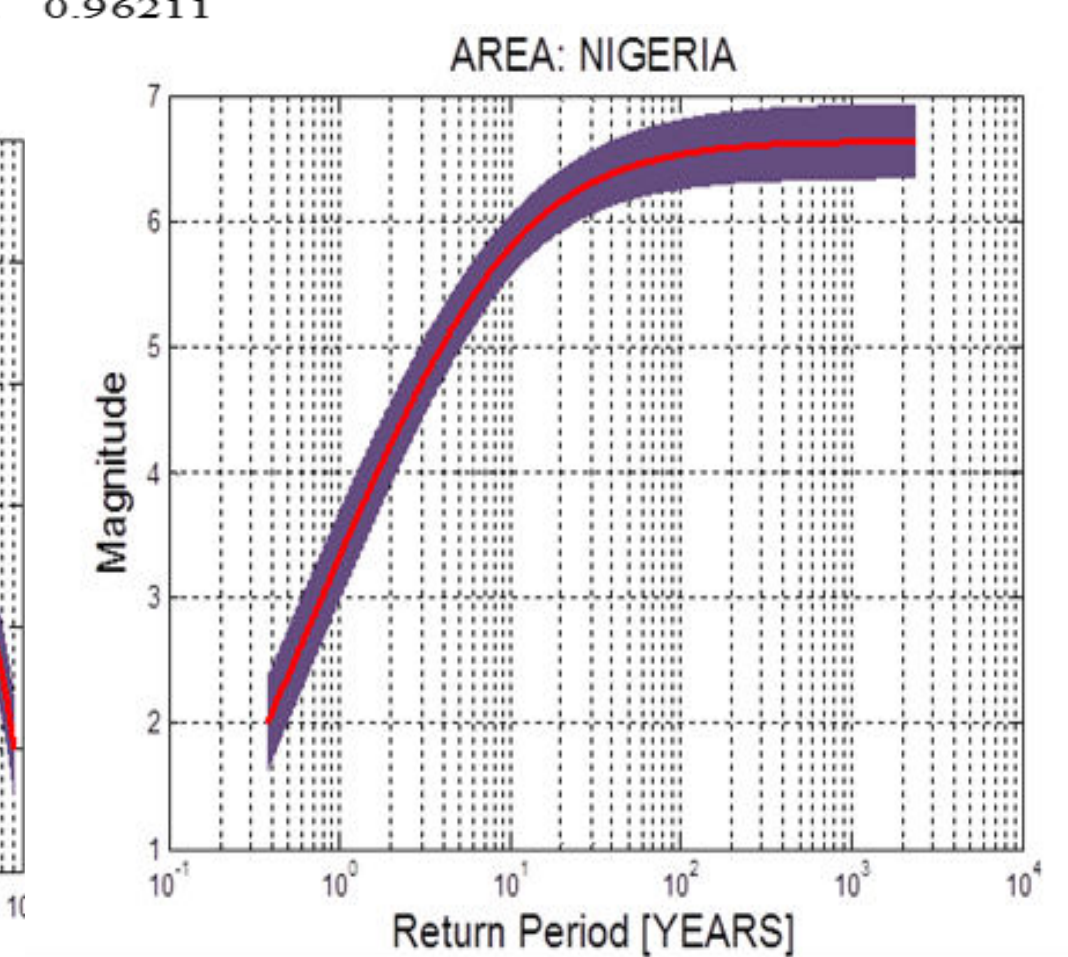


Fig. 9: Magnitudes and Return Periods (years) for Nigeria (1933-2009) projection

Figure 10 represent the gridded region used for earthquake hazard mapping on land to compute the Peak Ground Accelerations (PGAs) for Nigeria, while Figure 11 shows the computed PGAs for Nigeria. During the seismic mapping and gridding, areas covered with ocean were excluded in order to remove

