LESSONS OF THE APRIL 16TH, 2016 PEDERNALES, ECUADOR EARTHQUAKE:

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Abstract

On April 16th, 2016 a 7.8MW earthquake struck the earth close to the city of Pedernales in the Ecuadorian coast. The severe earthquake caused 668 deaths and induced economical losses that reached about 3000 million dollars due to damages and collapses of buildings, damages in routes and highways, port facilities, and communications. The presentation has been divided into four parts.

First part. Slides showing damages observed after the earthquake. The first group of slides corresponds to damages and collapses in non-engineered construction in areas close to Pedernales. Second group shows site effects in cities like Manta and Portoviejo, both located 180km from the epicenter, and damages in port facilities. The third group permits to observe masonry damage in modern buildings built in the last 30 years in Manta, Portoviejo, and in Guayaquil located 280km away of the epicenter.

Second part: Analysis of Guayaquil records. Three (3) seismic records of the April 16th earthquake were recorded for the city of Guayaquil.

The reports of the records from the Instituto de Geofísica-Escuela Politécnica Nacional (IG) do not show the type of soil where the accelerographs are located. However, for the city of Guayaquil the IG report published a map with the locations of the acclerographs making possible to assume correctly the soil type for the Guayaquil records. There has not been reports of soil type for the locations of the instruments for the other cities where IG captured records of the earthquake.

The maximum acceleration recorded in Pascuales in a rock site type B, AGYE record, was 2.4%g, while in the soft soil type E, in downtown Guayaquil, AGYE2 record showed a maximum acceleration of 9.6%g, that is, four times the acceleration recorded in Pascuales. This amplification is similar to the one recorded in downtown Mexico D.F. during the 1985 Michoacan earthquake, 350km away from the epicenter. In the south of Guayaquil, soft soil type E, where the third record, AGYE1 was captured, the maximum acceleration was 7%g, close to three times the Pascuales maximum acceleration.

The study was performed calculating the acceleration response spectra, based on annual probability, following NEC-15 specifications, for several earthquake levels: frequent, occasional, rare and very rare: 72, 225, 475 and 2500 years return period respectively. The recorded average maximum response accelerations for the three stations was less than the maximum acceleration for the NEC-15 frequent response spectrum for soil type B and E, respectively.

The seismic response spectra for Guayaquil records with no reduction were compared to the code elastic design response spectra reduced by strength modification factors (R): 2, 4, 6, and 8 according to NEC-15. The objective of the comparison was to determine the value of R that might have caused structural damage under the Guayaquil records.

The response spectral accelerations of AGYE records were below the NEC-15 elastic design response spectrum, for soil type B, reduced by a factor of 8. For AGYE1 record, the response spectral accelerations were, in general, below the NEC-15 elastic design response spectrum, for soil type E, reduced by a factor of 4. AGYE2 response spectral accelerations were between the NEC-15 response spectra, for soil type E, reduced by R = 2 and the one reduced by R =4.

Considering that the AGYE1 and AGYE2 records showed response spectra accelerations below NEC-15 frequent earthquake accelerations, reduced by R=3 and R=4, structures located on soft soil will not meet the performance based design philosophy expressed in NEC-15: "no structural and no non-structural damage for frequent earthquakes".

Third part. Damage prediction using energy methods. Several modern buildings that suffered severe masonry damage in the city of Samborondon, located in front of Guayaquil, just crossing the Guayas River have been modeled linearly and non-linearly and excited with the records of the Pedernales 2016 earthquake recorded in Guayaquil. The objective of the study was to determine damage indices relating the energy dissipated through structural damage 1) to the earthquake energy input into the structure, and 2) to the energy capacity of the structural elements.

Ductility ratios and the strength reduction factors, R, can be considered damage predictors however, predictions of damage based on energy methods can be considered more advance than the first two since it is possible to measure the cyclic energy dissipated by structural elements which is compared either, to the earthquake energy input into the structure, or to the energy dissipation capacity of the structural elements which is calculated as the area under one cyclic displacement equal to the monotonic displacement at which the first failure mechanism occurs in the element.

The results show that for the earthquake records on soft soils recorded in Guayaquil that excited modern buildings in a city located 280km away from the epicenter, the energy dissipated through structural damage is zero and therefore, the structure damage indices are zero, as observed during the earthquake. However the occurrence of non-structural damage during the earthquake at sites so far away from the epicenter demonstrated that structures designed according to the Ecuadorian codes are too flexible.

In effect, drifts values between 0.011 and 0.018 were calculated for 12 story buildings subjected to the AGYE2 record, showing that the maximum drift to protect masonry should be less than 0.011.

The study continued scaling the Guayaquil records to the accelerations specified in NEC-15 for soft soil type E. The results show large damage indices due to the development of plastic hinges in beams and columns forming collapse mechanisms in the frame structures.

The energy dissipated through damping was also calculated.

Fourth part. Main causes of structural and non-structural damages. The main causes of damages, according to the observations and studies of some structures, are due to: 1) non-engineering construction, 2) low quality of materials, 3) site effects not properly considered in design, and 4) The Ecuadorian Construction Code (Código Ecuatoriano de la Construcción: CEC) which since 1979 has been similar to the USA Uniform Building Code (UBC), and lately the Ecuadorian Code (Norma Ecuatoriana de la Construcción: NEC-15), similar to the American Society of Civil Engineers Standard (ASCE 7-10) being the reason the construction methods used in both countries. While in the USA masonry is not used for partitions, and shear walls are commonly built to take the lateral forces induced by earthquakes and to stiff the structural system, in Ecuador partitions are constructed with unreinforced masonry filling the frames, and structures are based on beam and column frames since shear walls are rarely used. NEC-15 permits large strength reduction factors: $1 \leq R \leq 8$ and drifts less or equal than 0.02. The result was the construction of too flexible frame structures that permit profuse masonry damage in new buildings in the cities of Portoviejo, Manta, and Guayaquil located far from the epicenter as above mentioned.

The studies performed show: 1) that the spectral accelerations of the records, in Guayaquil soft soils, should have not cause non-structural damage since the non-reduced amplitudes are lower than NEC-15 specified frequent earthquake accelerations, 2) that during the earthquake non-structural damage in the masonry walls was extensive for modern buildings even though since 1979 Ecuadorian codes establish, no non-structural damage for frequent earthquakes, 3) that frame structures will suffer extensive damage if earthquakes closer to cities like Manta, Portoviejo, and Guayaquil reach the accelerations prescribed in NEC-15.