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THE 1942 GUAYAQUIL EARTHQUAKE, RECENT EVIDENCES

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ABSTRACT

On 14 May 1942, a great earthquake with magnitude (Ms) 8 occurred off the Ecuadorian northern coast. Guayaquil city, located 250 Km far from the epicenter, suffered the strongest damages to more than 100 human lives and collapse of tall buildings.

In Guayaquil, the intensity had been reported to be VIII and IX in Modified Mercalli scale (MM) in the zone of so called "commercial center". Less intensities of VI and VII were reported in the rest of the city and in the other adjacent towns. The initial studies attributed the heavy damage to structural vulnerability factors despite the fact that those factors were common not only to the damaged zone but also to all the city at that time.

Later, the distribution of ground motion intensities felt in the city by another different earthquakes from the same epicenter showed that an important local site effect for seismic waves exists in the alluvial soft soil beneath the commercial center.

The record of accelerograms of the September 1990 earthquake with Ms 5.8 and the transmission model of the seismic waves through the alluvial soil point out that high amplification of moderate acceleration at the deep stratums, of which frequencies are inherently dangerous to tall buildings, would be an important factor to explain the heavy and selective structural damage suffered in Guayaquil in 1942.

KEYWORDS

Ecuador; Ecuadorian coast; Guayaquil; Nazca plate; South America earthquakes; soft soil; site effects; engineering resonance; vulnerability factors.

INTRODUCTION. DESCRIPTION OF GUAYAQUIL 1942 EARTHQUAKE.

At 2:13 GMT on the 14th of May in 1942, an earthquake with big magnitude, that was reported to be Ms 7.9 or Ms 8.3 based on different references (Project SISRA, 1985; Fiedler, 1988), affected the Ecuadorian coasts causing damages to Guayaquil and other cities. The ground motion intensity reached up to IX in Modified Mercalli scale (MM). Figure 1 taken from seismic catalogs shows the location of this earthquake epicenter as well as those of other earthquakes during this century.

It is well known that, although the intensity reached in general to VI in Guayas province (Guayaquil is the province's capital), VIII and IX intensities were reported in Guayaquil, pointing out that a local site effect caused that the earthquake affected the structures beyond what should have corresponded to normal damages for an earthquake with epicentral distance of 250 km. Despite the high intensities reported in Guayaquil, structural collapse and heavy destruction ocurred only in a narrow zone called "commercial center" inside the city. The rest of the city received damage corresponding to VII or less.

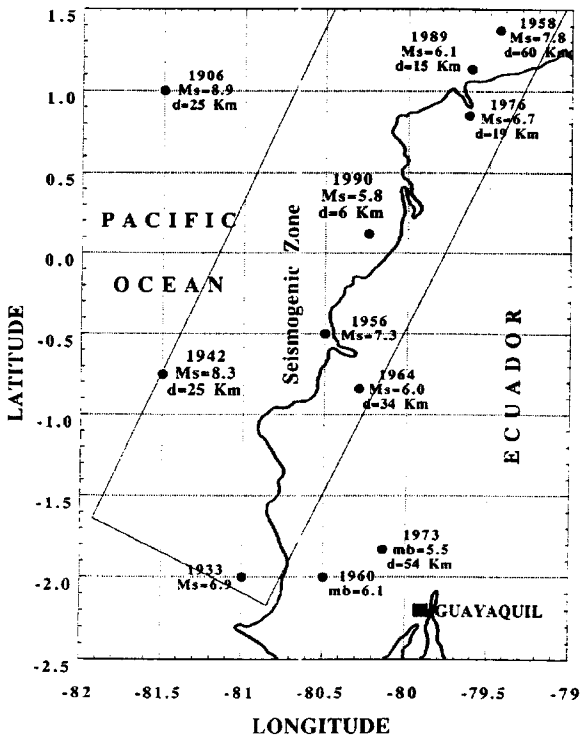

Fig. 1. Epicentral location of 1942 earthquake and others felt in Guayaquil during this century. After seismic catalogs.

Dr. Arnaldo Rufilli, in his description of the earthquake (Rufilli, 1949), identified the zone of worst damage as III zone and gave it the limits as shown in Fig 2.

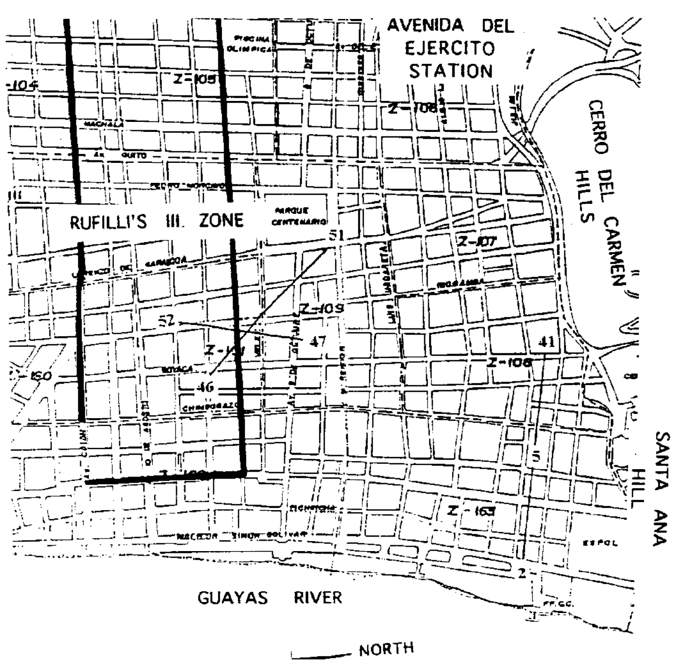

Fig. 2. Guayaquil "commercial center" : the zone defined by Rufilli as III zone (VIII and IX MM intensities).

The soil of that zone is described by Rufilli as follows: "here the soil is formed by yellow or brown clay saturated and always under the water level. This clay is covered by one or two meters of humus and other filling materials".

Damage at the zone III was described as follows: " in the little sector of six blocks in the north limit (of the zone III), five modern and important buildings were abandoned after the event, and a total number of nine were damaged. Three of the buildings were evidently inclined, and another three had the columns of the first floor so affected that an immediate supporting work was ordered before a decision for their repairs or demolition. In this zone the total collapse of a reinforced concrete building was verified and another one collapsed almost completely. These two building were close to each other wherein the soil had the aforementioned characteristics."

The structural type of affected buildings was of reinforced concrete frames and the collapsed and/or damaged structures were all buildings with three stories or more. Rufilli mentioned as causes of damage some vulnerability factors referring to bad construction practice, bad basement design and the common practice in Guayaquil at that time, where the first story was used to be between 4.5 and 5.0 meters in height for commercial reasons. The difference in stiffness between the first and the upper floors is still seen in many actual buildings as shown in Fig.3.

Fig. 3. Difference in stiffness between first and upper floors in a building at Guayaquil city. After Rufilli.

Being Guayaquil a city whose main activity is trade, the first floor was used, as is still seen today in some buildings, for commercial purposes and products storage, which implied the shortage of structural walls and the presence of large openings in the facade resulting in uneven distribution of stiffness in that level.

However, these vulnerability factors were not special to the structures of III zone but common to those in all the city. Zone III where the damage was notoriously higher than in other sectors of Guayaquil seems to have some influential engineering reasons. The selective behavior of heavy damage in reinforced concrete frame structures with more than three stories excluding other structures could be an evidence.

In Rufilli's classification of the city, the zones with minor damage (zones I and II) are located between the northern limit of III zone and the hills called Santa Ana and Cerro del Carmen, where the city was originally founded and extended to the south. Those hills are a part of the coastal mountain range called "cordillera de Chongon-Colonche" while the alluvial fan formed by the great Guayas river grew and spread to the south of the city. Therefore, the depth of alluvial soil increases in the southern district where the zone III is located. The zone IV in Rufilli's work is located in the south from the zone III, but at that time it was still new and developing sector and not many high buildings were constructed there. Anyway, the small buildings placed in the zone IV (near the limit with the zone III) were also damaged and one of them collapsed completely.

Before 1942, only two great earthquakes off the Ecuadorian northern coast had reported their magnitudes, locations of hypocenter and ground motion intensities. They were the January 1906 earthquake (Ms 8.9, epicentral distance is 400 km from Guayaquil) and the October 1933 earthquake (Ms 6.9, 129 km from Guayaquil). The highest intensity by these earthquakes reported in Guayaquil was VI. After 1942, various great earthquakes have been recorded in that area whose reports on magnitude, hypocenter and intensity are all available.

No ground acceleration records in Guayaquil during earthquakes had been obtained before the installation of the National Accelerograph Worknet in 1990 (Mera *et al.*, 1993). A Ms 5.8 earthquake with hypocenter close to that of 1942 ocurred on 1 September 1990, and ground acceleration was recorded in Guayaquil's soft soil. Therefore several actual seismological and geological studies together with the previous information will serve to establish evidences that a local site effect caused the buildings collapse and heavy damage during the 1942 earthquake at commercial center in Guayaquil city.

ECUADORIAN NORTHERN COAST SEISMICITY AND GUAYAQUIL INTENSITIES

The seismic activity along the northern Ecuadorian coastal area is the result of the subduction of the Nazca plate in the South America plate and has produced the highest magnitudes in the country during this century. The Fig.1. is also used to define the possible limits of such seismic zonation in Ecuador. The most destructive earthquakes in this area during this century are listed as:

1906.	January 31.	Ms=8.6-8.9	mb=7.4	Imax= IX
1933.	October 10.	Ms=6.9	mb=6.2	Imax= VII
1942.	May 14.	Ms=7.9-8.3	mb=7.0	Imax= IX
1956.	January 16.	Ms=7.3	mb=6.5	Imax= IX
1958.	January 19.	Ms=7.8	mb=6.7	Imax= IX
1964.	May 19.	Ms=6.0	mb=5.7	Imax= VIII
1976.	April 4.	Ms=6.7	mb=6.0	Imax= VIII
1989.	June 25.	Ms=6.1	mb=5.9	Imax= VII
1990.	September 1.	Ms=5.8	mb=5.4	Imax= VI

For practical purposes, intensity scale Imax in MM and MSK are regarded as essentially the same (Trifunac *et al.*, 1975) in this study. Imax is the maximum intensity reached in Ecuadorian northern coast.

As shown in Fig.4., the intensity reported from different sites during every earthquake are plotted against the focal (=hypocentral) distance. A correlation analysis on two parameters allows to evaluate the relationship between the mean intensity value and the focal distance. For the 1942 event, the mean intensity as a function of focal distance is therefore given by:

$$I = 18.644 - 5.015 \log X \qquad (1)$$

where I is intensity in Mercalli Modified scale and X is focal distance.

Considering the case of Guayaquil in regard to the 1942 earthquake, the focal distance to the city was 243.5 km resulting in the mean intensity value of 6.7 by the equation (1), which is different from the reported highest intensity of IX with errors of 2.3. A similar process was conducted to determine differences between mean intensities of every destructive earthquake in Ecuadorian northern coast and the intensity reported in Guayaquil. The differences were plotted against focal distance to obtain Fig. 5.

GROUND ACCELERATION AND SOIL AMPLIFICATION FACTORS.

The ground acceleration records in soft soil during the 1 September 1990 earthquake were obtained in the station of Avenida del Ejercito located as plotted in Fig.2. By using these acceleration records, spectral calculation was performed (Villacres *et al.*, 1993) to get the Fourier spectrums as shown in Fig.6.

Other researchers (Argudo *et al.*, 1994) modelled the transmission of seismic waves through the soft alluvial soil from the deep stratums of the Guayaquil city where a bi-dimensional multi-layer model based on soil profiles was used in order to estimate the amplification of ground acceleration. They concluded that the alluvial soft soil of the zone III in Guayaquil, in case of the incidence of seismic waves from far sources (>200 Km), shows an almost elastic soil response, dominated in the periods from 0.7 second to 0.9 second with amplification factors between 2.5 and 4.0 for not great than 0.05g acceleration levels in rock. For acceleration levels in rock between 0.05g and 0.15g, it was found an inelastic behavior, dominated by periods from 0.9 second and 1.1 second with amplification factors between 1.5 and 2.5.

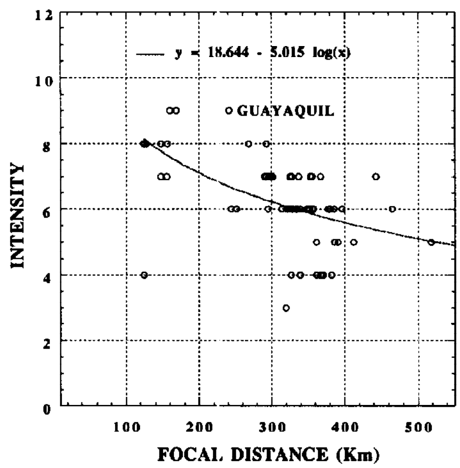

Fig. 4. Correlation between intensity and focal distance in the database of 1942 earthquake.

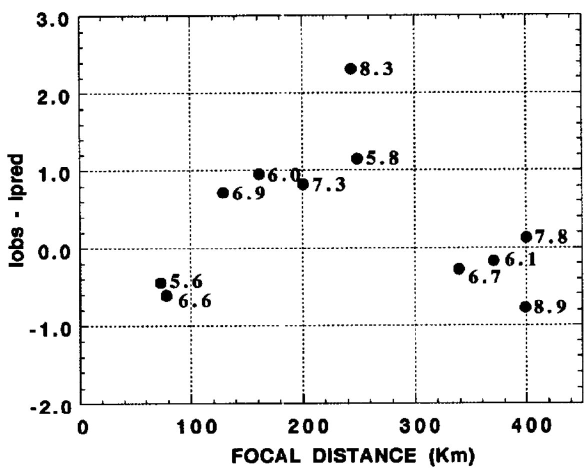

Fig. 5. Differences between observed and predicted mean intensities in Guayaquil. The values are magnitudes (Ms). Seismic source: Ecuadorian northern coast.

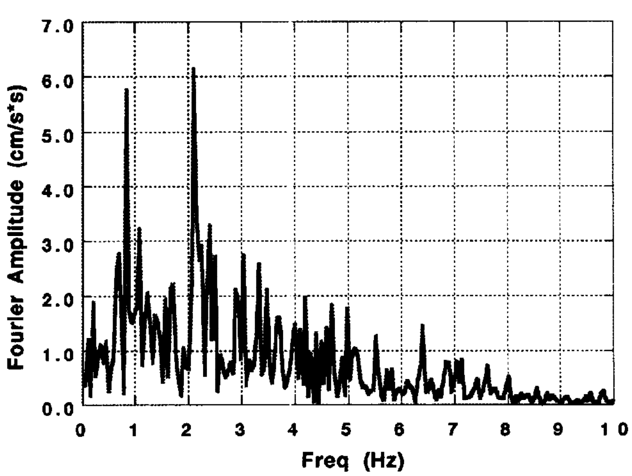

Fig. 6. Fourier spectra of horizontal components of ground acceleration recorded at Guayaquil during a 1990 earthquake. The spectra is the geometric mean of the NS and EW components.

SEISMIC RISK IN GUAYAQUIL

Finally, a seismic risk assessment was carried out for Guayaquil (Villacres *et al.*, 1995), expressing seismic risk for annual exceedance probability of a specific intensity I, as a function of annual exceedance rate V(I), given by:

$$V(I) = \sum_{k=1}^{n} Vk \int_X \int_M fIk(I/M,X)\, fMk(M)\, fXk(X)\, dM\, dX \qquad (2)$$

where Vk is the mean annual number of earthquakes not smaller than a specific magnitude in the earthquake source k, fMk (M) is the probability density function (PDF) of magnitude in the k source, fXk (X) is the PDF of focal distance from the source to the assessing site, and fIk (I/M,X) is the frequency with which the Intensity in the site exceeds the value I with a given magnitude M and focal distance X.

In this paper, only the annual exceedance rate of intensities due to earthquakes with epicenters off Ecuadorian northern coast is described. A Gutenberg-Richter relation in this seismic area was found to be:

$$\log N(mb) = 5.84 - 0.82\ mb \qquad R=0.99 \qquad (3)$$

The relationship between mb and Ms magnitudes obtained using 125 earthquakes with two different magnitudes reported in the area is:

$$Ms = 1.61\ mb - 3.22 \qquad R=0.97 \qquad (4)$$

where R is a coefficient of correlation.

The PDF of magnitude was defined as

$$fMk(M) = \frac{\beta e^{-\beta(M-Mo)}}{1 - e^{-\beta(Mu-Mo)}} \quad ; \qquad M \geq Mo\ , \quad \beta = \frac{b}{\log e} \qquad (5)$$

where b is 0.82 from equation (3), Mo is the minimum magnitude of an earthquake which could be expected to do damage to the site and Mu is the upper bound magnitude for the zone. When using mb scale those values are 4.5 and 7.5 for Ecuadorian northern coast.

The model applied to Guayaquil city provided Fig.7., where the V(I) values obtained with the model and those observed during this century are compared.

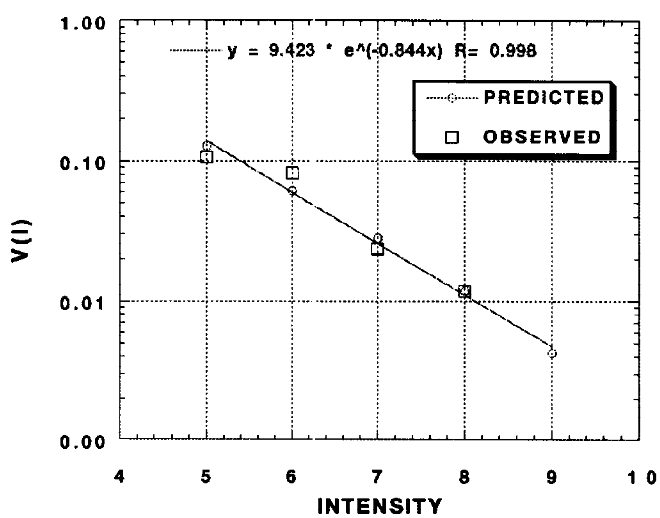

Fig.7. Comparison between observed and predicted V(I) values for earthquakes with epicenter into Ecuadorian northern coast. Site: Guayaquil city.

CONCLUDING REMARKS

The seismic intensities in Guayaquil city show that soil amplification of acceleration has been normal during this century even in the commercial center in case of great but shallow subduction earthquakes (Ms>6.0) with epicenter off Ecuadorian northern coast of which focal distances were between 100 and 300 km alike 1942 earthquake (243.5 km). On the other hand, for very far epicenters (>300 km) and very close ones (<100 km) the effect of amplification disappears. The acceleration amplification also shows a strong dependence on magnitude when comparing intensities in different earthquakes in Fig.5.

This tendencies agree with the results obtained by Argudo and Yela, showing that, for high accelerations in rock by an earthquake with near epicenters, the amplification is not so big as for moderate accelerations by an earthquake with far epicenters. This effect is characteristic of deep soft alluvial soil beneath the Guayaquil commercial center.

Regarding the structural damages suffered in the commercial center of Guayaquil, it should be concluded that it was attributed to the coincidence of various structural vulnerability factors (bad design and construction, weak first level and stiffness difference between first and upper levels) together with a strong ground motion caused by amplification of acceleration with a frequency range especially dangerous to tall buildings.

Both the historical earthquake review and the seismic risk assessment show that great magnitudes as that of 1942 earthquake have nowadays a high probability of occurrence in Ecuadorian northern coast and that magnitudes mb>6.5 should be expected in the area each 25.0 years in average.

The soil and structural characteristics, design and construction practice must be widely revised in the Guayaquil city where many buildings with similar type to those affected during the 1942 earthquake still remain. Some of those structures were constructed during the 1950 and 1960 decades and their risk is obviously high for the probability of a similar event is nowadays increasing.

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REFERENCES

Argudo, J. F. and R. Yela (1994). Microzonificacion sismica de Guayaquil. In: *VIII Jornadas Nacionales de Ingenieria Estructural*. Universidad Central del Ecuador, Quito.

Earthquake Mitigation Program in the Andean Region, Project SISRA (1985). Catalog of earthquakes for South America, hypocenter and intensity data, Ecuador. Vol 6, 42-100.

Fiedler, G. E. (1988). Historical seismograms recorded in Venezuela. In: *Historical Seismograms and Earthquakes of the World* (Lee, W.H.K., H. Meyers and K.Shimazaki), Chap 8, pp. 462-466. Academic Press, San Diego.

Mera, W. , L. Valarezo and J. Mancero (1993). Red Nacional de Acelerografos para movimientos fuertes del terreno. Facultad de Ingenieria de la Universidad Catolica de Santiago de Guayaquil, Guayaquil.

Rufilli, A. (1949). Los Terremotos de Guayaquil. In: *Lecciones de Estructuras* (Rufilli, A.), Chap 2, pp. 265-278. Universidad Estatal de Guayaquil, Guayaquil.

Trifunac, M.D. and A.G. Brady (1975). On the correlation of seismic Intensity scales with the peaks of recorded strong ground motion,. Bull.Seism.Soc.Am., 65, 139-162.

Villacres, A. and W. Mera (1993). Analisis espectral de acelerogramas para movimientos fuertes del terreno y estructuras. Facultad de Ingenieria de la Universidad Catolica de Santiago de Guayaquil, Guayaquil.

Villacres, A. and H. Ishida (1995). Seismic risk analysis for Ecuadorian northwestern coastal zone using both magnitude and intensity data. In: *I International Congress in Seismic Risk CIRS-96., Proceedings.* Universidad Catolica de Santiago de Guayaquil and Universita degli Studi di Lecce, Guayaquil.