# Proposed Considerations for Revision of EBCS-8:1995 for Conservative Seismic Zoning and Stringent Requirements for Torsionally Irregular Buildings

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**Abstract**: There is a significant variation in seismic zoning adopted in Ethiopia for urban areas between the seismic building code (EBCS-8:1995) and those reported in other research publications. Further, it is also believed that the torsional loads recommended by the current seismic building code to account for accidental torsion are not conservative enough for a seismically active country such as Ethiopia where there is inadequate quality control in construction practices. This paper deals with proposals for implementing a conservative seismic zoning for urban areas such as Addis Ababa and implementing a more stringent torsional load requirements in the current Ethiopian seismic building code (EBCS-8:1995).

## 1 Introduction

The seismic zone of an area determines the level of equivalent static forces that will be applied in a building frame in seismic design using the ESL (Equivalent Static Load) procedure. Likewise, the seismic zone also determines the level of dynamic loads to be considered for design based on response spectra analysis. However, among the published seismic zone maps for Ethiopia, there are distinct and significant differences in the predicted peak ground accelerations (PGA) for various seismically important regions of the country. It is therefore argued that, the variations in predicted PGA are significant enough to warrant a review of the seismic zoning of urban areas such as Addis Ababa.

On the other hand, to account for the presence of torsional motions in torsionally irregular buildings and also to account for torsional ground motion and the shift of the centers of mass due to a variety of reasons such as poor construction quality, codes often stipulate provisions for additional torsional moments. These code provisions for accidental torsion determine the location of where the lateral seismic loads are applied in a building and hence the magnitude of the torsional moments the building is designed for. The torsional moments at each floor are typically calculated as the floor shear force times the most unfavorable eccentricity. Adopting a conservative value for these eccentricity values is, therefore, crucial for particularly in places such as Ethiopia where quality control in the construction industry is not at adequate level yet.

## 2 Seismic Zoning for Ethiopia

Gouin (1976) who used probabilistic approach is credited for the initial attempts in producing the first seismic hazard map of Ethiopia as shown in Figure 1. Gouin's work served as a basis for the seismic zoning adopted by the ESCP-1:1983 building code of Ethiopia (see Figure 2). Since the production of Gouin's map, 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 (1996, 1997), Panza *et al* (1996) and Kebede and Vaccari (1996) 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 (1996), Kebede and Asfaw (1996) 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 (1996, 1997), Kebede and Asfaw (1996) along with the works of L. Asfaw (Asfaw 1994) served as a basis for the seismic zoning adopted by the current Ethiopian building code - EBCS-8:1995 as shown in Figure 3. 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 (1999) is a notable example.

## 2-1 Variations in Seismic Zoning

A close look at these various seismic zonings for the country reveals significant differences in the peak ground accelerations (PGA) assigned to such important locations such as the city of Addis Ababa, the Afar Triangle and the main Ethiopian rift (MER) (cf Table 1). For example, for the MER area, the peak ground accelerations predicted by Kebede and Vaccari (1996) seem to compare well with those predicted by Gouin (1976) using a probabilistic approach whereas for the Afar Triangle area, Gouin's hazard map gives higher values (Panza *et al* 1996). Further, the seismic zoning adopted currently by EBCS-8:1995 departs significantly from those reported elsewhere such as results from the RADIUS project (1999). For example, the city of Addis Ababa is classified as Zone 2 by EBCS-8:1995 (see Figure 3) with a peak ground acceleration of 0.07g whereas the report from the RADIUS project divides Addis Ababa into various microzones with peak ground accelerations varying from 0.13g – 0.50g as shown in Figure 2. Interestingly, the widely adopted building international codes such as UBC (UBC 1997) and IBC (IBC 2000) classify major cities in the Horn of Africa particularly Addis Ababa, Ethiopia as Zone 3 which corresponds to a peak ground acceleration of 0.3g as opposed to the 0.07g assigned by EBCS-8:1995.

A number of reasons could be sited for these differences among the various reported seismic zonings for the country.

i. The first reason is the consideration of local site conditions. For instance, the seismic zoning for the whole country as reported by Gouin does not take into account local site conditions and ground motion attenuations. A primary reason may be the lack of such data due to its prohibitive expense. The effect of soil conditions on PGA is highlighted by Asfaw who reported that site amplifications have resulted in significant recorded higher intensities of earthquakes in the Northwest corner and central part of Addis Ababa (near Filowha area) as compared to other areas of the city (Asfaw 1982). He attributes topographic prominences and alluvium deposits as the factors contributing to site amplifications. Looking closely, however, there is no adequate information on how Kebede (1996) has determined local site conditions. The same is true for the study by the RADIUS project that reported a seismic zoning for the city of Addis Ababa (cf. Figure 4) which does not provide verifiable evidence on how the site conditions were determined. In fact, the seismic zone map of Addis Ababa according to the RADIUS project suggests that the Northwest region of the city of Addis Ababa has one of the lowest PGAs. This is, however, in direct conflict with what is reported by Asfaw (1982) where the Northwest part of the city is credited as having some of the strongest earthquake intensities recorded due to its topographic prominence. Further, the PGA reported by the RADIUS project seem to be much higher than any of the reports in the literature suggesting that it is too difficult to argue that the site conditions alone warranty the use of more stringent classifications to the city of Addis Ababa with maximum PGA of 0.5g for southeast Addis Ababa. The issue of local soil and other site conditions is, therefore, an area that requires further investigations.

ii. The second source of variations in seismic zoning among the various reports is the selected return period of the earthquake considered for design. The return period used both in the current Ethiopian building code EBCS-8: 1995 and the previous code, ESCP-1:1983 is 100 years whereas the two international building codes UBC 1997 and IBC 2003 use a return period of 475 years. Mekonnen (1996) points that the PGA values for the different regions of the country are almost twice when a return period of 475 years is used as opposed to a return period of 100 years. With this argument, the PGA given by UBC and IBC for the city of Addis Ababa could be interpreted to be 0.15g for a return period of 100 years. Further, the return period considered for the 6.5M ‘scenario earthquake’ used in the RADIUS project is not specified even though it is feasible that it may have considered a higher return period as large as 200-475 years.

iii. The third source of variation is the influence of additional data obtained over the years from different sources including NEIS and the consideration of other major earthquakes in the region including the 1991 earthquake in Juba, southern Sudan. Reports from Kebede (1996) and Kebede and Vaccari (1996) have benefited from these additional data as compared to the original seismic zoning reported by Gouin (1976).

## 2-2 Proposed Interim Solutions

While some of the differences in the reported seismic zonings of the country could be accounted for as explained in the previous section, in balance, however, even with the consideration of the above rationale, there remain noticeable differences among the seismic zonings. For instance, the consideration of a comparable return period for the design PGA for the Addis Ababa region for UBC 1997 and the EBCS-8: 1995 still leaves a difference in PGA of 0.15g against 0.07g which is a factor of two. On the other hand, Kebede (1996) indicates that the seismic zoning adopted by him and other researchers (Kebede and Vacari, 1996) - which are supposed to be more complete than previous national seismic zoning attempts – are still preliminary and a thorough investigation is necessary to have a complete and reliable seismic zoning for the country. Again, with regard to the seismicity of the Addis Ababa region, the report by Asfaw (1992) strongly suggests that the majority of the strongest ground shakings recorded in the city were caused by earthquakes that occurred 200 kilometers northeast of the city (i.e., in Zone 3 and possibly Zone 4 areas). This certainly brings questions regarding the validity of assuming a PGA of 0.07g of Zone 2 for this region which seems to be affected quite significantly by the seismicity of Zone 3 and 4 areas within the western escarpments of the Afar Triangle and MER.

Therefore, in the face of these ambiguities and uncertainties reported above, further investigation and collaboration between seismologists and earthquake engineers is required before the controversy could be settled. For current design practice, until such information is widely available, however, it still remains difficult to the support the current ESBC8-95 classifications that put the maximum peak ground acceleration in Addis Ababa as 0.07g. In the same token, it also looks like the peak ground accelerations predicted by the RADIUS project are on the high-end and are not supported by strong data. As a temporary solution, until further data is available, it is proposed that a more conservative zoning than the EBCS-8:1995 be adopted that increases the PGA to those comparable to at least Zone 3 (PGA of 0.1g – 0.12g).

**Table 1.** Predicted PGA in Addis Ababa and Afar Depression as per different sources.

| | | Kebede and Asfaw (1996) | EBCS-8:1995 (1995) | RADIUS (1999) | UBC-97 (1997) |
|---|---|---|---|---|---|
| Addis Ababa | PGA for 0.01p | 0.08g [Eq 3] | 0.07g | NA | NA |
| | PGA for 0.005p | 0.12g [Eq 3] | NA | 0.13g – 0.5g (extrapolated) | 0.3g |
| Afar Depression | PGA for 0.01p | 0.14g [Eq 3]<br>0.53g [Eq 16] | 0.16g | 0.25g – 0.75g (extrapolated) | NA |
| | PGA for 0.005p | 0.19g [Eq 3]<br>1.05g [Eq 16] | NA | | 0.3g |

## 3 Seismic Torsional Provision and Accidental Torsion

Seismic torsional provisions are mainly intended to account for the differences between actual and computed eccentricities of building structures, dynamic effects of torsional response, and the spatial variation of the ground motion. These provisions are applicable for both symmetrical and torsionally irregular buildings. Historically, the use of 2-dimensional frame analysis – prior to the advent and wide-spread use of computer-based tools – had necessitated the consideration of additional story shears for torsionally irregular buildings due to torsional moments. Since these 2-dimensional analyses did not explicitly considered the effect of the shift of the center of rigidity of a building from the centers of mass, it was, therefore, a rational approach to account for additional story shears. Subsequently, almost all building codes, like UBC-78, UBC-88, ESCP-1:1983 (the old Ethiopian building code), and ATC had traditionally defined the seismic torsional provisions to account for not only the shift in the centers of mass and the spatial variation of the ground motion (i.e., accidental torsion), but also some magnification of the actual eccentricity between the center of rigidity and the center of mass (i.e., dynamic eccentricity). However with the widespread availability of three-dimensional analysis tools that explicitly distribute the story shears to each of the frames according to their relative stiffness, the scope of seismic torsional provisions – particularly in the US - have then be modified to account only for what is called accidental torsion, i.e., torsional moments due to the shift in the centers of mass and the spatial variation of the ground motion. This explains why the modern revisions of the Uniform Building Code (1994, 1997) define accidental torsion as a percentage of only the linear geometry (depth or width depending on the geometry). With regard to the Ethiopian building code, EBCS-8:1995, Section 2.3.2.1 of the code says:

"*In addition to the actual eccentricity, in order to cover uncertainties in the location of masses and in the spatial variation of the seismic motion, the calculated center of mass at each floor 'i' shall be considered displaced from its nominal location in each direction by an additional eccentricity.*"

It can be argued that the wording of the code with regard to the actual eccentricity considered is vague and subjected to misinterpretation. For analysis of buildings based on three-dimensional models, one can argue that the actual eccentricity between the centers of rigidity and mass has been explicitly accounted for by the model and hence the only eccentricity to be considered is the shift of the center of mass. This is what is commonly practiced in the interpretation of codes like UBC 1997 and it seems that EBCS-8:1995 had followed suit and adopted seismic torsional provisions for accidental torsion without calculated eccentricity. However, it can also be argued that the code expects the story forces to be applied at a location which is the sum of the actual dynamic eccentricity and the accidental eccentricity. In this interpretation, the factor used in multiplying the dynamic eccentricity (i.e., $\alpha$) is then unity as opposed to 1.5 which was used in the previous code, ESCP-1:1983 as shown in Equation 2.a.

### 3-1 Accidental Torsion in Equivalent Static Load Procedure

The accidental torsion for ESL (equivalent static load) procedure as per EBCS-8:1995 is of the form:

$$e_i = 0.05\, L_i\, A_x \tag{1.a}$$

where,

$$A_x = \left(\frac{\delta_{\max}}{1.2\delta_{ave}}\right)^2 \leq \quad 3.0 \qquad \text{for } \delta_{max} > \delta_{ave} \tag{1.b}$$

and Li is the depth (*d*) or width (*b*) of the building depending on the direction of load considered.

Most buildings codes with similar seismic risk levels such as Ethiopia like Mexico (1987, 1993) and New Zealand (1992) still have maintained the old provisions where the actual eccentricity is taken as the sum of a given percentage of the building depth or width and the distance between the center of rigidity and center of mass of the buildings (see Table 2). The same procedure is used in the Canadian code NBCC-95 which takes the total accidental eccentricity as the sum of 10% of the building weight or depth and 1.5 times the distance of the center of rigidity from the center of mass at a given floor level.

The general form of the design eccentricity adopted by most building codes can be expressed as:

$$e_x = \alpha e_{CG,X} \pm \beta b \qquad (2.a)$$

The same expression as used by some of the international codes is given below,

$$\begin{aligned} e_x &= 1.5 e_{CG,X} \pm 0.1b \\ e_y &= 1.5 e_{CG,Y} \pm 0.1d \end{aligned} \quad \text{(Equation 4.1.9.2-28 of NBCC-95)} \qquad (2.b)$$

$$\begin{aligned} e_x &= 1.7 e_{CG,X} - \frac{{e_{CG,X}}^2}{b} \pm 0.1b \\ e_y &= 1.7 e_{CG,Y} - \frac{{e_{CG,Y}}^2}{d} \pm 0.1d \end{aligned} \quad \text{(New Zealand Code, 1992)} \qquad (2.c)$$

In comparison to other international codes for countries with similar level of construction practice, it may be argued that the EBCS-8:1995 is not conservative enough if $A_x$ is less than 2 for seismic torsional provisions. Despite the fact that the code is built on a rational approach, adopting a 5% ratio much like UBC 1997, however, may not be adequately conservative. It can further be argued that the adoption of 5% eccentricity by the UBC 1997 code that is commonly used in the US may be acceptable to US practices given the availability of adequate level of construction quality control. Therefore, a recommendation is proposed here that the accidental eccentricity provisions in the Ethiopian building code be revised to adopt a larger (i.e., 10%) percentage of the width or depth to reflect the Ethiopian construction industry practices.

### 3-2 Accidental Torsion in Response Spectra Analysis

The EBCS-8:1995, much like most building codes, specifies accidental torsion for response spectra-based dynamic analysis. The accidental torsion for dynamic cases is, however, limited to generating an additional static equivalent torsional moment. For engineers, this additional step of combining *dynamic* story shears (or member forces) with additional *static* story forces (or member forces) may be unnecessary additional step, particularly when modern structural engineering software can simply consider a given shift in the centers of mass and extract periods and mode-shapes in preparation for response spectra analysis that accounts for accidental torsion. Therefore, it is proposed that the code also specifically address accidental torsion in dynamic analysis where at least the automatic dynamic analysis that accounts for accidental torsion is given as an alternative. It is believed that this option will encourage design engineers to account for accidental torsion in dynamic analysis through a direct and rationale approach.

Table 2 summarizes the common practices adopted by some of the international building codes and the Ethiopian building code along with the proposed remedial approach.

**Table 2.** Comparison of accidental torsion provisions by different codes.

| | UBC-1988 | UBC-1997 | ESCP-1:1983 | EBCS:8-1995 | Proposed Change for EBCS:8-1995 |
|---|---|---|---|---|---|
| Static analysis | $e_x=1.5e_{CG,x}\pm0.05b$<br>$e_y=1.5e_{CG,y}\pm0.05d$ | $e_x=\pm0.05b$<br>$e_y=\pm0.05d$ | $e_x=1.5e_{CG,x}\pm0.1b$<br>$e_y=1.5e_{CG,y}\pm0.1d$ | $e_x=\pm0.05b$<br>$e_y=\pm0.05d$ | $e_x=\pm0.1b$<br>$e_y=\pm0.1d$ |
| Dynamic analysis | $M_x^i = e_x^i F_x^i$<br>$M_y^i = e_y^i F_y^i$ | move CMs by $\pm e_x$, $\pm e_y$ and do RSA or<br>$M_x^i = e_x^i F_x^i$<br>$M_y^i = e_y^i F_y^i$ | $M_x^i = e_x^i F_x^i$<br>$M_y^i = e_y^i F_y^i$ | $M_x^i = e_x^i F_x^i$<br>$M_y^i = e_y^i F_y^i$ | move CMs by $\pm e_x$, $\pm e_y$ and do RSA or<br>$M_x^i = e_x^i F_x^i$<br>$M_y^i = e_y^i F_y^i$ |

**CM = center of mass. 'i' – story number. RSA – Response spectra analysis. Fx and Fy are story shears. Mx and My are the torsional moments.**

## 4 Conclusions

The seismic zoning of Ethiopia as reported by different researchers over the past 30 years or so is marked by distinct and significant variations in PGA for the most economically important parts of the country such as the Addis Ababa region and the Afar Triangle. This study investigates these variations and suggests that newer data, a difference in the earthquake return period and the consideration of local site conditions could account for some of the differences. However, it is suggested that more detailed and well-documented research in effect of local site conditions is required before a significant amount of confidence could be built in the seismic zoning adopted by the current seismic building code. As an interim solution, increased PGA is suggested for the Addis Ababa region.

The study also investigates seismic code requirements on accidental torsion for dynamic analysis practiced in the country at the present time. Based on the argument that the quality control in construction industry is on a developing stage, the study suggests the implementation of a more stringent torsional requirements in the current Ethiopian seismic building code in par with other countries of comparable construction practice and similar earthquake hazard levels.

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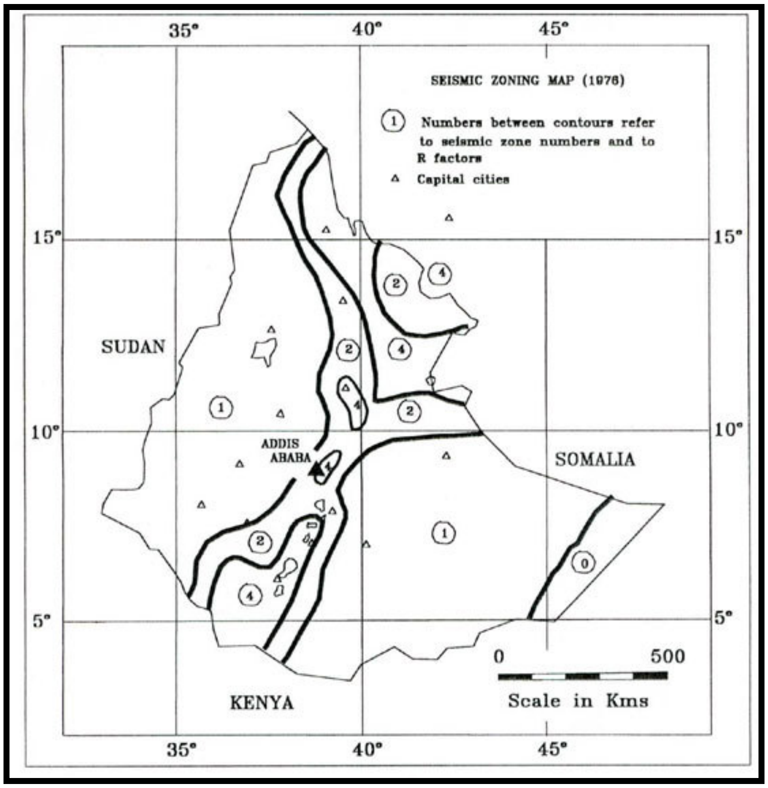


Figure 1. Seismic zoning of Ethiopia as per Gouin (1976).

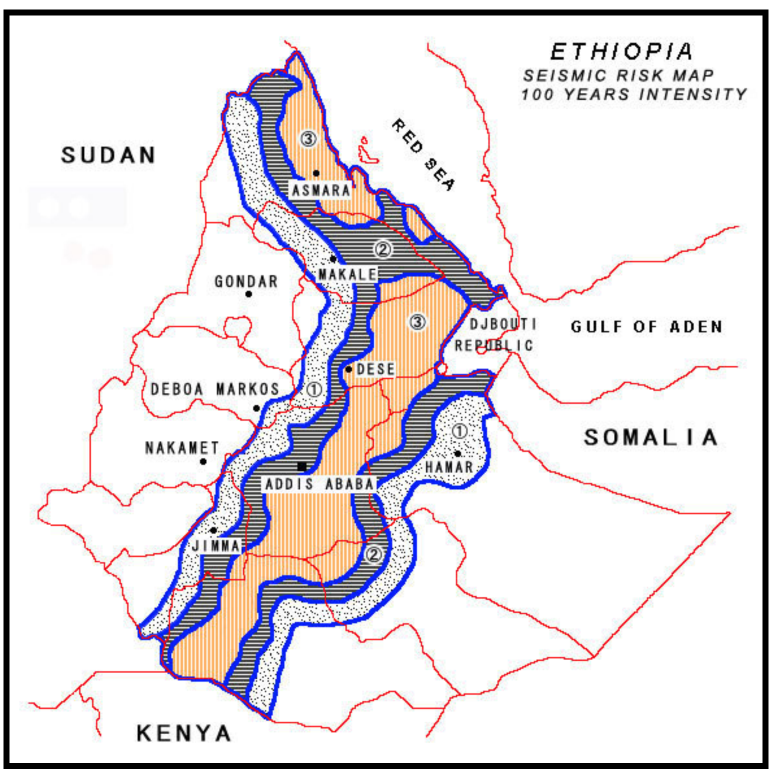


Figure 2. Seismic zoning of Ethiopia as per ESCP-1:1983.

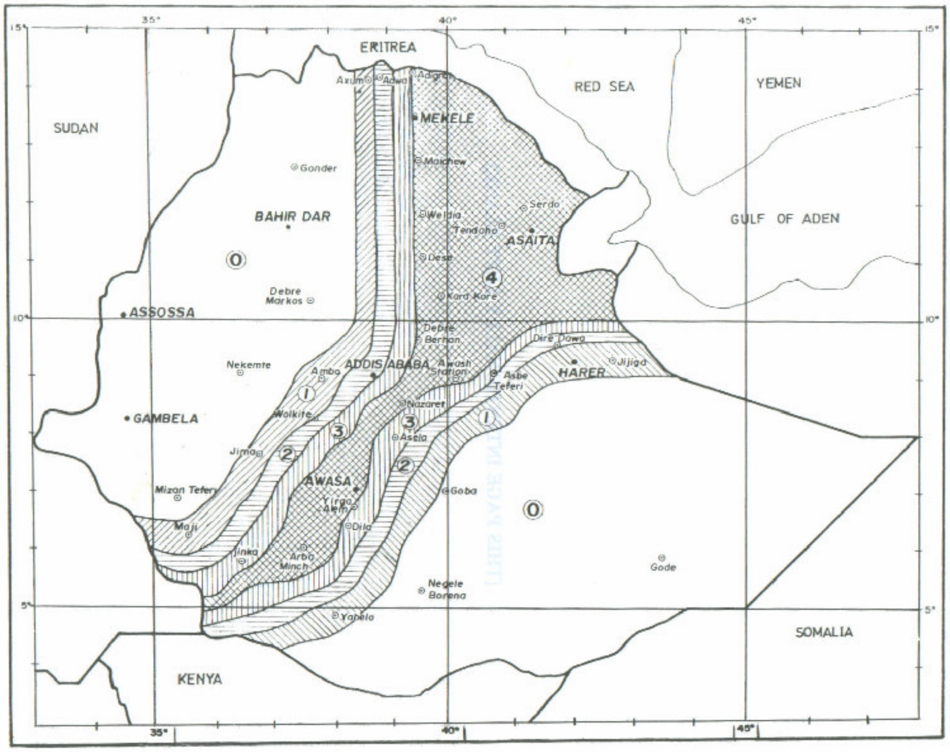


Figure 3. Seismic zoning of Ethiopia as per EBCS-8:1995.

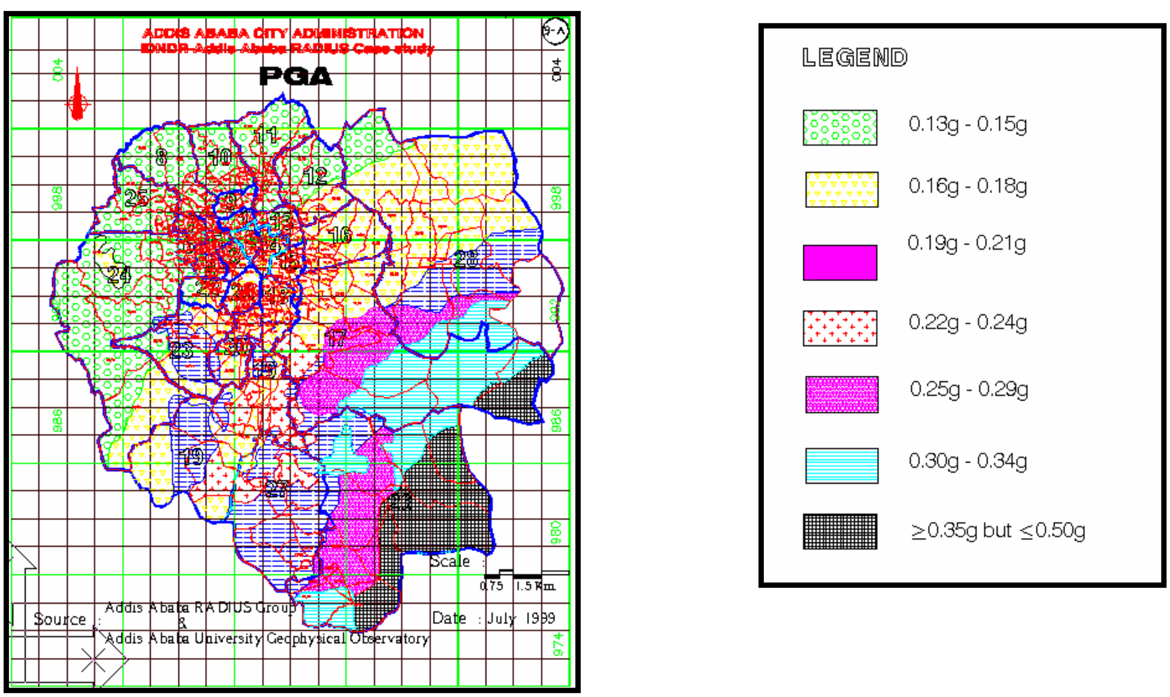


Figure 4. Seismic zoning of Addis Ababa as per RADIUS Project (1999).