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SEISMIC DESIGN CONSIDERATIONS FOR EAST AFRICA

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ABSTRACT

It is our belief that as engineers, geologists, seismologists, architects and designers we have the responsibility to improve the world's infrastructure, so that the world becomes a more resilient place to live. Too often we take the easy option of "*doing what the code says*" and not thinking about how we can improve the status quo. This is important everywhere but essential in the developing regions so the investments made can make a real difference.

This paper is an example of work carried out at Arup to investigate the suitability and appropriateness of local codes in the East African region. The paper begins with examining the seismic hazard, by developing a new probabilistic seismic hazard model, then reviews the codes and makes recommendations for future development.

The East African region was chosen since several major earthquakes have occurred over the last century but luckily there have been few fatalities. Will this continue to be the case as major cities in the region grow at a fast pace?

Though these are still preliminary studies, and should be treated as such, we hope this information will allow more informed discussions with local governments, NGO's and investors so that more informed decisions can be made and hopefully the resilience of East African communities improved.

INTRODUCTION

East Africa is a developing market and constructing new infrastructure is one of the keys to the successful growth and prosperity for the region. However, the region is split by the active East African Rift Valley, which has a history of generating large earthquakes, such as:

- 7.4Ms Rukwa Tanzania earthquake on 13th December 1910 (Ambraseys, 1991a)
- 6.9M_S Subukia, Kenya earthquake on 9th January 1928 (Ambraseys, 1991b);
- 7.4M_S South Sudan earthquake on 20th May 1990; and
- 7.0M_W Manica, Mozambique earthquake on 22nd February 2006 (Fenton and Bommer, 2006).

Though earthquakes such as these have not led to significant loss of life or destruction of key infrastructure it is only a matter of time until this transpires. Ambraseys (1991a) was one of the first to highlight the increasing risk in East Africa from major earthquakes.

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Comparison of existing seismic hazard studies in the region, such as GSHAP (Giardini et al., 1999), seismic zonation maps in national codes, and more recent site specific studies, suggest that the hazard may be underestimated, sometimes significantly. For example GSHAP indicates the 475 year peak ground acceleration (PGA) on rock for Juba in South Sudan is 0.13 g, whilst Abdalla et al (2001) indicate a value closer to 0.3 g. Moreover, local seismic codes where they exist (Ethiopia, 1995; Kenya, 1973; and Uganda, 2003) are often obsolete, generally unconservative and worst of all often not adequately enforced. Therefore, as cities grow, both old and new structures could be at significant risk which apart to leading to loss of life could significantly derail the development aspirations of the region. Table 1 presents a very brief review of building codes and more specifically seismic requirements in East Africa.

Table 1: Review of East African seismic design requirements.

Country	**Code or Standard**	**Seismic Code?**	**Comments**
Ethiopia	Ethiopia Building Code Standard (EBCS) 1995, Volume 8 Seismic.	Yes	An earlier version of the code was based on UBC but the most recent version is based on the Draft ENV 1998:1994 Eurocode 8. This code is often used as a reference in other African countries for seismic design provisions. An updated code has been in development since 2013 but the authors were unable to obtain a draft.
South Sudan	No code exists.	No	Eurocode 8 is the international standard most often used as no formal building code is mandated in South Sudan.
Uganda	Ugandan Ministry of Lands, Housing and Urban Development, Building Regulations, 2005. Standard Seismic Code of Practice for Structural Design, June 2003.	Yes	Uganda has historically relied on British Standards in general. The country is in the process of adopting a code based on the latest version of Eurocode. The current seismic code is based on an older version of UBC. It does not apply to structures smaller than 20 m^2 or buildings over 30 storeys high.
Rwanda	Building Regulations Manual (2009) from the Rwanda Ministry of Infrastructure (MININFRA).	Yes	Building Regulations Manual refers to current British Standards, BS EN 1998 Eurocode 8 using a PGA of 1.6 m/s^2 and a return period of 475 yrs.
Burundi	Not known.	No	
Kenya	Code of Practice for the Design & Construction of Buildings & other Structures in relation to Earthquakes (1973).	Yes	Uses an intensity based zoning without a specified return period. Does not require seismic design for many structures 4 - 6 storeys or less depending on the zone and usage classification.
Tanzania	Not known.	No	Old British Standards (BS 8110 and BS 5950) are generally used. They do not include any provisions for seismic design.
Malawi	Various Malawi Standards including for building materials and construction practices.	No	
Djibouti	Not known.	No	
Democratic Republic of Congo	Not known.	No	Local engineers sometimes refer to old French codes.
Mozambique	A version of the Portuguese Code from the colonial era (Bommer 2010).	No	Local engineers are of the opinion that the code requirements are generally very conservative and therefore could provide un-intentioned lateral resistance against seismic loading (Bommer 2010). The South Africa Building Code (SABS) is sometimes used.

This study aims at providing an overview of the seismic hazard at principal cities in the East Africa region as well as a preliminary up to date guidance on seismic design specific to the region, so design engineers can provide resilient and sustainable solutions for local communities and regional and national governments.

To this end, a new probabilistic seismic hazard assessment has been developed for the region, which is based on collating the data from pre-existing published studies but making use of the latest earthquake data and ground motion predictive equations to derive revised hazard values. Seismic hazard criteria have subsequently been developed according to both the requirements of Eurocode 8 (EN 1998) and ASCE 7 for the principal cities within the region.

GEOLOGY AND TECTONICS

Africa is the oldest continent and had more or less taken on its current assemblage of cratons and intervening orogenic belts by the start of the Cambrian period 540 million years ago, following the Pan-African orogeny. Between then and the Cenozoic era the continent's current interior experienced a long period of relative stability as part of the Gondwana and Pangea super-continents. Separation of the super-continents and delineation of the current continental profile began around 200 million years ago, lasting till around 65 million years ago when South America and Madagascar finally drifted away from the African mainland.

Continental extension along the East African Rift System (EARS) started during the Tertiary around 45 million years ago and continues to the present day resulting in a significant level of seismic hazard in parts of southern and eastern Africa. In places the EARS follows the alignment of the earlier orogenic belts, including the Mozambique and Ubendian belts, and some re-activation of older faulting has occurred. The origin of the rifting is now generally believed to be related to rising thermal plumes in the mantle below Africa, which the continent has passed over during its drift north, hence the initiation and greater rates of spreading in the northern sections.

The East African Rift System comprises a series of connected fault bounded depressions separating the main African (Nubian) Plate from the Somali Plate. It extends for over 3000 km from the Afar triple plate junction, through east Africa and into Mozambique. South of Ethiopia it divides into the western and eastern (or Gregory) rift valleys around Lake Victoria and the Tanzania craton. The western branch is younger (12 million years) and more seismic whereas the eastern branch is more associated with volcanism.

The rift system also includes a number of major transform fault zones and secondary branches, some along the alignment of earlier orogenic belts, as follows:

- The Aswa (or Assoua) shear zone trending NW-SE across South Sudan and into Uganda and against which the western branch terminates.
- The Tanganyika – Rukwa – Malawi transform fault zone
- The North Tanzania Divergence where the eastern rift splits into three. An eastern Pangani branch runs south-east to link with marginal extensional basins along the Tanzanian coastline, a central Manyara – Balangida branch passes around the edge of the Tanzanian craton and links with the western rift at a triple junction near Lake Rukwa and a western branch which terminates against the craton near Lake Eyasi.
- The extensional basins in the Indian Ocean (Kerimbas – Lacerda rifts) continue south and have reactivated the Davie Ridge, an intercontinental transform along which Madagascar was displaced.
- The NE-SW trending Luangwa – Okavango (or Kariba) rift system, considered to be a nascent rift at the edge of the Okavango intracontinental delta.

GPS surveys indicate that extension is greater at the northern end of the East African Rift System at around 6.5 mm/year decreasing to 1mm / year at the southern end. Figure 1 shows an extract of the recent seismotectonic map for the region (Milanesi et al., 2010). The main branch and the secondary branch of the East African Rift system are highlighted by grey shadows while the main transform zones are in light blue (Dauteuil et al. 2009). The background colours show the geology of the East Africa area.

SEISMIC HAZARD ANALYSIS

The Probabilistic Seismic Hazard Assessment (PSHA) combines seismic source zoning, earthquake recurrence and the ground motion attenuation to produce hazard curves in terms of level ground motion and an associated annual frequency of exceedance. The basic methodology, based on Cornell (1968) and modified to include integration of the aleatory variability of the ground motion prediction equations, is implemented in the Arup in-house program Oasys SISMIC, which has been validated using the Pacific Earthquake Engineering Research Cente tests (Thomas et al., 2010).

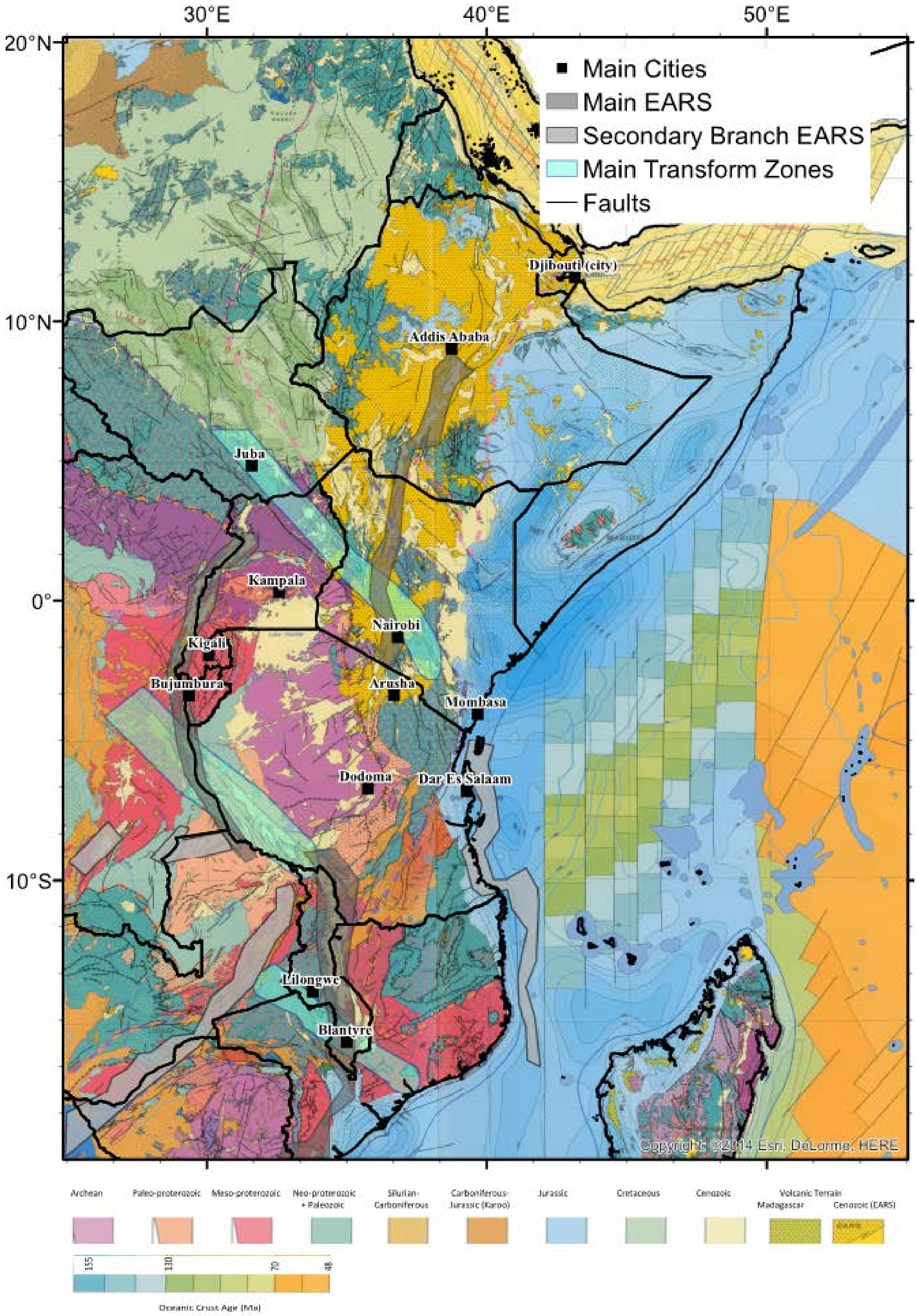

Figure 1: extract of the seismotectonic map for the region from Milanesi et al., 2010. The main branch and the secondary branch of the East African Rift system are in grey shadows while the main transform zones are in light blue (Dauteuil et al. 2009).

Earthquake catalogue and seismic sources model

As a first step an earthquake catalogue was assembled considering a study area bounded by Latitudes 10°N – 22°N and Longitudes 37.75°E –47.50°E. The data sources considered in this process are summarized in Table 1. The final catalogue (Figure 2) after the removal of the duplicates, fore-and aftershocks and conversion of magnitudes, includes 1972 seismic events occurred between 1631 and December 2013 with magnitudes $4 \leq M_w \leq 7.3$.

Table 2: Source data for the compilation of the earthquake catalogue.

Period	Reference	Time Period	Magnitude	Notes
Historical Period	Global Historical Earthquake (GEH) Catalogue	1000-1903	$M_w \geq 6$	The catalogue was compiled based on the review of 7 core references for the region
	NOAA/NGDC	2150BC-1903AD	$M \geq 4$	"uncritical" compilation of data
Instrumental period	ISC-GEM	1903-2009	$M_w \geq 5.5$	Groomed version of the ISC Catalogue for >5.5M_w events.
	EHB	1960-2008	$M_w \geq 4$	Update of ISC catalogue based on the hypocentrelocation algorithm by Engdahl *et al.* (1998).
	Reviewed International Seismological Centre (ISC) catalogue	2009-2011	$M_w \geq 4$	Hypocentre location algorithm by Bondar & Storchak (2011). From 2011 to 2013 the seismic events are not reviewed in the catalogue
	National Earthquake Information Centre (USGS/NEIC)	2011-2013	$M_w \geq 4$	Preliminary earthquake data from USGS. Source of most recent events.

The seismic source zones (SSZ) have been defined based on the distribution of observed seismicity together with the simplified tectonic features identified in the area (see Figure 2).These zones represent areas where the seismicity is assumed to be homogenous, i.e. there is an equal chance that a given earthquake will occur at any point in the zone. Faults capable to produce moderate-to-large earthquakes, with e.g. a characteristic behaviour are not considered in this preliminary model, although they will be included in the future. Note that the simplified transform zone in the south (blue shadow zone in Figures 1 and 2) does not have any associated event and thus, it wasn't modelled in the analysis. This may be reviewed in the future.

In order to evaluate the completeness of the catalogue, the seismic sources were geographically grouped, accounting for the main seismotectonic features of the region. A visual cumulative method with the basic assumption that on a time scale of decades, the rate of seismic occurrence for the earth is roughly constant, was adopted and checked against the Stepp (1972) approach. Table 3 shows the completeness results, highlighting that the catalogue cannot be considered complete between magnitude 4 and 4.5.

Table 3: Threshold years (Tc) starting from which the earthquake catalogue is considered complete. The last row indicates the maximum observed magnitude in each group.

M_w	Group 1	Group 2	Group 3	Group 4	Group 5
4.0	-	-	-	-	-
4.5	1980	1980	1980	1980	1980
5.0	1960	1960	1960	1960	1960
5.5	1960	1960	1960	1960	1960
6.0	1900	1900	1900	1900	1900
$M_{max,obs}$	**7.1**	**7.1**	**6.8**	**7.3**	**7.3**

A model of earthquake recurrence with respect to magnitude is needed for the description of the seismicity. There are, generally, more small (low-magnitude) earthquakes than large (high-magnitude) earthquakes. Again, observed seismicity is used to determine the earthquake recurrence relationships. Two basic assumptions are made for these SSZs: (i) the temporal behaviour of the seismicity can be approximated with a Poissonian distribution; and (ii) the magnitude distribution of seismicity is represented by the truncated Gutenberg and Richter (1956) power law model. In our study the minimum magnitude threshold is M_{min}=4. The upper bound limit, M_{max}. is required in order to prevent the possibility (even small) that an infinitely large earthquake be assigned a non-zero occurrence rate and it is estimated with consideration of the tectonic properties of the SSZ. In this study the maximum magnitude value observed in each completeness group was assigned to each source.

The regression of the seismicity rates was performed through a maximum likelihood approach, as formulated by Weichert (1980), which (1) accounts for the fact that the smaller the number of the events represented by the cumulative rate and the lower the reliability of recurrence value and (2) handles varying levels of catalogue completeness. Table 4 shows the Gutenberg-Richter parameters in terms of b-value, its standard error σ_b and the annual number of earthquake with $M_w \geq 4$, as well as the observed maximum magnitude, $M_{max,obs}$, associated with each source.

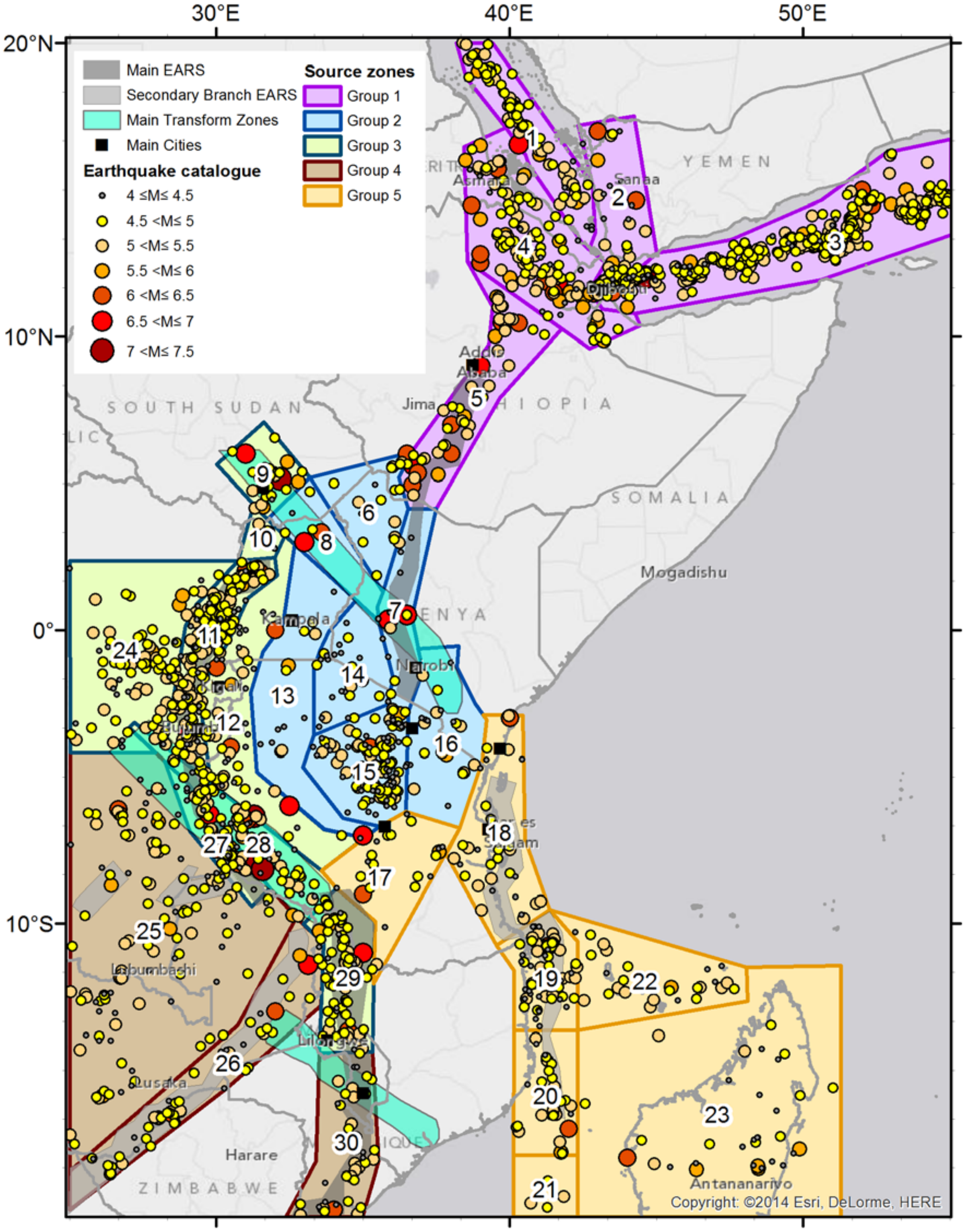

Figure 2: Final earthquake catalogue (graduate circles) and seismic source model (coloured polygons) developed for the area. The main simplified tectonic features are also shown (grey and blue shadowed zones) as well as the cities where the PSH results are computed.

Ground motion prediction equations

The last ingredient for estimation of seismic hazard is the description of the ground motion attenuation, generally performed using empirical ground-motion prediction equations (GMPEs), also referred to as or attenuation relationships. These models provide the expected ground motion parameters of engineering interest, such as response spectrum ordinates, as a function of a few independent parameters (magnitude, source-to-site distance, site classification, focal mechanism, etc). The variability of these predictions is usually referred to as aleatory variability and is represented by the standard deviation (or standard error, $\sigma_{\log}$) of the logarithmic residuals.

Table 4: Parameters of seismicity for the 30 seismic source zones.

Zone ID	**Area (km^2)**	b	σ_b	$N(M\geq4)$/yr.	$M_{max,obs}$	$M_{max,obs}$ (group)
1	116333	1.11	0.101	7.315	6.6	7.1
2	112911	0.84	0.19	0.759	6.3	7.1
3	356011	0.97	0.039	29.233	7.1	7.1
4	250335	1.00	0.085	6.991	6.6	7.1
5	164020	0.72	0.09	2.169	6.8	7.1
6	100642	1.13	0.255	1.298	6.3	7.1
7	89133	0.65	0.223	0.302	7.0	7.1
8	82860	0.62	0.267	0.19	6.8	7.1
9	64219	0.93	0.154	1.525	7.1	6.8
10	21292	1.14	0.497	0.309	5.4	6.8
11	118191	0.91	0.062	8.692	6.6	6.8
12	207271	0.76	0.11	1.552	7.3	6.8
13	206845	0.87	0.235	0.619	6.9	7.1
14	103694	1.62	0.383	2.861	5.5	7.1
15	131725	1.23	0.107	10.352	6.5	7.1
16	153999	1.11	0.24	1.376	6.0	7.1
17	137302	0.95	0.218	0.818	6.5	7.3
18	182688	0.98	0.17	1.507	6.1	7.3
19	99815	1.01	0.132	2.81	6.3	7.3
20	110074	0.97	0.164	1.549	6.1	7.3
21	53428	1.11	0.477	0.313	5.0	7.3
22	179515	0.98	0.182	1.313	5.7	7.3
23	785114	0.80	0.165	0.819	6.1	7.3
24	315801	1.13	0.122	4.97	6.0	6.8
25	808124	1.09	0.097	7.035	6.3	7.3
26	204899	1.08	0.11	5.355	6.7	7.3
27	51291	0.85	0.117	1.92	7.2	6.8
28	101252	0.91	0.104	3.08	7.2	6.8
29	113933	1.13	0.108	6.361	6.8	6.8
30	138816	1.14	0.179	2.536	6.1	7.3

In order to capture the epistemic uncertainty related to the attenuation of ground motion in a seismic hazard analysis, more than one ground-motion prediction equation should in general be usedcombining multiple models is the logic tree. According to Cotton et al. (2006) and Bommer et al. (2010) candidate GMPEs for a logic tree should be selected so as to obtain the smallest possible suite of equations that can capture the expected range of possible ground motions in the target region. From a comprehensive list of available equations several rejection criteria are defineds such as that the model is from a clearly irrelevant tectonic regime.

For the East Africa area a few regional GMPEs were developed, such as those by Jonathan (1996) and Twesigomwe (1997), both using data from Eastern and Southern Africa earthquakes. However, these models have not been included in this analysis since they are developed only for the peak ground acceleration (PGA) and for hard rock sites.

Ground motion models for shallow crustal environments in active tectonic regions (ASCR) have been selected to preliminarily model the distribution of ground motions in East Africa. However, a more detailed study is required to better investigate the type of attenuation occuring in the area. Table 5 shows the main characteristics of the attenuation equations for the SSZs included in the study: two are from the Next Generation Attenuation (NGA West 1) project, Abrahamson and Silva (2008) and Campbella dn Bozorgnia (2008), mainly based on Californian data and the third one is Akkar et al. (2013) based on records from Europe and Middle East.

All the computations assume rock sites with V_{s30}=760 m/s. The depth at which the shear wave velocity reaches 1 km/s and 2.5 km/s, $z_{1.0}$ and $z_{2.5}$ respectively, have been estimated according to the guidance in the papers.

Table 5: Selected Ground Motion Attenuation Equations

GMPE	**Region**	**Regime**	**Mean**	**M**	**R**	**Focal Mech**	**Soil**	**T_{max} (s)**
Abrahamson and Silva (2008), AS2008	Worldwide (California)	ASCR	G_{Mro}	M_W	R_{rup} R_{jb}	REV, SS, N	$V_{s,30}$	10.0
Campbell and Bozorgnia (2008), CB2008	Worldwide (California)	ASCR	G_{Mro}	M_W	R_{jb}	REV, SS, N	$V_{s,30}$	10.0
Akkar and Bommer (2010), AB2010	Europe and Middle East	ASCR	GM	M_W	R_{jb}	REV, SS, N	Soil classes	3.0
GM: geometric mean; G_{Mro}: rotated geometric mean (Boore *et al,* 2006); Focal Mechanism – Normal (N), strike-slip (SS) and reverse (REV) style of faulting; T_{max} (s) – Maximum response period in seconds for which a GMPE is formulated.								

Treatment of uncertainties: the logic tree approach

In the PSHA the uncertainties affecting the different parameters play a critical role. They are generally divided into epistemic and aleatory uncertainties. In simple terms, the epistemic uncertainty is due to incomplete data and knowledge regarding the earthquake process (including the characteristics of the seismic sources, the model of earthquake occurrence processes, the maximum magnitude, the description of the ground motion attenuation). On the other side, the aleatory uncertainty is related to the unpredictable nature of future earthquakes. Thus, most important among the aleatory uncertainties are associated with the ground motion predictive equations (GMPEs), and are quantified by the standard deviation of the prediction.

The standard procedure for accounting for the epistemic uncertainties is to include the different possible choices of the input parameters in a logic tree. The approach was firstly introduced by Kulkarni et al. (1984). Each branch of the tree represents a different choice regarding a specific step of the analysis, and a normalized weight is assigned to it. The final result derives from the combination of the "weighted" hazard curves calculated by following all the possible branches of the logic tree.

Figure 3 shows the logic tree developed for this study, as well as weights assigned to each choice. In particular the following uncertainties have been included:

- *b*-value
- M_{max} of the SSZ. Due to the incompleteness of the earthquake catalogue it has been assumed: $M_{max,Low}$= $M_{max,obs}$, M_{max} = $M_{max,,obs}$+ΔM and $M_{max,High}$ = $M_{max,obs}$+2ΔM, where $M_{max,obs}$ refers to the maximum magnitude observed in the groups of sources (see Table 2) and ΔM=0.5.
- GMPE.

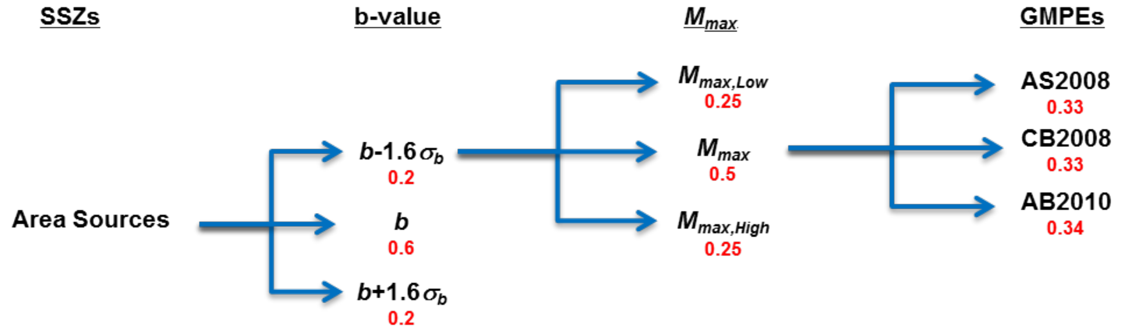

Figure 3: Logic tree adopted in the analysis.

One key question in any PSHA calculation for very low probabilities of exceedence (long return periods) is how many standard deviations around the median value should be used in the analysis. It has been shown (Strasser et al., 2008) that a value between three and four is probably appropriate, though it is still subject to some debate. For the purpose of this analysis, five standard deviations have been used.

Seismic Hazard results

The results of a PSHA are expressed in terms of uniform hazard response spectra (UHRS) which indicates, for a fixed annual probability of exceedance (return period), the value of the ground motion parameter vs. the structural periods. In this study the 5%-damped UHRS on rock are computed for return periods of 475 yr. (probability of 10 % in the next 50 yr.) and of 2,475 yr. (i.e. probability of 0.02% in the next 50 yr.) at 13 principal cities in the East Africa region.

Figure 4 shows the UHRS spectra for 475 yr.-RP at the 13 cities considered in this study (grey curves). The EN 1998 (blue grey) elastic design spectra and the ASCE07-05 (red curves) elastic design spectra are also plotted in the same figure. The comparison between the two design codes highlitghts the more conservative shape of EN 1998 at intermediate and long period (T>~0.3s), while in most cases ASCE07-05 spectra, as expected, fit better the UH spectral shape.

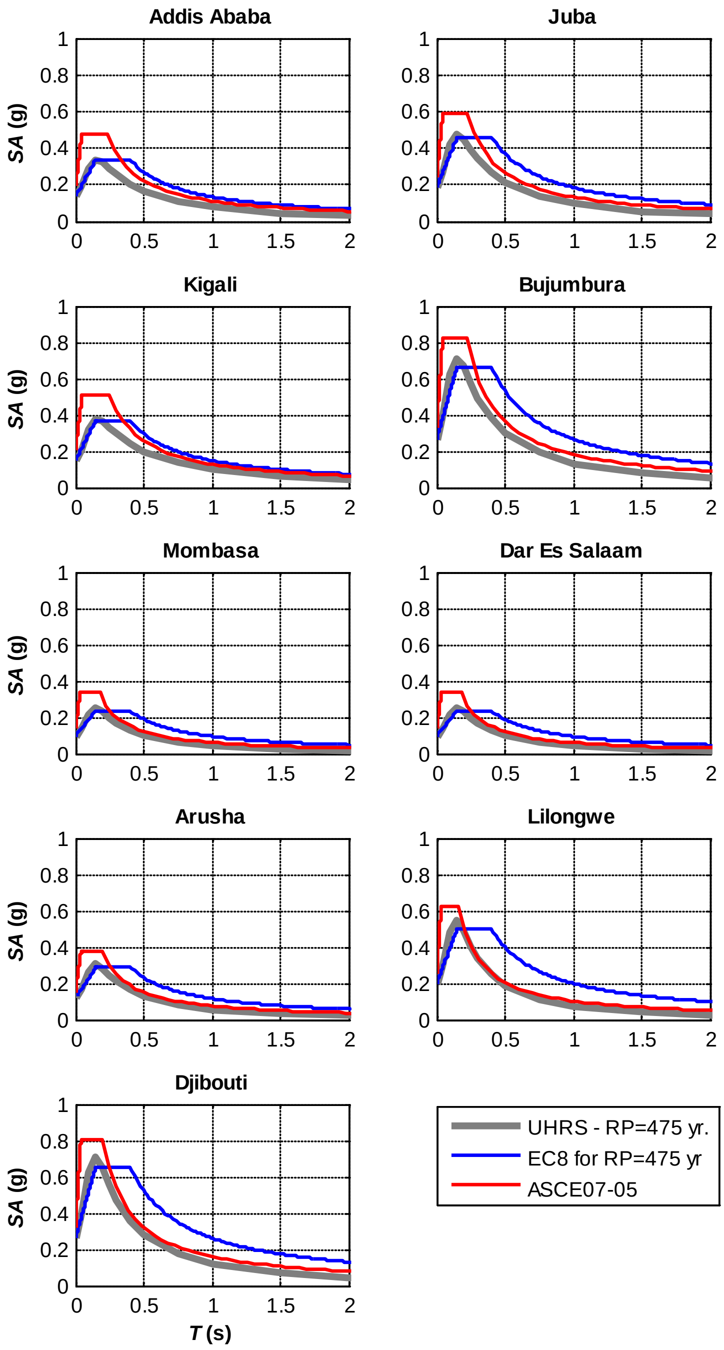

Figure 4: Uniform hazard spectra at selected main cities in East Africa (grey thick curves) compared with the elastic acceleration spectra derived from EN 1998 based on the PGA for RP=475 yr. (blue curves) and those from ASCE07-05 (red curves).

Table 6 shows the spectral values at T=0 s (PGA), 0.2 s and 1 s for both RP=475 and 2475 yr., as well as the values provided by GSHAP. It is highlighted that the PGA values for RP=475 yr. derived in this study are generally larger than those provided by GHSAP with differences larger than three times in Mombasa, Dar Es Salaam, Dodoma and Lilongwe. It also shows the highest hazard is in Bujumbura and Djibouti, again substantially higher than the equivalent GSHAP values.

Table 6: PSHA results in terms of spectral acceleration at T=0 s (PGA), 0.2 s and 1 s for RP=475 and 2475 yr. The PGA values provided by GSHAP are also show for comparison.

		SA(ζ=5% - RP=475 yr.) (g)		**SA(ζ=5% - RP=2475 yr.) (g)**		
Country	**City**	**PGA**	**PGA GSHAP**	**PGA**	**SA (T=0.2s)**	**SA (T=1s)**
Ethiopia	Addis Ababa	0.13	0.11	0.29	0.71	0.17
South Sudan	Juba	0.18	0.13	0.36	0.89	0.20
Uganda	Kampala	0.09	0.09	0.18	0.45	0.13
Rwanda	Kigali	0.15	0.06	0.31	0.76	0.19
Burundi	Bujumbura	0.27	0.13	0.48	1.24	0.27
Kenya	Nairobi	0.09	0.06	0.21	0.54	0.14
Kenya	Mombasa	0.09	0.01	0.20	0.51	0.09
Tanzania	Dar Es Salaam	0.09	0.03	0.20	0.50	0.09
Tanzania	Dodoma	0.12	0.03	0.23	0.56	0.12
Tanzania	Arusha	0.12	0.16	0.23	0.56	0.11
Malawi	Lilongwe	0.20	0.05	0.37	0.94	0.15
Malawi	Blantyre	0.12	0.09	0.25	0.62	0.10
Djibouti	Djibouti	0.26	0.17	0.47	1.21	0.24

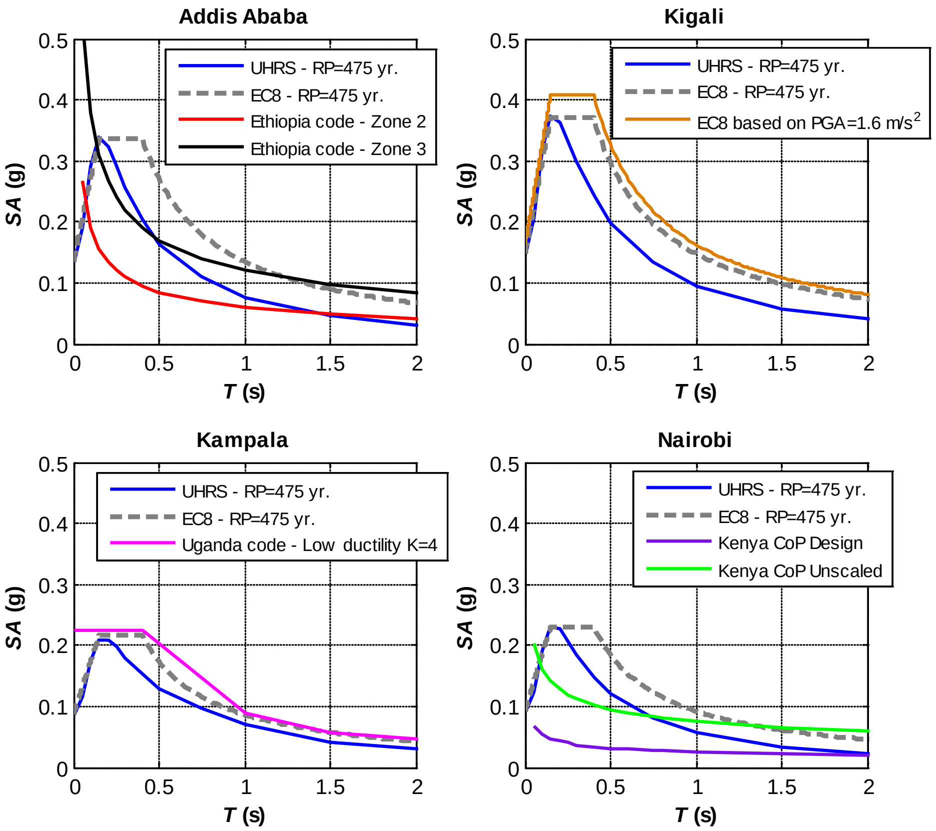

Figure 5: Uniform hazard spectra at Addis Ababa, Kigala, Kampala and Nairobi (blue curves) compared with the elastic acceleration spectra derived from EN 1998 based on the PGA for RP=475 yr. and country seismic code criteria.

COMPARISON TO EAST AFRICAN SEISMIC CODES

A comparison of the UHRS in Addis Ababa, Kampala and Nairobi with the elastic seismic code spectra for each country has been performed and the results are shown in Figure 5. The methodology for the code criteria is described and the results of the comparison are discussed in Table 7.

Table 7: UHRS RP=475 yr. results comparison with seismic code spectra

City	Seismic Code Methodology	Code base shear coefficient calculation	Discussion
Addis Ababa	The EBCS 1995, Volume 8 Seismic provides a zoning map for the country based on a 100 yr return period.	$C_s = \alpha_0 I \beta_0 S \gamma$ where $\alpha_0 = 0.05$ for Zone 2 (Addis Ababa) $\beta_0 = 1.2/T^{2/3}$ S = 1.0 for rock (vs30 > 800 m/s) I = 1.0 $\gamma = 1.0$ for elastic spectra	It is not possible to directly compare our results as the code criteria are based on a different return period. As Addis Ababa sits so near the border to Zone 3 ($\alpha_0 = 0.07$), this is also shown and it may be advisable to adopt Zone 3 criteria for the city. Worku (2011) also points out that the EBCS significantly underestimates the effects of site soil amplification, leading to significant underestimate of the hazard for most sites.
Kampala	Standard Seismic Code of Practice for Structural Design, June 2003 is assumed to be based on a 475 yr. return period as it is based on a version of UBC.	Cd(T) = C(T)ZIK where Z= 0.7 for Zone 3 (Kampala) I = 1.0 K = 4.0 for structures of minimal ductility	Due to the method of multiplying up by a K factor depending on the type of lateral system, there is not a directly comparable elastic code spectra. The least ductile type has been chosen instead for the purposes of comparison. The code is capturing the hazard well for this example when compared to our UHRS results.
Nairobi	Code of Practice for the Design & Construction of Buildings & other Structures in relation to Earthquakes (1973) does not have a specified return period.	C is specified by type of ground and intensity zone in tabular form. For this comparison, Table 3 was referred to for flexible frames for Zone VII (Nairobi) and Hard/Medium ground assumed $C = 0.5(0.05/T^{1/3})$	Once again, it is difficult to compare to the elastic UHRS 475 yr results as the Kenyan code is based on intensity (perception of damage) rather than acceleration and does not specify a return period. Response modification factors for difference structural types are not given so a factor of 3 has been used to scale up the design spectra. This would be an appropriate factor for a system with limited ductility such as an ordinary concrete moment frame. This comparison implies that the Kenya code may significantly underestimate the hazard for the short period range (T< 0.7 sec) for Nairobi.
Kigali	Building Regulations Manual (2009) from the Rwanda Ministry of Infrastructure (MININFRA) refers to BS EN 1998 Eurocode 8 using a return period of 475 yr.	$a_{gR} = 1.6\ m/s^2$ (0.16 g) $\gamma_I = 1.0$ S= 1.0 for rock $\eta = 1$ for 5% damping	The building regulations refer to the British version of Eurocode 8 but then specifies a different return period than in the UK Annex. No specific provisions of the Eurocode are given in the regulations. The regulations are capturing the hazard well for this example when compared to our UHRS results.

CONCLUSIONS

This paper has proposed a new seismic hazard model for the East African region. Though the model still requires further development (e.g. inclusion of specific faults etc) it shows that the existing seismic hazard models such as GSHAP underestimate the seismic hazard in many of the major cities in the region.

A comparison of the seismic hazard against four local codes shows a similar situation, except for the more recent seismic codes for Uganda and Rwanda. Based on this preliminary study it would seem more appropriate to use a more modern code such as Eurocode 8 or ASCE 7 when undertaking new developments in the East African region.

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