TECHNICAL NOTES

NOTES AND PROPOSED GUIDELINES ON UPDATED SEISMIC CODES IN ETHIOPIA
IMPLICATION FOR LARGE-SCALE INFRASTRUCTURES

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ABSTRACT

In light of recent expansion in the planning and construction of major building structures as well as other infrastructures such as railways, mass-housing, dams, bridges, etc, this paper reviews the extent of seismic hazard in Ethiopia and proposes a review and update of the current out-dated and - in most cases - non-conservative seismic code. In specific terms, the last three seismic codes are reviewed and a comprehensive set of discussions on seismic zoning and PGA (peak ground acceleration), special provisions in concrete and steel beams and columns design, and seismic analysis are provided through a comparison with major international building codes. Sets of recommendations in updated and conservative seismic zoning, need for separate seismic codes for non-building type structures, a choice of 475 years as return-period instead of the current 100 years, and a revisit of the basic seismic design philosophy to focus on performance basis are provided.

Key-words *– seismic design, building code, seismic hazard, earthquake, infrastructure, codes and standards.*

INTRODUCTION

The current economic expansion in Ethiopia which seems to be driven by a number of enabling factors has had substantial impact in the transportation, energy, and water supply sectors with a growing number of large-scale infrastructure projects such as dams, power-plants, highway roads, water reservoirs, and expansion of railways either coming online or entering construction phase. Furthermore, pressure from other natural developments - the staggering population growth of the country being a primary one - continue to force rapid implementation of large-scale engineering infrastructure works such as mass-housing, water-supply reservoirs, power-plants, dams, new cities, etc. As things stand, the country's population is projected to reach a staggering 120 million by 2025 positioning Ethiopia to be among the top 10-15 populous countries on the planet (see Fig. 1) [1-3].

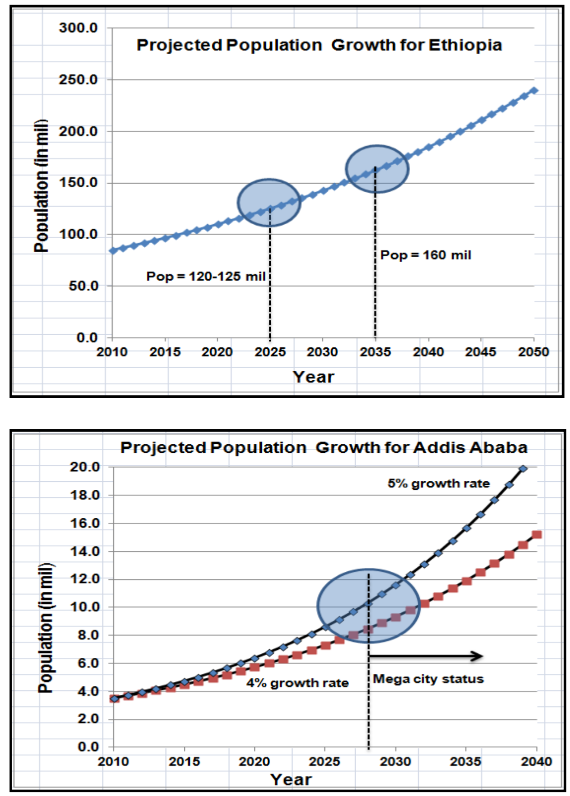

Figure 1 Population Projection - (a) Ethiopia (b) Addis Ababa [1-3].

In addition to a multitude of other threats that this population growth could bring, the issue of housing these additional 30-40 million Ethiopians in the next few decades will pose a huge risk factor. In a recent paper, it has been argued that 25 new cities with size equivalent to present Dire Dawa are needed or the current 10 cities such as Addis Ababa and Dire Dawa will have to become mega cities of 10 million or more to accommodate this growth [4]. While these projections regarding urbanization may be a little bit on the high-side, there is no denying regarding the need for housing these additional millions of citizens in the next several decades.

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Interestingly, however, a substantial amount of these large infrastructure works already lie or will be in or in close proximity to the some of the most seismically active regions of the country such as Afar Triangle, the Main Ethiopian Rift (MER), and the Southern Most Rift (SMR) where well-documented damage-causing earthquakes are common. A review of the engineering reports associated with some of the largest and most expensive infrastructure projects in the country suggest that - despite the presence of a substantial amount of published literature on the significant seismicity of the region - the severity of threats posed by seismic hazards on the safety and serviceability of these structures is not well-understood by the main stake-holders such as policy-makers, insurance companies, real-estate developers, capital investors, building design-checkers and, not infrequently, the engineering community itself as well.

Against this background, therefore, the need for preparing for this real and substantial threat of seismic hazards in the country is pressing and requires attention at all levels. It is relevant to mention that, in this paper, the discussions on seismic hazard pertain to both building-type structures as well as other structures such as railways, bridges, dams, power-plants and the like. However, since the existing seismic code in the country covers only building structures, the discussions here are a bit biased towards buildings. Historically, the country had adopted three revisions of seismic codes (specifically for building structures) since 1978 to address seismic hazards. The enforcement of building code standards to *'determine the minimum national standard for the construction or modification of buildings or alteration of their use in order to ensure public health and safety'* was not legislated until 2009 [5]. This is certainly an encouraging progress with (a) requirements and mechanisms for building plan/design checks/reviews by building officials outlined (Part Two - Administration), and (b) requirements for ensuring *'safety for people, other construction and properties"* by designing buildings according to *'acceptable building design codes'* now legislated (Part Three - Land Use & Designs). However, several fundamental problems still main before rationale seismic design is practiced well in the country. These are: (i) there is growing evidence that the current building codes themselves are inadequate, out-dated, and not stringent enough when compared to the level of seismic risks associated with the country [6], (ii) ambiguities that exist in this first legislation attempt that do not explicitly address the seismicity of the country (i.e., Part Three-Design, Item 34 that reads *"buildings may not exhibit signs of structural failure during their life span under normal loading")* may give a ground for stake-holders to ignore seismic effects because *'normal loadings'* may arguably not include seismic loads, and (iii) the mechanism for enforcing strict adherence through design checks at the municipality offices (as opposed to external peer-review system) is inadequate because it relies on design-checkers who are neither well-aware of the seismicity of the country nor well-trained in seismic design to start with. Further, the legally mandated requirements and design review process do not apply to public and government large-scale infrastructures (dams, railway structures, electrical transmission structures, etc) which actually are the sources of some of the major concerns. Therefore, ambiguities of the new building construction law coupled with the lack of awareness and mechanism for truly enforcing code requirements continue to introduce a significant risk of endangering the useful life of these expensive projects as well as human life.

In this research report, therefore, the objective is to (i) demonstrate that there is substantial amount of literature on seismicity in Ethiopia that needs to be disseminated to a wider audience, (ii) provide a background and critical review of the last three building codes of the country, (iii) provide a background argument and facts that could serve as starting points for the long-awaited complete review of the current out-dated seismic code, and (iv) propose guidelines for rationale and conservative seismic design in Ethiopia and surrounding countries for large-scale projects with particular emphasis on dams, highway structures, as well as railways and railway structures.

SEISMIC HAZARD AND ITS HISTORICAL RECORD IN ETHIOPIA

Review of Historical Records of Earthquake

It is well established now that, due to its location right on some of the major tectonic plates in the world, i.e., the African and Arabian plates, earthquakes have been a fact of life in Ethiopia for a very long time. The earliest record of such earthquake dates as far back as A.D.1431 during the reign of Emperor Zara Yaqob [7]. In the 20th century alone, a study done by Pierre Gouin suggests that as many as 15,000 tremors, strong enough to be felt by humans, had occurred in

Ethiopia proper and the Horn of Africa [7]. A similar study by Fekadu Kebede [8] indicated that there were a total of 16 recorded earthquakes of magnitude 6.5 and higher in some of Ethiopia's seismic active areas in the 20th century alone. The most significant earthquakes of the 20th and 21st centuries like the 1906 Langano earthquake, the 1961 Kara Kore earthquake, the 1983 Wondo Genet earthquake, the 1985 Langano earthquake, the 1989 Dobi graben earthquake in central Afar, the 1993 Adama earthquake, and the 2011 Hosanna earthquake were all felt in some of the major cities in the country such as Addis Ababa, Jimma, Adama and Hawassa. In addition to Gouin's book that describes the earthquakes of 1906 and 1961 that shook Addis Ababa and caused widespread panic, a recently published Amharic biography of Blaten Geta Mersie Hazen Wolde Qirqos vividly describes the effect of the 1906 Langano earthquake in Addis Ababa and Intoto [9].

"In the afternoon of Nehase 19, 1898 (August 25, 1906), there was a very large earthquake. The whole day was marked by a huge pouring of rain mixed with lightning and thunder. The earthquake in the middle of such rain and thunder caused many to panic thinking doomsday had come. I was studying oral traditional lessons leaning against the pillar of the house when the earthquake struck. I was thrown off-balance and fell to the ground. As the roof rumbled, we thought a calamity had befallen Intoto and fear gripped us. The people then pleaded with the Almighty".

In addition to these well-documented seismic events starting from the 15th century, a number of earthquakes have shaken the Main Ethiopian Rift (MER), and the Southern Rift Valley of the country recently between 2005 and now bringing the danger of seismic hazard to the forefront [10-15]. As built up environments and human development activities increase in areas close and within the MER, the Afar Triangle and the Southern Rift Valley of the country, it is expected that the damage on property and loss of human life due to seismic hazard will increase very significantly. Because this period coincides with noticeable infrastructure build-out through the majors regions of the country, a review of these events and the damages that they had caused will be provided later One of the important observations is that newer buildings are experiencing damages under these relatively moderate earthquakes of magnitude around 5.0.

Review of Seismic Mechanisms and Seismicity in Ethiopia

There is a comprehensive amount of literature in the area of seismology in the Afar Triangle and Main Ethiopian Rift (MER) regions of Ethiopia [7, 16-25]. An extensive amount of earthquake records on Ethiopia that extend up to the 15-th century exist [7]. Publications on research on the seismicity of the Horn of Africa, in general, and Ethiopia proper, in particular, date as far back as 1954. The seismicity of the Afar Triangle, specifically that of the so-called Wonji Fault belt has been studied by Gutenberg and Richter who located 23 earthquakes in the area [17]. A further five events were located by Sykes and Landisman [18] and Fairhead [19] for the period January 1955 to December 1963. These included an event north-east of Lake Turkhana and an event close to Chabbi volcano near Hawassa. Later notable publications include that of Mohr [20-22], Mohr & Gouin [23], Gouin [24], Gouin and Mohr [25].

The seismicity of the neighboring region of Kenya which forms a natural extension of the southern Ethiopian Main Rift (MER) for the period of 1880-1979 is also well documented by Shah [26]. In extension, the seismicity of the East African Rift System has been studied by Gutenberg and Richter [17] , Sykes and Landisman [18] and Fairhead [19]. More localized studies have been made by Sutton and Berg [27], De Bremaecker [28], and Wohlenberg [29]. Fig. 2.a gives a distribution of seismic events in and around Ethiopia up until 1995 [30-31]. Fig. 2.b summarizes the number of publications that had appeared over the past few decades with the key word of 'Ethiopia earthquake'.

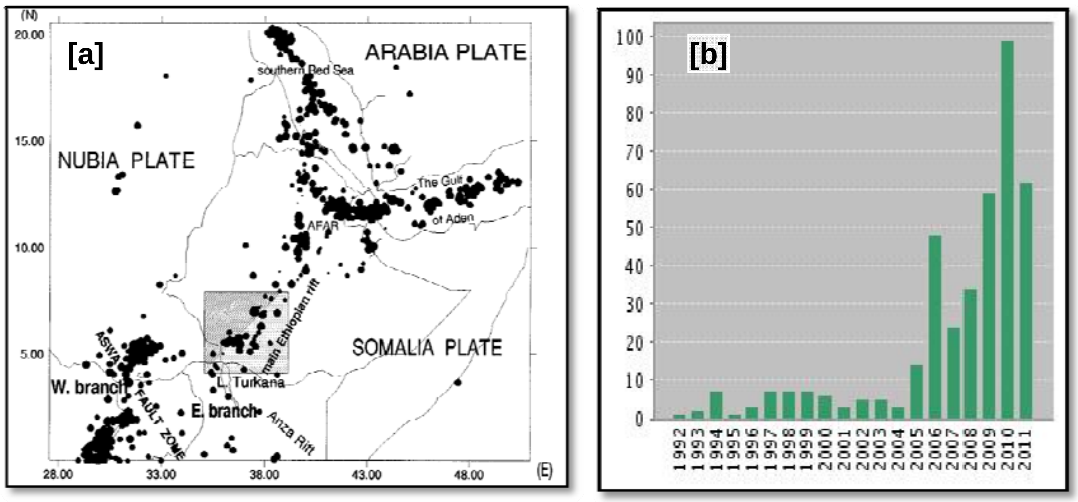

Figure 2 (a) Seismicity of Ethiopia, with particular emphasis on the Main Ethiopian Rift as well as the southern Rift Valley (Atalay Ayele 1995) [30-31]. The dots represent earthquake locations. (b) Distribution of published literature on earthquakes in Ethiopia

In terms of the mechanism that give rise to seismic hazard, the well-accepted theory suggests a simplified model that typically considers three distinct seismic zones in Ethiopia proper. These are: the Afar Triangle seismic zone (which further consists of the junction between Red Sea, Gulf of Aden, and the Main Ethiopian Rift), the Escarpment seismic zone (characterized by N-S running faults associated with some of the devastating earthquakes such as the 1961 magnitude 6.7 Kara Kore earthquake), and the Ethiopian Rift System seismic zone (which links the Red Sea, Gulf of Aden with the East African Rift System through the Afar Triangle) [32]. Kebede and Asfaw - based on recent data and recent developments in the understanding of the tectonics of the region - have proposed a more complicated model consisting of eight unique seismic zones in proper Ethiopia and its surroundings as main contributors of damaging earthquakes [33]. These are (i) the Aswa shear zone in South Sudan (Zone 1), (ii) the southernmost rifts (SMR) of Ethiopia and Main Ethiopian Rift (MER) (Zone 2), (iii) the western margin of Afar depression (Zone 3), the Afar depression including Djibouti (Zone 4), the region connecting northern Afar with the axial trough of the Red Sea (Zone 6), the western Gulf of Aden (Zone 7) and the Yemen extensional tectonics region (Zone 8).

Newer studies regarding the seismicity of the region continue to contribute towards gaining better understanding of seismic hazards in the country. For example, a multi-disciplinary program called Ethiopia Afar Geoscientific Lithospheric Experiment (EAGLE) was carried out between 2001-2003 to explore the kinematics and dynamics of continental breakup using a broadband seismic array [34]. Another recent effort involves the Afar Rift Consortium which is a project funded by the UK Natural Environment Research Council that is made up of scientists from the UK, with partners in Ethiopia, France and the US. Its aim is to conduct a major set of experiments in the Afar area to further understand the tectonic processes involved in shaping the surface of the Earth. The consortium also has a stated focus in combining the results from the above to determine the mechanisms of magma movement that allow the lithosphere to extend, the crust to evolve and grow as the plate split apart. These efforts will have definite dividends for the Ethiopian earthquake engineering discipline and community by providing better understanding and more complete picture of both seismic and volcanic threats in the Afar Triangle and - by extension - the Main Ethiopian Rift. However, the significant gap that exists today in detail site-specific conditions and fault zones catalogue for the whole country remains a largely unattained goal with prohibitive cost being the main culprit.

Review of Response of Built-up Structures to Seismic Events in Ethiopia

As discussed above, while an extensive amount of earthquake records on Ethiopia exist, the structural damage to infrastructures in the vast part of this period was obviously very low due to the extreme limitation of built-up environments in the country. It is only, perhaps, starting from the 1950s and 1960s that one sees what could be characterized as noticeable building and infrastructure activity in the country, particularly in the seismic-prone areas. Therefore, this study concentrates exclusively in the period from 1978 to the present.

For the period between 1960 and 1978, Gouin's work [7] provides a wealth of information on the response of built-up structures like buildings and bridges to some of the large and damaging earthquakes such as Karakore (1961) and Serdo (1969). With regard to infrastructural damages from 1978 onward, there have been isolated reports [35-45] of which some are unpublished [43]. Interestingly, this period coincides with a growth in built-up areas and infrastructure in some of the seismically active areas, particularly MER and the Afar Triangle. Areas where there were no infrastructure damages even under strong ground motions - such as the 6.3 intensity Chabbi Volcano earthquake of 1960 near the present day Hawassa - have now seen encroachment of built-up areas which have suffered damages under recent but much less-strong ground motions. Therefore, it has increasingly become clear that structural damages to buildings and infrastructure due to earthquakes are on the rise in the country. A catalogue of these damages presented in Table 1 - particularly for the time period after 1978 - is a first attempt in understanding the pattern of damages observed so far and preparing the groundwork for predicting the potential structural damages that could occur in the years to come. Fig. 3 and Fig. 4 show the distribution of damage-causing earthquakes in Ethiopia with damage defined as damage to property or injury, or human life loss or all. Fig. 5-7 shows photo of structural damages due to recent earthquakes.

Table 1**:** List of earthquakes and reported damages between 1979-2011.

Earthquake	Intensity	Year	STRUCTURAL DAMAGE	Reference
Akaki 8.85N 38.7E	Magnitude 4.1. Intensity VII near epicenter	1979 (28 July)	• No damage to the then Aba Samuel HEP station a few kilometers away. • Cracks in poorly built masonry structures.	[36]
8.9N 39.9E	5.1	1981 (Feb 7)	Cracks in masonry buildings in Awara Melka town, north of the Fentale volcanic center.	[42]
7.03N 38.6E	5.1	1983	• Rock slides and damage and destruction of masonry buildings in Wendogenet, east of Lake Hawassa. • Well-built single-story building cracked at the Forestry Institute. • Large boulders dislodged, plaster fallen off walls, electric poles thrown down.	[42] [43]
Hawassa	5.3	1983	• Damage to steel frames in Hawassa. • Damage to Wetera Abo Church in Wondo Genet (1983 earthquake, masonry building with irregular vertical and horizontal stiffness. Damage seems to occur where there is stiffness discontinuity).	[41]
11.37N 38.7E Near Lake Hayk.		1984 (Apr 10)	High-rise buildings shaken. Mortgage Bank Building in Kazanchis.	[39]
8.95N 39.95E		1984 (Aug. 24)	Concrete building in Piazza shaken	[39]
8.3N 38.52E Oitu Bay (Langano)	5.1	1985	• Strongly felt in Lake Langano camp, central MER. • Cracks in buildings in resort area hotels.	[37] [43]
9.47N 39.61E Langano	(4.8), 105 Km away	1985 (Oct)	Panic in high-rise buildings in Addis Ababa.	[38]

	5.4	1987 (Oct 28)	• Already weakened blocket building collapsed, strongly felt – Arba Minch. • Panic – No damage in Jimma. • Students knocked against one another in classroom, poorly built house collapsed in Sawla.	[43]
Hamer and Gofa Earthquake Swarm	5.3 – 6.2 magnitude.	1987 (Oct 7 – 28)	Details given separately for Hawassa, Jima and Arba Minch.	[39]
	5.3	1987 (Oct 7)	• Light-sleepers woken. No structural damage in Hawassa. • Poorly built structures cracked, many woken up, birds shaken-off trees.	[43]
8.9N 40E	4.9	1989	• Cracks in buildings in the town of Metehara, northern MER. • Felt like passing truck by many, shaking beds.	[42] [43]
Dobi Graben [Afar]		1989	Several bridges damaged.	
Mekelle	5.3	1989 (Apr 13)	Felt by many causing some panic.	[41]
Dichotto	5.8	1989 (Aug 20)	Dining people thrown-off table, masonry house collapsed, landslides killed 4 people and 300 cattle, 6 bridges destroyed in Dichotto.	[43]
Soddo 6.84N 37.88E	5.0	1989 (June 8)	Widespread panic, broken windows and some injured in Soddo.	[43]
8.1N 38.7E	5.1	1990	Minor damage in towns at the western escarpment, i.e., at Silti and Butajira, West of Zway town.	[42]
8.3N 39.3E Nazareth	5.0	1993	• Collapse of several adobe buildings in Nazareth town northern MER. • Felt as far as Debre Zeit and Addis Ababa.	[42]
7.2N 38.4W	5.0	1995	Cracks in flour factory building at Hawassa town.	[42]
Mekelle	5.2	2002 (Aug 10)	Buildings shaken in the city of Mekelle.	[44]
Afar Triangle		2005 Sept. 26	Fumes as hot as 400 ^{o}C shoot up from some of them; the sound of bubbling magma and the smell of sulfur rise from others. The larger crevices are dozens of meters deep and several hundred meters long. Traces of recent volcanic eruptions are also visible. This was followed by a week-long series of earthquakes. During the months that followed, hundreds of further crevices opened up in the ground, spreading across an area of 345 square miles.	[45]
Ankober	5.0	2009 Sep 19	Earthquake strikes near Ankober Town and was widely felt in Addis specially by residents who live on multistory buildings.	[10]
Hosanna	5.3	2010 (Dec 20)	Damage sustained by reinforced concrete frame dormitory building at Jimma University with in-filled walls at where as many as 26 students were injured. structural damage to slab and column joint. Damage to many building in Hosanna.	[12]
Ethio-Somali Border	6.1	2011 (March 3)	Buildings shaken in Dire Dawa, Jijiga, and Somalian towns.	[13]
Abosto/ Yirga Alem	5.0	2011 (March 9)	Damage to unreinforced cinder-block cladded timber building. 100 houses were destroyed and 2 people were injured in this earthquake.	[14]

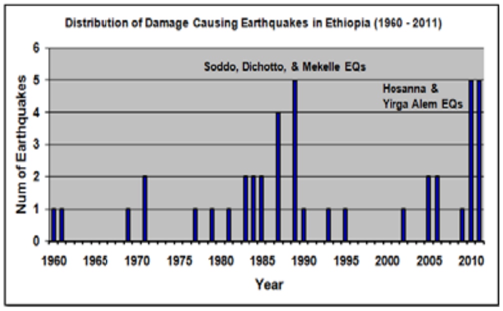

Figure 3 Distribution of damage causing earthquakes between 1960 - 2011. These represent magnitudes 4.9 and above with reported damage to property or life or both. Note that in 2005 alone, the earthquake sequence in Dabbahu resulted in more than 200 earthquakes of Magnitude mb > 4.5 just in about 10 days!

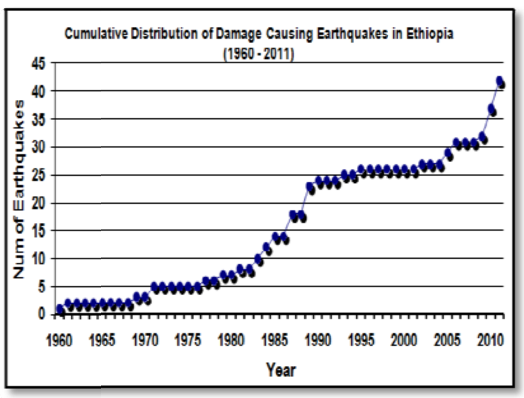

Figure 4 Cumulative distribution of damage causing earthquakes between 1960 - 2011. These represent magnitudes 4.9 and above with reported damage to property or life or both. Inclusion of data from the 2005 earthquake sequence in Dabbahu could significantly alter this picture further emphasizing the associated risks.

Figure 5 (a) Damage to Wetera Abo Church in Wondo Genet (1983 earthquake). (b) Damage to Arba Minch Kebele Warehouse (1987 Earthquake Swarm, masonry building. Damage seems to be caused by biaxial bending at corner of building). (*Photo source: Dr. Laike Mariam Asfaw - private communications*).

Figure 6 Photographs of structural damages due to the December 2010 Hossana earthquake. [a]-[c] show damages to reinforced concrete frame dormitory buildings at Jimma university where 26 students were injured. [b] structural damage to slab and column joint. [c] debris from damaged frame. [d] damage to the masonry clad of a timber building. EBCS-8:1995 classifies Jimma as seismic zone 1.(*Image Source: Ethiopian TV*.)

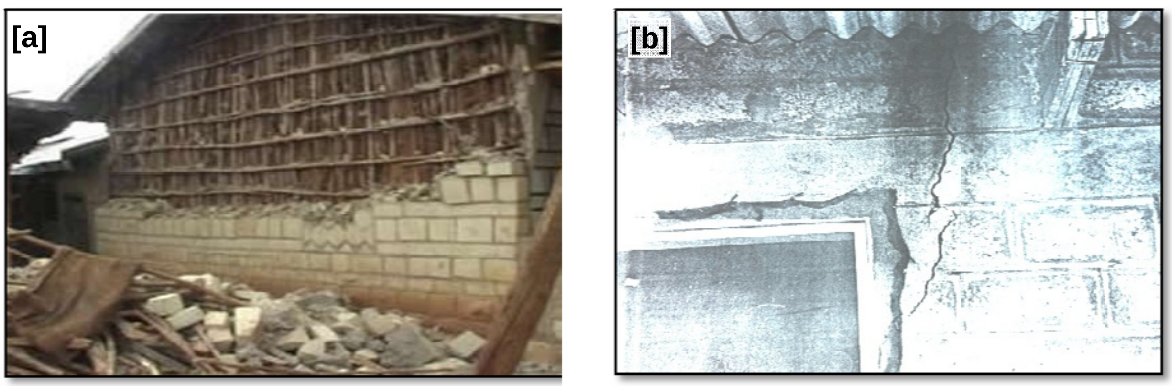

Figure 7 (a) Damage to unreinforced cinder-block cladded timber building due to Abosto/Yirga Alem Earthquake of March 19, 2011. 100 houses were destroyed and 2 people were injured [14] (b) damage to cinder-block building in Awara Melka due to Awara Melka earthquake of April 1980 [35].

BACKGROUND AND CURRENT STATE OF CODE-REQUIRED SEISMIC DESIGN IN ETHIOPIA

Ethiopian Building Standard Codes

The first seismic code for buildings in Ethiopia was introduced in 1980 (CP1-78). This code defined four seismic code regions (i.e., 0, 1, 2, and 4) with a return-period of 100 years and 90% probability of not being exceeded [46,47]. To each zone, a danger rating was assigned with *'no'*, *'min'*, *'moderate'*, and *'major'* corresponding to zones 0, 1, 2, and 4. Figure 8.a shows the seismic zoning adopted by this code. The zone numbers corresponded to the seismic factor ***'R'*** used in SEAOC (Structural Engineers Association of California) and UBC's equivalent static load procedure [7,47]. The next revision was introduced in 1983 as ESCP1-83 [48].

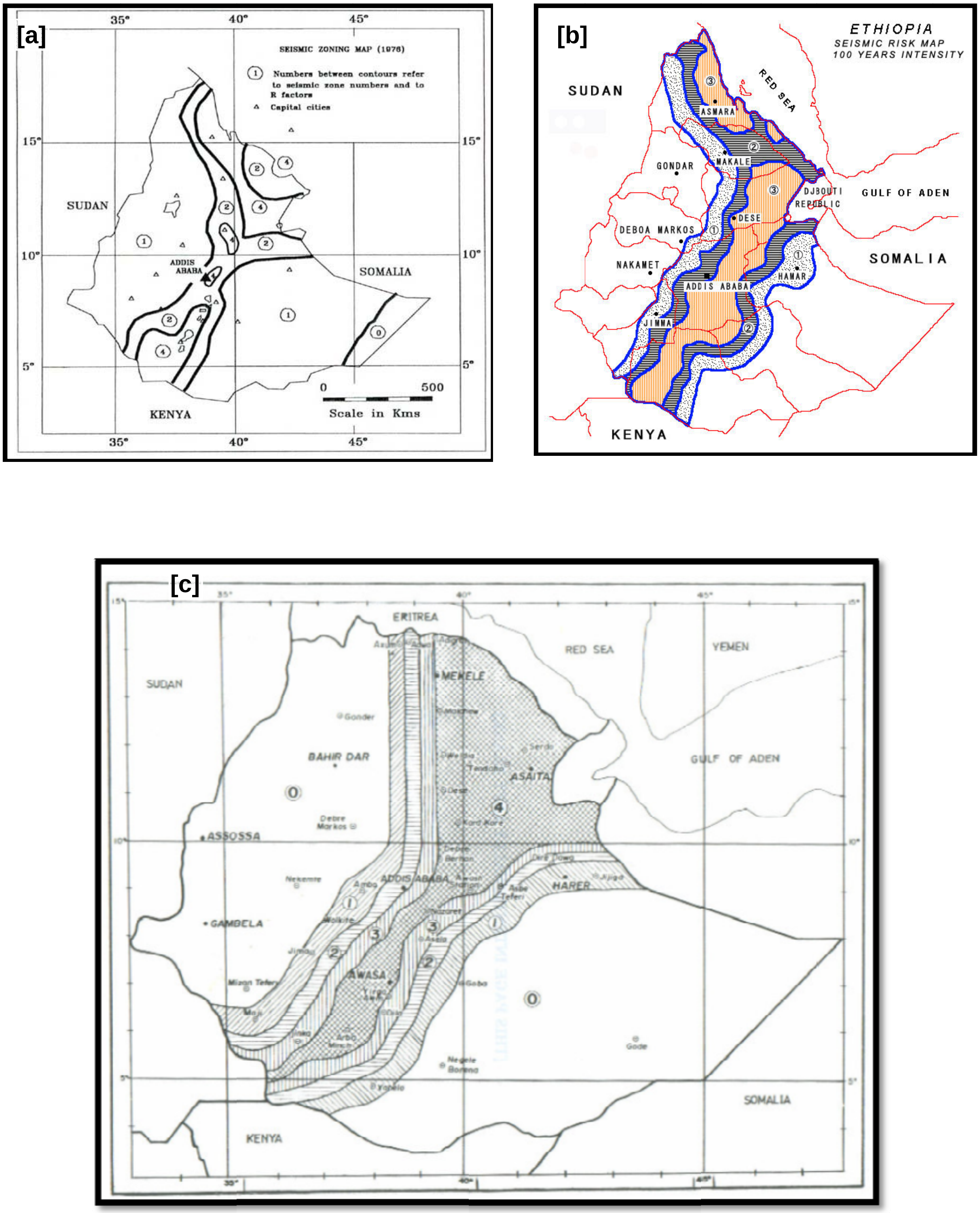

Figure 8 (a) Seismic zoning of Ethiopia as per Gouin (1976) which was also used by CP1-78. (b) Seismic zoning of Ethiopia as per ESCP-1:1983, (c) Seismic Zoning of Ethiopia as per EBCS-8: 1995

Both codes were influenced by the so-called SEAOC Blue Book and UBC (Uniform Building Code) [49,50]. The CP1-78 code dealt primarily with seismic zoning and determination of equivalent static loads on structures and left actual aseismic design of structural members (beams, columns, and shear walls) to the judgement of the engineer with other established international building codes, primarily UBC, serving as a basis for aseismic design. ESCP1-83 has a separate code (ESCP-2:1983 - Ethiopian Standard Code of Practice for the Structural use of Concrete) for guidelines for concrete design [51].

These were followed by a substantial change introduced in 1995 as EBCS-1995 by the Ministry of Works and Urban Development [52]. The seismic zoning was an improvement over previous codes based on additional data obtained from newer earthquake records inside Ethiopia as well as neighbouring countries. However, the whole Ethiopian Building Code Standard (EBCS) that consisted of 10 volumes was predominantly based on the European Pre-Standard (experimental) code (ENV 1998) which was drafted by CEN (European Committee for Standardization). The seismic provisions code, EBCS-8: 1995 (Design of Structures for Earthquake Resistance), was also predominantly based on ENV 1998:1994 Eurocode 8 - Design Provisions for Earthquake Resistance of Structures - except the equivalent static load procedure which still had the UBC influence [53]. The use of the draft Eurocode as a model was a significant departure from earlier codes which used UBC as a model to a large extent. It appears that there was no overriding technical basis for this departure. Further, the adaptation of this *'draft'* code before the Europeans themselves commented on it and approved an improved version as a standing code causes - as will be shown later - a number of significant inconsistencies and controversies [54-55]. It seems likely, therefore, that, in the next code review cycle, the issue of whether to continue in the traditions of UBC (and hence IBC and ASCE-inspired codes) or follow Eurocode will be in the forefront and deserves a well-thought and unbiased discussion that considers the long-term interest of the building/construction industry in the country.

A commonality between all the three codes introduced in the country over the past 30 years is the choice of 100 years return-period in contrast with a 475 years return-period which is adopted by most codes around the world. The main argument in favor of this choice has been the relatively economical construction of structures designed for a less powerful earthquake [53]. In general, PGA (peak ground acceleration) values corresponding to a return-period of 475 years are about twice those of 100 years return-period [53].

While the existence of history of three generation of seismic codes in the country is a commendable effort, its legal enforcement was never codified by the country's legal systems until 2009 when the Ethiopian Building Proclamation 624/2009 was introduced as a legal document that outlines the building regulations and requirements, for use by local authorities to ensure building standards are maintained in their jurisdiction [5]

Seismic Zoning

Gouin who used probabilistic approach is credited for the initial attempts in producing the first seismic hazard map of Ethiopia as shown in Figure 8.a [46]. Gouin's work also served as a basis for the seismic zoning adopted by the ESCP-1:1983 building code of Ethiopia (see Figure 8.b). Since the production of Gouin’s seismic zoning maps, quite a large number of destructive earthquakes have occurred in the country causing damages both to property and human life. Further, destructive earthquakes that occurred in the neighboring countries were not included in the production of the first map in 1976. Subsequently, Kebede [56,57] and Panza *et al* [58] produced a new seismic hazard map of Ethiopia and its northern neighboring countries to account for these additional earthquake records. Unlike previous works, the seismic zoning of Ethiopia and the Horn of Africa reported by Kebede [56], Kebede and Asfaw [59] also account for ground motion attenuation in addition to newer data obtained from such sources as the US National Earthquake Information Service (NEIS). The works of Kebede [56-57] and Kebede and Asfaw [59] served as a basis for the seismic zoning adopted by the current Ethiopian building seismic code - EBCS-8:1995 as shown in Fig. 8.c. Further, there have been other attempts on seismic zoning of some of the country’s important economic regions such as the city of Addis Ababa. The work of the RADIUS project is a notable example [15]. There have been additional studies that are continually shaping understanding of seismicity in Ethiopia.

A summary of the seismic zonings corresponding to each of these three codes are given in Figure 8. Seismic Zoning of Ethiopia as per CP1-78, ESCP1-83 and EBCS-8:1985 all considered 4 seismic zones. The availability of relatively newer data was credited for the changes in seismic zoning of Ethiopia as per EBCS-8: 1995 which considers some areas in MER to have the same zoning as the severest of the Afar region. The nature and location of recent damage-causing earthquakes such as the December 2010 Hosanna [12] and March 2011 Aboso/Yirga Alem [13] earthquakes is expected to add further support for the need for further improving the current seismic zoning to account for previously unknown and less-understood faults as well as local site conditions.

DEFICIENCIES IN CURRENT CODE AND PROPOSED REVISIONS

Substantial amount of new data has been accumulated from earthquakes that have occurred in Ethiopia in the 90s as well as early parts of the current century that suggest that the current seismic zonings adopted in the codes are incomplete, inadequate, and non-cognizant of local site effects that could amplify earthquake effects. Further, the inherent weakness and flaws of basing the country's code on a *'draft'* European code that was not even reviewed and critiqued by the Europeans themselves at that time add a lot of urgency on the call for the substantial review of the current building code, EBCS-1995. In fact, the European code has not been accepted *'as is'* even by its member states like Italy who have added not insignificant modifications for national uses [60].

In this section, a review of some of the outstanding deficiencies of the current building code along with suggested improvements that could serve as basis for the proposed code review process is given. Particular emphasis on seismic zoning, structural design, and dynamic analysis issues is provided. A summary of the discussions is given in a comparative way in Table 2.

Seismic Zoning and PGA

As stated earlier, the works of Fekade Kebede [56-57] and F. Kebede and L.M. Asfaw [59] served as a basis for the seismic zoning adopted by the current Ethiopian building seismic code - EBCS-8:1995 (with a return-period of 100 years which corresponds to 0.01 annual probability of exceedance). Associated with this, there are at least three areas that offer an opportunity to improve the usefulness as well as address some of the inadequacies of the current seismic zoning.

1. The effects of local site-conditions such as local fault lines and soil conditions for - at least the major population areas - need to be considered. While preparing a detailed one may be too prohibitive of an expense and beyond the means of the country, doing so for major cities like Addis Ababa, Jimma, Adama, Hawassa, Mekelle, and Dire Dawa may be a reasonable approach. Even in current practices, there have been isolated attempts in performing such local site-effects for some infrastructure projects around the country. The inconsistencies of the current seismic zoning devoid of local site-conditions becomes more apparent when considering the case of Addis Ababa where areas such as Nefas Silk which is only 20-25 kilometers away from Debre Zeit (zone 4, α_0=0.1) has the same seismic zone 2(α_0=0.05) classification as Intoto and its mountainous surroundings. Interestingly, Akaki which is only 5 or so kilometers away from Nefas Silk and has no overriding geological dissimilarities with the latter is classified as zone 3 with α_0=0.07. Against this background, the work of L.M. Asfaw's where he showed that there is significant geological and topographic variation in different parts of Addis Ababa that had resulted in variations in the felt intensities in past earthquakes adds another dimension to the argument [36]. In general, L.M. Asfaw's work suggests that the southwestern part of Addis Ababa mainly consists of thick alluvium deposits whereas the northern part of the city has prominent topographies (mountains) with thin soil cover. Both types of topographies are known to increase felt intensities. Interestingly, L.M. Asfaw shows that, due to local site effects, the felt intensities in Intoto area (seismic zone 2 according to EBCS-8:1995) were higher than those in the southeast of the city towards Bole field (seismic zone 3) [36]. Therefore, until a complete site-specific zoning is available sometime in the future, it is suggested that - for consistency purposes as well as conservative designs - the city of Addis Ababa and its industrial surroundings adopt similar seismic zoning of at least zone 3. This could be addressed, for example, by establishing the contour lines of seismic zones near major metropolitan areas to be continuous with no jump in zones giving continuity in seismic zoning.

2. The current code considers a return-period of 100 years only which effectively reduces peak ground acceleration by <u>almost half</u> as compared to the commonly used 475 years return-period (10% probability of exceedance in 50 years) [53]. As discussed before, economical considerations were often cited as the main argument in favor of this choice. However, this view needs a revisit in light of the current significant boom in construction activities across the country which is expected to continue in the foreseeable future despite some hiccups along the way as well as with regard to continuity and compatibility of risk levels in the region and beyond. Does the cost-saving in designing for lower seismic loads offset the risk of losing large investments in these infrastructures due to large earthquakes with return periods of 200-475 years? While it may be argued that a return-period of 475 years may introduce a sudden substantial jump in cost, that the level of investment going to these structures is substantially high enough to warrant consideration of 475 year return-period. Further, it is suggested that for large infrastructure projects such as dams, bridges, power-plants, railway structures - these structures should be mandated by specialized codes as is done elsewhere -, the tendency to use existing practice of 100 year return-period should also be discouraged and disallowed and the proposed use of 475 years of return-period should also be extended to these specialized codes.

3. While the catalogue of earthquakes used for the current zoning extended up until 1990 only, the earthquakes that have occurred since then in the past 20 years have some interesting aspects that could have a bearing on the current seismic zonings. A good example is the 5.3 magnitude Sunday December 19, 2010 Hosanna earthquake that injured as many as 26 students in Jimma and damaged buildings. While the current seismic zoning puts Jimma in seismic one 1(with α_0=0.03) and the city is at least 100 kilometers away from the epicenter, the damage caused is surprising. Interestingly, the city of Jimma had always felt the effect of past earthquakes in the MER (Main Ethiopian Rift) and SMR (Southern Most Rift) including the Woito earthquake swarm of October - December 1987 that rattled the city and its residents [43]. As development in the Jimma area expands, the damage from earthquakes centered in the MER, SMR and beyond could cause more damages and this current classification of this city of increasing commercial importance as seismic zone 1 and α_0=0.03 is non-conservative and hard to support.

Structural Design

Over the past several years, a number of deficiencies with the European draft code, ENV 1998:1994, that could have significant design bearings have been brought up with the intent of rectifying them in the actual ratified building code [53-54]. These include: criteria for regularity of buildings, accidental torsion, use of 2D building models and torsional effects, design response spectra for linear analysis, P-delta effects, user-defined time history records, etc. In addition to these, there has been additional progress in modern structural engineering practice such as the increasing acceptance of performance-based design approach and the use of nonlinear time history analysis. All these will have a bearing on the usefulness of the current building code and - more importantly- on what sort of remedies need to be considered in the expected code updating process.

Dynamic Analysis

Again, over the past several decades, there have been significant developments in structural engineering practice, particularly in the areas of software supported structural analysis and design. These structural analysis/design software have enabled the building of complex 3-dimensional models and the design of all structural members and reinforcements almost routine. As a result, code requirements that had long assumed 2-dimensional frame models as substitutes for the whole 3-dimensional (spatial) model because of simplification in analysis and modeling efforts using traditional - but increasingly rarely used - methods continue to appear redundant and unnecessary. In fact, to account for irregularity and hence additional torsional effects, the use of these 2-dimensional models was accompanied by additional (sometimes confusing) considerations for inherent and accidental torsion. As a result, there is a push for modern building codes to move towards completely eliminating these arcane requirements. The adoption of spatial (3-dimensional) building models as the default is recommended coupled with discouraging the use of 2-dimensional simplifications.

Along the same line of argument, in Table 2, a detailed list of code specifications that need special attention along with suggested revisions are provided. It is hoped that this serves as a starting point for a substantial review of the current out-dated seismic code.

Table 2**:** Summarized comparison of past Ethiopian codes with proposed code modifications.

Criteria	EBCS8-1995	Model/International Codes	Proposed Review for Ethiopia
Seismic Zoning and PGA			
1. Seismic Zoning	4 zones	UBC 1997 - 5 in the US (1, 2A, 2B, 3, 4). But generally 4.	Keep 4 zones for buildings
2. Soil Type	Limited to 3: A, B and C.	UBC-1997 has 6 soil type, i.e., S_A-S_F	Consider more to account for variation in different parts of the country
3. Return Period	100 years	475 years in most codes and countries.	475 years for buildings as well as large infrastructures like bridges, dams, power plants. Also makes it consistent with the region.
4. Seismic ground motion used	Allows user defined typical ground motion records	Same	Consider shallow ground motions for time history analysis, recent earthquakes tend to be that type.
5. Topographic/Site amplification effects	Does not consider site effects	Eurocode (2004) considers when $\gamma > 1$.	Need to consider
Design			
1. Model Code used	Predominantly Eurocode	For IBC, ASCE 7-10 is used as the model code	Use ASCE 7-10 as engineering curricula in Ethiopia is based on ASCE predominantly.
2. Design Philosophy Basis	Elastic response	Performance-based	Move towards Performance-based
3. Special Seismic Provisions - Concrete	Three ductility classes are defined: DC"L" - (Basic EBCS 2) DC"M" - (well within the elastic range under repeated reversed loading with no brittle failures). DC"H" - (ensure, in response to the seismic excitation, the development of chosen stable mechanisms associated with large dissipation of energy)	Eurocode (EN 1998-1:2004) defines essentially similar classes of ductility. DCL or L - Basic (low dissipation) design; use EN 1992-1-1:2004. DCM - medium ductility, DCH - high ductility. For both DCM and DCH ductile modes of failure (flexure) to precede brittle failure modes (e.g., shear) with sufficient reliability. IBC-2006 references to ACI-318 which uses 'seismic design category' A-F, A &B being used in seismic zones 0 and 1, B in zone 2, and D,E,F in zone 3 and 4.	Keep the same; but if IBC is followed, consider using ACI-318.
4. Special Provisions for Beam Design	**DC"L"** a) Anchorage: d_{bL} (Φ of long. bars of beams anchored along beam-column joint)	Eurocode (EN 1998-1: 2004) **DCL** Left to concrete code. **DCM** a) Anchorage: d_{bL} $d_{bL}/h_c \leq 7.5\ (f_{cm}/f_{yd})(1+0.8\nu_d)/(1+0.75k_D$	Adopt ACI-318 or keep it as simple as Eurocode 2004. EBCS:8 is not

	$d_{bL} \le 6.0$ $(f_{cm}/f_{yd})(1+0.8v_d)h_c$ (interior joint) $d_{bL} \le 7.5$ $(f_{cm}/f_{yd})(1+0.8v_d)h_c$ (exterior joint) b) critical length l_{cr} l_{cr} = 1.0 h_w (height of beam) c) ductility max. tension rein. ρ_{max} p_{max} = 0.75*max. ratio of EBCS 2 **DC"M"** a) Anchorage: d_{bL} $d_{bL} \le 4.5$ $(f_{cm}/f_{yd})(1+0.8v_d)h_c$ (interior joint) $d_{bL} \le 6.5$ $(f_{cm}/f_{yd})(1+0.8v_d)h_c$ (exterior joint) b) critical length l_{cr} l_{cr} = 1.5 h_w (height of beam) c) ductility max. tension rein. p_{max} $p_{max} = 0.65*f_{cd}*p'/f_{yd}/p +$ 0.0015 d_{bw} > 6mm (dia. of hoops) $s = min\ (h_w/4;\ 24d_{bw};$ 200mm; $7d_{bL})$ First hoop placed ≤ 50mm from end section of beam. At least 2 S400 bars with d_b = 14mm@top and bot. of span of beam. **DC"H"** a) Anchorage: d_{bL} $d_{bL} \le 4.0$ $(f_{cm}/f_{yd})(1+0.8v_d)h_c$ (interior joint) $d_{bL} \le 6.0$ $(f_{cm}/f_{yd})(1+0.8v_d)h_c$ (exterior joint) b) critical length l_{cr} l_{cr} = 1.5 h_w (height of beam) c) ductility max. tension rein. p_{max} $p_{max} = 0.35*f_{cd}*/'/f_{yd}/p +$ 0.0015 d_{bw} > 6mm (dia. of hoops) $s = min\ (h_w/4;\ 24d_{bw};$ 150mm; $5d_{bL})$	ρ'/ρ_{max}) (interior joint) $d_{bL}/h_c \le 7.5\ (f_{cm}/f_{yd})(1+0.8\nu_d)$ (exterior joint) b) critical length l_{cr} l_{cr} = 1.0 h_w (beam frames to beam-column joint) l_{cr} = 2.0 h_w (beam supports discontinued columns) c) ductility max. tension rein. ρ_{max} $\rho_{max} = \rho' + 0.0018*f_{cd}/f_{yd}/\mu_{\phi}\ \varepsilon\ sy,d$ $\rho_{min} = 0.5(f_{ctm}/f_{yk})$ d_{bw} > 6mm (dia. of hoops) $s = min\ (h_w/4;\ 24d_{bw};$ 225mm; $8d_{bL})$ First hoop placed ≤ 50mm from end section of beam. **DCH** a) Anchorage: d_{bL} $d_{bL}/h_c \le 7.5\ (f_{cm}/f_{yd}/1.2)(1+0.8\nu_d)/(1+0.75k_D\ \rho'/\rho_{max})$ (interior joint) $d_{bL}/h_c \le 7.5\ (f_{cm}/f_{yd}/1.2)(1+0.8\nu_d)$ (exterior joint) b) critical length l_{cr} l_{cr} = 1.5 h_w (beam framing to beam-column joint as well as beam supporting discontinued columns) c) ductility max. tension rein. ρ_{max} $\rho_{max} = \rho' + 0.0018*f_{cd}/f_{yd}/\mu_{\phi}\ \varepsilon_{sy,d}$ $\rho_{min} = 0.5(f_{ctm}/f_{yk})$ $s = min\ (h_w/4;\ 24d_{bw};$ 175mm; $6d_{bL})$ At least 2 high-bond bars with db = 14mm @ top and bot for entire span. 25% of max top reinf. at support to run along entire span. First hoop placed ≤ 50mm from end section of beam.	conservative for beams supporting discontinued columns.

	First hoop placed ≤ 50mm from end section of beam. At least 2 S400 bars with d_b = 14mm@top and bot. of span of beam.		
5. Special Provisions for Column Design	<u>**DC"L"**</u> a) <u>critical length l_{cr}</u> l_{cr} = max (1.0d_c, l_{cl}/6, 450mm) *b)* <u>ductility</u> A_{sh} = 0.02 sb_o f_{ck}/f_{yk} (spiral hoop) A_{sh} = 0.02 (sb_o f_{ck}/f_{yk}) [A_c/A_o - 1] (rectangular hoop) A_c/A_o ≥ 1.3 No specs on d_{bw} s = min (b_o/2; 200mm; 9d_{bL}) dis between bars restrained by hoops ≤ 250mm <u>**DC"M"**</u> a) <u>critical length l_{cr}</u> l_{cr} = max (1.5d_c, l_{cl}/6, 450mm) <u>b) ductility</u> A_{sh} = 0.025 sb_o f_{ck}/f_{yk} (spiral hoop) A_{sh} = 0.025 (sb_o f_{ck}/f_{yk}) [A_c/A_o - 1] (rectangular hoop) A_c/A_o ≥ 1.3 d_{bw} ≥ 0.35 $d_{bL,max}$sqrt(f_{ydL}/f_{ydw}) s = min (b_o/3; 150mm; 7d_{bL}) dis. between bars restrained by hoops ≤200mm <u>**DC"H"**</u> a) <u>critical length l_{cr}</u> l_{cr} = max (1.5d_c, l_{cl}/5, 600mm) <u>b) ductility</u> A_{sh} = 0.03 sb_o f_{ck}/f_{yk} (spiral hoop) A_{sh} = 0.30 (sb_o f_{ck}/f_{yk}) [A_c/A_o - 1] (spiral hoop) A_c/A_o ≥ 1.3 d_{bw} ≥ 0.40 $d_{bL,max}$sqrt(f_{ydL}/f_{ydw}) s = min (b_o/4; 100mm; 5d_{bL}) dis between bars restrained by hoops ≤150mm	Eurocode (EN 1998-1: 2004) <u>**DCL**</u> Left to concrete code. <u>**DC"M"**</u> a) <u>critical length l_{cr}</u> l_{cr} = max (h_c, l_{cl}/6, 450mm) <u>b) ductility</u> ductility defined in terms of curvature ductility factor (5.4.3.2.2.6P,7P, and 8) <u>**DC"H"**</u> a) <u>critical length l_{cr}</u> l_{cr} = max (1.5d_c, l_{cl}/6, 600mm) <u>b) ductility</u> ductility defined in terms of curvature ductility factor (5.5.3.2.2.6P,7P, and 8)	Adopt ACI-318 or keep it as simple as Eurocode 2004.

6. Drift Limit	Δs = 0.01h (brittle non-structural elements) Δs = 0.015h (fixed non-structural elements) [61]	2009 IBC - Δs = 0.025h or 0.015h (RC structures) UBC 97 - $\Delta_m \leq$ 0.025h (T < 0.7 sec) and $\Delta_m \leq$ 0.020h (T ≥ 0.7 sec) [61]. Eurocode 2004 introduces ν - reduction factor.	Keep as is.
7. Soil structure interaction	No provisions	IBC 2009 Section 9.5.5 of ASCE7.	Adopt Section 9.5.5 of ASCE7
Analysis			
1. Reference method for determining seismic effects	ESF (Equivalent Static Force procedure)	Eurocode 2004. Modal response spectrum analysis (linear)	Move towards modal response spectrum analysis (linear)
2. Accidental Torsion (Static)	e_x=±0.05b e_y=±0.05d Amplification Factor 'A' ≤ 3.0 used.	UBC 97 e_x=±0.05b e_y=±0.05d	e_x=±0.1b e_y=±0.1d due to limited quality-control [6]
3. Accidental Torsion (Dynamic)	$M_x^i = e_x^i F_x^i$ $M_y^i = e_y^i F_y^i$	UBC-1997 move CMs by ±e_x, ±e_y and do RSA or $M_x^i = e_x^i F_x^i$ $M_y^i = e_y^i F_y^i$	move CMs by ±e_x, ±e_y and do RSA or $M_x^i = e_x^i F_x^i$ $M_y^i = e_y^i F_y^i$
4. Cracked concrete and masonry properties	No	UBC 97 - 0.5 for flexure and shear (ACI 318)	Adopt ACI-318
5. P-Delta Effect	Considers if $\theta = P_x \Delta / V_x h_x$ > 0.1 and < 0.2; but θ_{max}=0.25	UBC 97 - Consider P-Delta if θ > 0.1 Eurocode 8, θ_{max} = 0.3. [61]	Keep the same.
6. Joint Deformation	Neglected	Consider	Consider as it is already automated by most software.
7. Drift Requirements	$\Delta s \leq$ 0.01h (with brittle non-structural elements) $\Delta s \leq$ 0.015h for buildings with fixed non-structural elements	IBC 2009 - $\Delta s \leq$ 0.007h to 0.025h (depending on structural system and importance) UBC 97 - $\Delta m \leq$ 0.025h for T≤ 0.7 sec; $\Delta m \leq$ 0.020h for T≥ 0.7 sec	Keep EBCS:8-1995 which is aggressive.
8. Structural analysis/design software use	Hand calc required for plan check	No specification	Review Process needed at design-check. Add hand calcs for beam, column, and shear wall design and detailing.
9. Push-over analysis	No	Yes	Allow as transitional approach
10. Base Shear Calculation $S_d(T_L)\gamma$	γ = 1	m. λ in Eurocode (EN 1998-1:2004)	-
11. F_t in story shear calculations	$F_t = 0.07T_1F_b$	UBC 97 F_t = 0 for T ≤ 0.7 sec; = 0.07TV ≤ 0.25V (for T>0.7sec) F_t = 0 for Eurocode 8 (uses linear fundamental mode; no higher modes) F_t = 0 for IBC2009	Follow IBC, UBC, and Eurocode 2004.

12. 2D Models for dynamic Response spectra analysis	Allowed	Allowed	Encourage the use of spatial (3D) models
13. Dynamic Load Cases Combinations	SRSS + CQC	CQC	CQC (more accurate). Drop SRSS.
CM = center of mass. 'i' – story number. RSA – Response spectra analysis. F_x and F_y are story shears. M_x and M_y are the torsional moments [6].			

CONCLUSIONS AND RECOMMENDATIONS

In this paper, it has been argued that as a boom in large-scale infrastructure projects such as dams, power-plants, highway roads, and expansion of railways in Ethiopia continues along with pressure from the staggering population growth of the country, the severity of threats posed by seismic hazards on the safety and serviceability of these structures needs to be known by all stake-holders. Currently, this awareness does not seem to be adequate and several observations of engineering reports of large infrastructure projects suggest that this substantial threat is actually not well-understood and appreciated.

Therefore, driven by this observation, in this research report,

1. it has been demonstrated that there is substantial amount of literature on seismicity in Ethiopia that needs to be disseminated to a wider audience,
2. a background and critical review of the last three building codes of the country is given,
3. background arguments and facts that could serve as starting points for the long-awaited complete review of the current out-dated seismic code are provided, and
4. guidelines for rationale and conservative seismic design in Ethiopia and surrounding countries for large-scale projects with particular emphasis on dams, highway structures, as well as railways and railway structures are provided.

Further, the following recommendations are made:

1. Due to the importance of site-specific zoning and inconsistencies in metropolitan areas, until a complete site-specific zoning is available sometime in the future, - for consistency purposes as well as conservative designs - the city of Addis Ababa and its industrial surroundings adopt similar seismic zoning of at least zone 3.
2. The seismic zoning of important metropolitan areas like Jimma which have suffered in recent moderate earthquake be revised to higher seismic zoning.
3. Large infrastructure projects such as dams, bridges, power-plants, railway structures need to be governed by a separate specialized seismic code which is more stringent than the building code.
4. The current return-period of 100 years is not conservative enough for buildings as well as large infrastructures. The use of return-period of 475 years is recommended as strong candidate for consideration. Further, for large infrastructure projects such as dams, bridges, power-plants, railway structures, the tendency to use existing practice of 100 year return-period should also be disallowed immediately and the proposed use of 475 years of return-period should also be extended to these specialized codes.
5. The numerous findings summarized in Table 2 strongly advocate that the current code needs a complete revision in all aspects including the special concrete and steel seismic provision chapters. It is also anticipated that, in the next code review cycle, this issue of whether to continue in the traditions of UBC (and hence IBC and ASCE-inspired codes) or follow Eurocode will be in the forefront. It is hoped that this determination of the path to be followed should be based on well-thought and unbiased discussions that consider the long-term interest of the building/construction industry in the country.
6. The basic design philosophy approach to seismic design had continued to evolve towards a performance-based approach with both IBC and Eurocode 2004 implementing this approach. The next revision of seismic code for Ethiopia should either directly adopt this approach that has gained increasing

acceptance among the world-wide engineering community or offer it as an option till its wide usage in Ethiopia becomes common.

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