MOTION PERCEPTION IN THE TALL BUILDINGS OF BUENOS AIRES CITY CAUSED BY THE GREAT CHILEAN SEISMIC EVENT AND ITS KINEMATIC

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SUMMARY
The motion caused by the 2010 Great Chilean Mw=8.8 earthquake on the tall buildings of Buenos Aires city, at nearly 1300km from the epicentre, was clearly perceived, despite not causing structural damage.
The ground motion acceleration recorded in La Plata (50km away from Buenos Aires city and with the same type of subsoil), a quaternary loess with approximately 500m thickness, shows a maximum of 2.0gals in the N-S component, the strongest interval lasting approximately 300sec. The 2% damping curve of its acceleration response spectrum shows peaks with values of 7 and 16 gals for T=1.18sec and T=2.85sec, respectively, periods which are associated with subsoil properties.
Moreover, the measured horizontal vibration periods of these buildings reach about 3sec in the tallest one, which is 160m high. These dynamic properties explain why the distant, large magnitude seismic events have been perceived well and also with alarm on their uppermost floors.

Keywords: tall buildings, Buenos Aires city, 2010 Great Chilean earthquake

1. INTRODUCTION

On February 27, 2010, at approximately 3hs 35m local time, 6hs 35m UTC, and during several tens of seconds, the occupants of the upper levels of the tallest buildings of Buenos Aires city, the capital of Argentina, suddenly perceived oscillations whose amplitudes, frequencies and duration generated unpleasant emotions and sometimes also considerable alarm because they assumed it was an unknown emergency which could affect the structural stability of the building. After the motion ceased, the first inspection of the buildings did not detect any damage, but many inhabitants evacuated them. Afterwards, when the news of the great earthquake that shook the central southern territory of Chile broke, those frightened occupants of the tall buildings of Buenos Aires city learnt that the cause of the oscillations in those buildings were the seismic waves generated in the epicentral area 1300km away and which had propagated to the site. However, these seismic waves were not felt by the people who were at ground level in the same city.

Buenos Aires city, with a metropolitan population of nearly twenty million inhabitants, is located on the eastern side of an extended plane area formed by 500m deep sedimentary alluvial soil layers, which are known as the Argentinian *pampas*. The seismic activity of the area is low. However, since the beginning of the past century, when the number and height of the buildings increased, more occupants of the upper floors have reported feeling the building motion caused by large-magnitude seismic events occurring in the western part of Argentina or in Chile, at distances longer than 1000km from Buenos Aires. Although these motions have not damaged buildings yet, their amplitudes, frequencies and duration have made their occupants feel unpleasant emotions and sometimes great alarm like that experienced on February 27, 2010.

The tallest buildings of Buenos Aires city are now over 100m in height and the seismic history of the western part of Argentina and the neighbouring territory of Chile shows that seismic events of a magnitude larger than Ms=8 occur several times in a century. In order to evaluate the building safety, it is convenient to estimate the amplitudes of the motion when the building is shaken by these earthquake waves, which are almost imperceptible at ground level.

Therefore, in 1994 the fundamental periods of various tall buildings in Buenos Aires city, including one of the tallest with a height of 160m, were obtained by microvibrations and, since 1996, the accelerations caused by several distant seismic events of different magnitudes have been recorded in the Seismological Station of Universidad Nacional de La Plata, located 50km away from Buenos Aires city and with similar subsoil properties.

The accelerations of the motion caused by the very large magnitude, Mw=8.8, February 27, 2010 seismic event were recorded, with a maximum value of 2.0gals in the N-S component. This 2010 La Plata accelerogram has been the most outstanding record obtained in La Plata since its installation in 1996.

The analysis of the kinematic properties of this earthquake and the evaluation of the acceleration response curves of the 2010 La Plata accelerogram that will be described in the following paragraphs are important tools to better understand the behaviour and safety conditions of the tall buildings of Buenos Aires city when there are large magnitude seismic events in Chile at more than 1000km of epicentral distance. For example, from the 1906, 1922, 1943 and 1960 events, the only information available about the inhabitants' perceptions can be found in the local newspapers.

2. THE 2010 GREAT CHILEAN Mw=8.8 EARTHQUAKE

Early in the morning of February 27, an extended coastal area of the southern central part of Chile was strongly shaken by a great earthquake whose magnitude reached Mw=8.8. In South America in the last century this magnitude value has only been exceeded by the Mw=9.6 of the Extraordinary Seismic Event occurred on May 22, 1960, whose rupture area was located close to the south from that of the February 27, 2010 (Barrientos S., 2010).

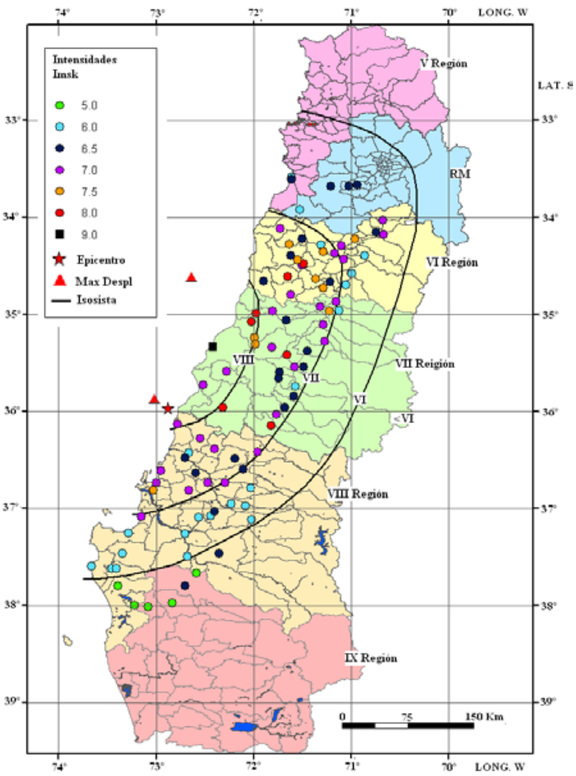

Figure 2.1 – 2010 Great Chilean Earthquake- Seismic Intensities. (Astroza M. et al, 2010)

This 2010 Great Chilean Earthquake generated an important tsunami whose waves devastated the shore towns increasing the damage and causing nearly five hundred victims. Fig. 2.1 shows the distribution of the seismic intensity in the most shaken area according to the evaluation made by (Astroza M. et al., 2010).

Some evidence of the tectonic aspects associated with this 2010 Great Earthquake was the displacement of the earth crust detected by GPS measurements and detailed in Fig. 2.2 (Barrientos S., 2010) with a maximum of 3.7m in the city of Concepción in Chile.

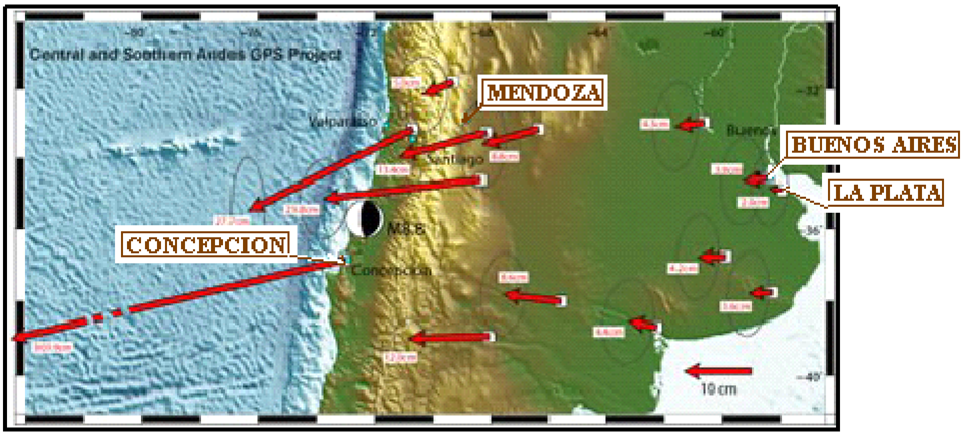

Figure 2.2- 2010 Great Chilean Earthquake – Displacement of Earth Crust by GPS (Barrientos S.,2010)

2.1 The Effects in the Argentinean Territory

The 2010 Great Chilean Earthquake motion was also felt with intensity –decreasing towards the east – in an extended area of Argentina, causing alarm among the inhabitants who were closer to the rupture area but without causing any damage or victims. In Buenos Aires city and its surrounding area, approximately 1300km from the source, the ground level motion was slightly perceived by a few people and only at the upper levels of the tall buildings the lengthy oscillations were felt.

3. GROUND ACCELERATIONS RECORDED IN LA PLATA AND MENDOZA CITIES DURING THE EVENT

La Plata Seismological Station (LPA) is located 50km away from Buenos Aires city and has the same type of subsoil. The acceleration recorded during the 2010 Great Chilean event, see Fig. 3.1, reached a maximum value of Amx=2gal in the N-S component.

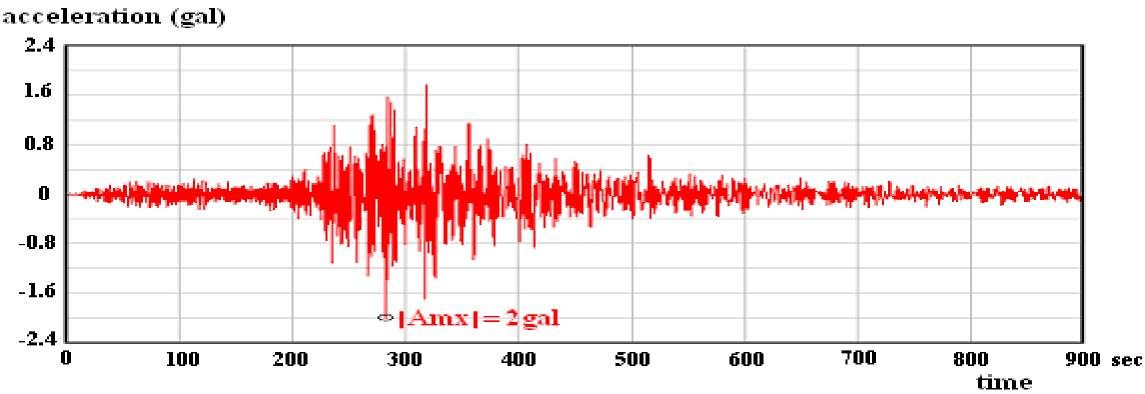

Figure 3.1- N-S Component of La Plata Acelerogram Recorded During 2010 Great Chilean Earthquake

In order to compare the attenuation effects by distance, it was measured that the maximum ground acceleration recorded in Mendoza city, located in the western part of Argentina, see Fig. 2.2, was

16gal, while in the epicentral area in Concepción (Barrientos S., 2010) the ground accelerations were over 600gal.

4. KINEMATIC PARTICULARITIES OF THE 2010 LA PLATA ACCELEROGRAM

4.1 Duration of Larger Amplitudes

One outstanding aspect of the acceleration, (Acel), time evolution of the 2010 Great Chilean event, see Fig. 3.1, is the duration (DUR) of the amplitude acceleration values (Acel). Given the time between the first and the last instant with an acceleration larger than one quarter of the maximum (Am), Acel>0.25Amx, $DUR_{0.25Amx}$ is equal to 239sec, and when it is larger than half of the Amx, Acel > 0.5Amx, $DUR_{0.5Amx}$ is equal to 130sec. It should be noted that the Source Time Function was developed in 110sec (Barrientos S., 2010), value which is comparable with $DUR_{0.5Amx}$.

4.2 Velocity and Characteristic Period

To obtain the velocity of the ground motion recorded at LPA, a pass band filter 0.01-5 hertz was applied. The maximum velocity obtained for the N-S component was Vmx=1.5cm/seg. By contrast, in Mendoza city the maximum velocity was 8cm/sec, while at the epicentral area in Concepción city it was 44cm/seg, which is nearly thirty times larger than in La Plata. From each pair of values Amx and Vmx, it is possible to obtain the average period $T_{AV}=2\pi.Vmx/Amx$, which discloses the first information about the frequency distribution of the acceleration record. Whereas it is T_{AV}=4.7sec for 2010 LPA record, it is 3.2sec for 2010 Mendoza and 1.5sec for 2010 Concepción. The larger value of T_{AV} for 2010 LPA record shows that the quantity of long period components is relatively more important. This is a known consequence because of the attenuation with the increasing epicentral distance that is greater for short period waves.

5. OTHER ACCELEROGRAMS RECORDED IN LA PLATA DUE TO DISTANT AND LARGE MAGNITUDE EVENTS

The second largest acceleration recorded at LPA since 1996 has been Amx=0.75gal, due to the October 15, 1997 Mw=7.1 earthquake, see Fig.5.2, with its epicenter located also on the coast of Chile, (Sabbione, N. et al, 2004) at approximately 700km to the north of the 2010 Great event and at a distance of 1350km from LPA, see Fig. 5.1. The motion was felt only in the upper levels of the tall buildings of Buenos Aires city. This Amx amplitude is 2.5 times lower than that recorded during the 2010 Great event.

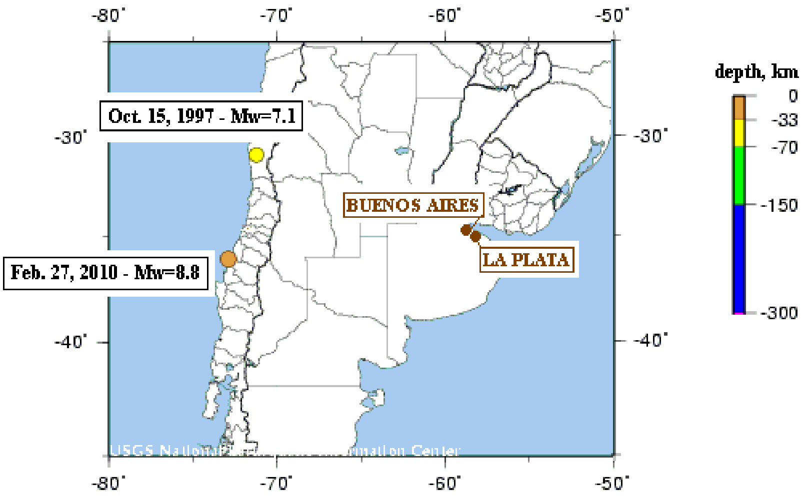

Figure 5.1- Epicenters of Feb.27, 2010 Mw=8.8 and Oct. 15, 1997 Mw=7.1

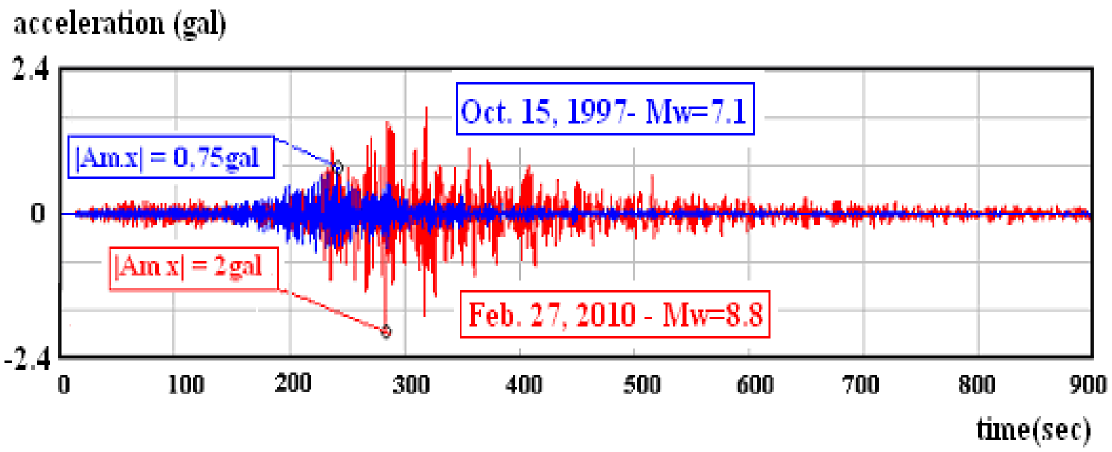

Figure 5.2- N-S Components of La Plata Acelerograms of Feb.27, 2010 Mw=8.8 and Oct. 15, 1997 Mw=7.1

Other significant acceleration records from LPA are those due to the June 18, 2002 Mw=6.6 and June 20, 2003 Mw=6.7 earthquakes, (Sabbione, N. et al, 2004) whose maximum accelerations were Amx=0.66gal and Amx=0.60gal, respectively, both with epicentral areas not far away from that of the October 15, 1997 event. We can also mention the largest acceleration previously recorded from the same epicentral area as that of the Great 2010 Chilean event, Amx=0.50gal, recorded during the May 3, 2004 Mw=6.6 event. The kinematic particularities of the acceleration records mentioned above are presented in Table 5.1.

Table 5.1 Kinematic Particularities of the La Plata Acceleration Records Considered

DATE	Amx(NS) (gal)	Vmx(NS) (cm/seg)	$T_{AV} = 2\pi$ Vmx/Amx (seg)	$DUR_{0,25Am}$ (seg)	$DUR_{0,5Am}$ (seg)
Oct. 15, 1997	0,75	0,26	2,2	213	97
Jun. 18, 2002	0,66	0,26	2,5	166	59
Jun. 20, 2003	0,60	0,25	2,6	135	30
May 03, 2004	0,50	0,28	3,6	131	22
Feb. 27, 2010	2,00	1,50	4,7	239	130

As the seismic events detailed in Table 5.1 have epicentral distances to LPA ranging from 1300 to 1350km, the increasing values of DUR show the influence of their magnitudes. With regard to the values of $T_{AV,}$ we should keep in mind that the 2010 Great was an interplate process event (Barrientos S., 2010), whereas the October 15, 1997 was classified as an intraplate process, (Sabbione, N. et al, 2004) and then this particularity can account for the difference between their T_{AV}. If this is correct, the 2003 and 2004 events of Table 5.1 are intraplate processes and the 2004 event is an interplate process.

5.1 Accelerogram Frequency Distribution

To study the frequency distribution of accelerograms, their Fast Fourier Transform, (FFT), has been evaluated. One smooth out has been applied to see the predominant frequency more clearly. The resulting curves corresponding to three of the accelerograms listed in Table 5.1 are shown in Fig. 5.3. In these FFT, there are outstanding frequencies of approximately 0.35 c/s (period of T= 2.85sec) and 0.85 c/s (period of T=1.18sec), whereas in that of the 2010 Great Event additional outstanding frequencies of 0.2c/s (period T=5sec) and 0.083c/s (period T=12 sec) have been detected.

As these accelerograms correspond to different magnitudes and epicentral azimuth directions, the assumption that the first two frequencies are associated with subsoil natural vibration properties of LPA is valid, (Pinciroli et al, 1997) these corresponding to the quaternary loess of Argentinian “pampas” with approximately 500m thickness.(Russo, a. et al, 1979) The other two lower frequencies, 0.2 and 0.083 hertz, are those attributed to surface waves generated (Gershanik,S., 1996) by the large magnitude of the 2010 Great Chilean event.

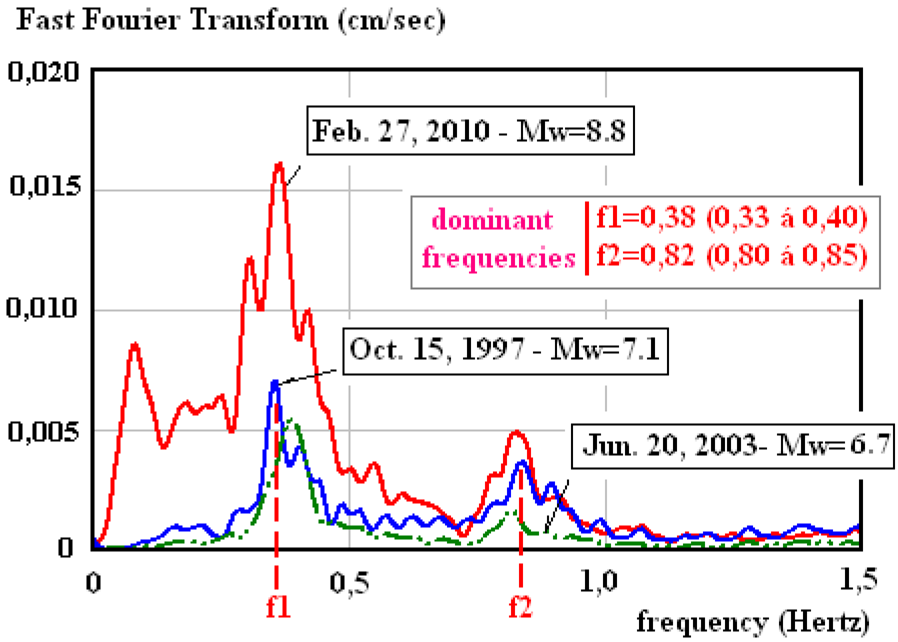

Figure 5.3 – Fast Fourier Transform of Three of the Chilean Accelerograms Listed in Table 5.1

6. ACCELERATION RESPONSE SPECTRUM CURVES

With the purpose of evaluating the response of the tall buildings of Buenos Aires city to distant and large magnitude seismic events, the acceleration response spectrum of the accelerograms recorded in LPA has been analysed. Fig. 5.3 shows that the acelerogram dominant periods are 1.2 and 2.7 seg and that the fundamental horizontal vibration period measured for some tall buildings of Buenos Aires city range from 1.5 to 3.0 sec. Therefore, the curves of the acceleration response spectrum will be evaluated for periods between 0.6 and 4sec.

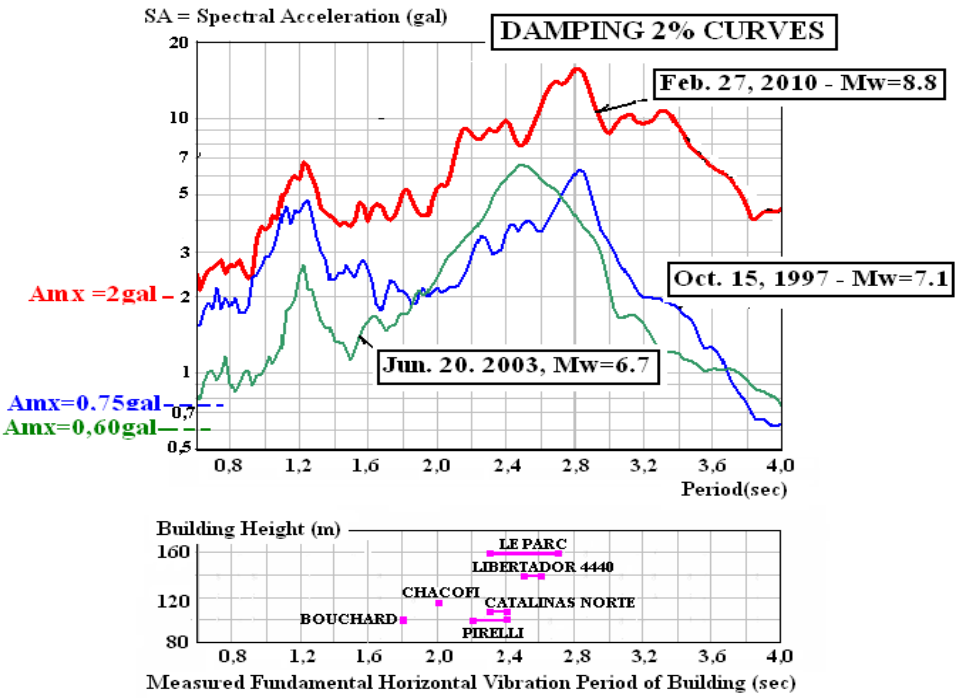

Figure 6.1 – Damping 2% Acceleration Response Curves and Building Horizontal Vibration Period

Due to the relatively small amplitudes of the building vibrations under study and the results obtained from the analysis of their environmental microvibrations, (Carmona, J. et al,1995) the 0.02 critical damping values will be selected for the spectrum curves of this study. Fig. 6.1 shows the 2% damping value acceleration response curves corresponding to the three N-S components of the accelerograms selected to prepare Fig. 5.3. They show peaks at approximately 1.2sec and 2.7sec, like the dominant periods detected in their FFT, see Fig. 5.3. While these peaks are several times its maximum acceleration component, they are 3.5 and 8Amx respectively, with a minimum of 2Amx for periods between them, during the 2010 Great Chilean event.

7. RESPONSE OF THE TALL BUILDINGS OF BUENOS AIRES CITY TO THE DISTANT AND LARGE MAGNITUDE SEISMIC EVENT

La Plata is approximately 50km away from Buenos Aires city, see Figs. 2.2 and 5.1, and both cities have the same type of subsoil, which is the quaternary loess of Argentinian “pampas” with approximately 500m thickness.(Russo, A. et al, 1979) As the distance between both cities is relatively small compared to the distance between La Plata and the considered earthquakes, we can assume that the seismic waves attenuation are similar.

Therefore, it can be assumed that the accelerograms recorded in LPA are similar in amplitude, frequency and temporal evolution to the accelerograms that are recorded in the ground level of the tall buildings of Buenos Aires city and, consequently, the 2% damping value acceleration response curves of Fig. 6.1 will be applied to evaluate the response of the tall buildings of Buenos Aires city to the motion caused by distant and large magnitude seismic events such as the 2010 Great Chilean Mw=8.8.

In Fig. 6.1 there is also information about the height and the fundamental period of the horizontal vibrations of a sample of six of the numerous tall buildings of Buenos Aires city, including one of the tallest, which is 160m in height. Their periods were obtained in 1994 by analysing the records of the horizontal microvibrations induced by environmental excitations on the upper levels. (Carmona, J. et al, 1995) What is outstanding in Figure 6.1 is that the period values of these buildings are on the same intervals as the largest values of the spectral acceleration response curves. If the building modal shape is included, on the upper levels of more than 25 floors, the motion amplitude will be lower than four times the maximum ground acceleration, which for the 2010 Great event is not lower than 8 gals and could increased to 25gals for the highest.

This result is very important because it explains why people who live on the upper level of the tall buildings of Buenos Aires city clearly perceive their oscillations when large magnitude seismic events occur in the Chilean territory, while the earthquake waves are almost imperceptible at ground level. This result also allows us to use the press information about the perception of individuals in the effects of distant and large magnitude seismic events.

In the twentieth century in the extended Chilean coastal line various seismic events occurred with magnitudes larger than Mw=8, such as the Mw=8.2 August 6, 1906, causing damage and victims in the area of Valparaiso city; the Mw=8.5 November 10, 1922, causing damage and victims around Copiapo city; the Mw=8.2 April 6, 1943, causing damage and victims around Illapel city; and the extremely great magnitude Mw=9.6 May 22, 1960, causing damage and victims mainly around Valdivia city (SSN, 2010). They generated destructive tsunamis, in particular the last one, whose effects reached the Japanese coast. According to local newspapers, when these events occurred, no building structural damage was detected; the occupants of the upper floors of the tall buildings of Buenos Aires city perceived: the oscillations; a visible swinging of pictures hanging on the wall; light fittings hanging from the ceiling; the opening of office equipment doors, drawers in offices and of home furniture that was not locked, in a similar way as that described as the effects of the 2010 Great event. However, again there was no information about the quite evident perception of the motion at ground level, which means that the maximum ground accelerations were around the 2gals as recorded in La Plata.

After analysing the above newspaper information and the results obtained by evaluating the acceleration response curves in Fig. 6.1, perhaps the most important conclusion is that, for safety reasons, the structure of the tall buildings of Buenos Aires city must be prepared to face a motion similar to the recorded acceleration in LPA during the 2010 Great Chilean event.

8. CONCLUSIONS

The amplitude of the motion on the upper floors of tall buildings in the city of Buenos Aires, which was clearly perceived by frightened occupants as a consequence of the Mw=8.8 February 27, 2010 Great Chilean seismic event, has been estimated.

The data used to develop the analysis was:

- The accelerogram LPA2010GCH corresponding to this 2010 event which was recorded in the Seismological Station of Universidad Nacional de La Plata, located 50km away from Buenos Aires city.
- The measured fundamental period of horizontal vibrations on six of the numerous tall buildings of Buenos Aires city, including one of the tallest that is 160meters high.

After the analysis of the LPA2010GCH the following has been obtained:

a- The main kinematics particularities are a maximum acceleration of Amx=2gal in the N-S component and the relatively long stay in time between the first and the last instant with an acceleration larger than half the maximum Amx, equal to 130sec. Another particularity is the accelerogram velocity obtained, whose maximum is Vmx=8cm/sec with a characteristic period $T_{AV}=2\pi.Vmx/Amx=4.7$sec. This shows that the quantity of the larger period components is relatively more important as a consequence of the greater attenuation for short period waves with an increasing epicentral distance.

b- The frequency distribution of the LPA2010GCH accelerogram evaluated by means of the Fast Fourier Transform (FFT) shows two outstanding frequencies of approximately 0.35 c/s (period of T= 2.85sec) and 0.85 c/s (period of T=1.18sec). As a similar result has been obtained in the FFT of all the accelerograms analyzed in LPA, it can be assumed that these two frequencies are associated with the subsoil natural vibration properties of LPA, which is quaternary loess of the Argentinean pampas of approximately 500m in thickness.

c- The 2% damping value acceleration response curve corresponding to the LPA2010GCH shows peaks at approximately 1.2sec and 2.7sec, like the dominant periods detected in its FFT. These acceleration peaks are 7 and 16 gals respectively, which are 3.5 and 8Amx times the maximum ground acceleration, while there is a minimum of 2Amx for periods between them. The 0.02 critical damping value was selected due to both the relatively small amplitudes of the building vibrations under study and the results obtained from the analysis of their environmental microvibrations.

d- LPA is approximately 50km away from Buenos Aires city. This distance is relatively small compared to the epicentral distance from the 2010 Great Chilean event and both cities have the same type of subsoil. Then it can be assumed that the accelerogram recorded in LPA has similar seismic wave attenuation, amplitude, frequency and temporal evolution than the accelerograms that could have been recorded at ground level in Buenos Aires city. Consequently, the 2% damping acceleration response curve of LPA2010GCH can be applied to study the response of the tall buildings of Buenos Aires city to the motion caused by the distant and large magnitude 2010 Great Chilean Mw=8.8 seismic event.

e- The period values of the tall buildings of Buenos Aires city are on the same intervals as the largest values of the acceleration response curve of LPA2010GCH. If the building modal shape is included, on the upper levels of more than 25 floors, the motion amplitude will not be lower than four times the maximum ground acceleration. This means that there can be an acceleration of 8 gals increasing to 25gals. This result is significant because it explains why people who live on the upper levels of tall buildings clearly perceive oscillations when large magnitude seismic events occur in the Chilean territory, while the earthquake waves are almost imperceptible at ground level.

f- In the twentieth century various seismic events occurred in the extended Chilean coastal line with magnitudes larger than Mw=8, such as the Mw=8.2 August 6, 1906; the Mw=8.5 November 10, 1922; the Mw=8.2 April 6, 1943; and the extremely great magnitude Mw=9.6 May 22, 1960. Like the Mw=8.8 February 27, 2010, they generated destructive tsunamis and caused damage and victims. According to Argentinian newspapers, when these events occurred, no building structural damage was detected although the occupants of the upper floors of the tall buildings of Buenos Aires city perceived the oscillations: a visible swinging of pictures hanging on the wall; light fittings hanging from the ceiling; the opening of office equipment doors, drawers in offices and of doors and drawers in houses and flats, in a similar way as that described as the effects of the 2010 Great event. However, again there was no information about the perception of the motion at ground level, which means that the maximum ground accelerations were around the 2gals, as recorded in La Plata on February 27, 2010.

g- After analysing the newspaper information and the results obtained by evaluating the acceleration response curve of LPA2010GCH, the most important conclusion is that, for safety reasons, the structure of the tall buildings of Buenos Aires city will have to be prepared to face a motion similar to the recorded acceleration in LPA during the 2010 Great Chilean event.

It is important to highlight that this conclusion should not be applied when a large magnitude intraplate event occurs in Argentinian territory, like the Mw=7.4 November 1977 one. The motion generated in Buenos Aires for this kind of earthquakes has not been measured yet.

REFERENCES

Astroza M., Cabezas F., Moroni M.O., Massone L.., Ruiz S., Parra E., Cordero F. and Mottadelli A. (2010)- "Intensidades Sismicas en el Area de Daños del Terremoto del 27 de Febrero de 2010" **-** *Departamento de Ingeniería Civil, Universidad de Chile*-- Santiago-Chile –2010

Barrientos, S.(2010), "Terremoto Cauquenes 27 Febrero 2010- Informe Técnico Actualizado al 27 Mayo 2010"- *Servicio Sismológico, Departamento de Geofísica, Universidad de Chile*, Santiago, Chile, 2010

Carmona, J. S., Sisterna, C. A. and Magrini, M.C.,(1995) "Periodos de Vibración Medidos en Edificios Torre de la Ciudad de Buenos Aires con Altura Mayor de 100 m.", *Proceedings XXVII Jornadas Sudamericanas de Ingeniería Estructural*, Tucumán, Argentina, Vol. 6, pp561-571.

Gershanik, S.(1996)**, "**Sismología", Universidad Nacional de La Plata, pp789-790.

Pinciroli, R., Sabbione, N. and Rosa, M.L.,(1997) "Aspectos del Ruido Sísmico en la Estación LPA", *Proceedings 19ª Reunión Científica de Geofísica y Geodesia*, San Juan, Argentina, pp237-241.

Russo, A, et al.,(1979) "Llanura Chaco Pampeana", *Proceedings Segundo Simposio de Geología Regional Argentina,* Academia Nacional de Ciencias, Córdoba, Argentina, Vol. I, pp139-183.

Sabbione, N.C., Carmona, J.S. , Pinciroli, R. y Palau, R. (2004) "Espectros de Respuesta de la Aceleración Sísmica Registrada en La Plata en Ocasión de Grandes Sismos Distantes**",** *XXII Reunión Científica de la Asociación Argentina de Geofísicos y Geodestas*, Buenos Aires, Argentina, 6 a 10 septiembre 2004.

SSN(2010)- **"**Sismos Importantes Y/O Destructivos (1570 - Mayo 2005)" - *Servicio Sismológico – Departamento de Geofísica- Universidad de Chile*- Santiago, Chile, 2010

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