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DEPENDENCE OF TIME OCURRENCE AND THE INFLUENCE ON SEISMIC RISK ANALYSIS IN LIMA CITY

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Abstract

Lima city is the most populated city in Peru (10.5 million on urban area – National Institute of Statistics and Informatics of Peru, INEI, 2018), however is located in a seismic gap zone (SATREPS Japan-Peru 2015), a city without experience a severe earthquake since 1974 (Lima quake 3/10/1974). We can consider Lima as a city of young people, where around 75% of the population have never experience a strong earthquake, and only 25% experience and have a memory of the damage in Lima areas. Cities in the world have a diversity of cultures, customs and habits that differentiate them from each other. Therefore, the life style of the population, considering the resting time at home, working or study hours, transportation, and others is studied in this paper to find where population is located at an earthquake target time. By the use of the collected seismic data base of CISMID-FIC-UNI (Aguilar et.al. 2017) a function of population rate and location is generated to know the amount of people by time as function of the location. Using SRSND (Zavala et.al. - 2007) and DALILA (Zavala, Reyna, Diaz - 2015) self-developed software by the authors for compute deterministic and probabilistic risk analysis for Peruvian structures and earthquake scenarios, computing the risk analysis to estimate the casualties, amount of damage dwellings and concentration of the population by time. Analysis of the results show the dependence of time occurrence of earthquake in the estimation of damage and victims due to a severe seismic scenario. The results will help the decision makers to take into consideration for the disaster risk management and consider it for the planning and management prior the occurrence of a big event.

Keywords: seismic risk; damage buildings; time occurrence; victims on dwellings

1. Introduction

During 2010-2015 a joint research project under SATREPS cooperation scheme produce a comprehensive research on earthquake and tsunami disaster mitigation in Peru. This research has been carried out through strong collaboration among researchers from Peru and Japan [1]. Lima Metropolitan area and Tacna city were selected as two case study areas of the project. For Lima metropolitan area, this is the largest city in Peru, with about 10.5 million in population (National Institute of Statistics and Informatics of Peru, INEI, 2018). Scenario earthquake events for damage assessment were determined based on recent studies [2, 3]. For Lima city the major historical earthquake shown in Fig. 1 was selected for this purpose because this event is the most damaging and are expected to have significant effects on Peru. The event is the 1746 Lima-Callao earthquake (Mw 8.6) that destroyed the city of Lima completely and produced about 6,000 deaths.

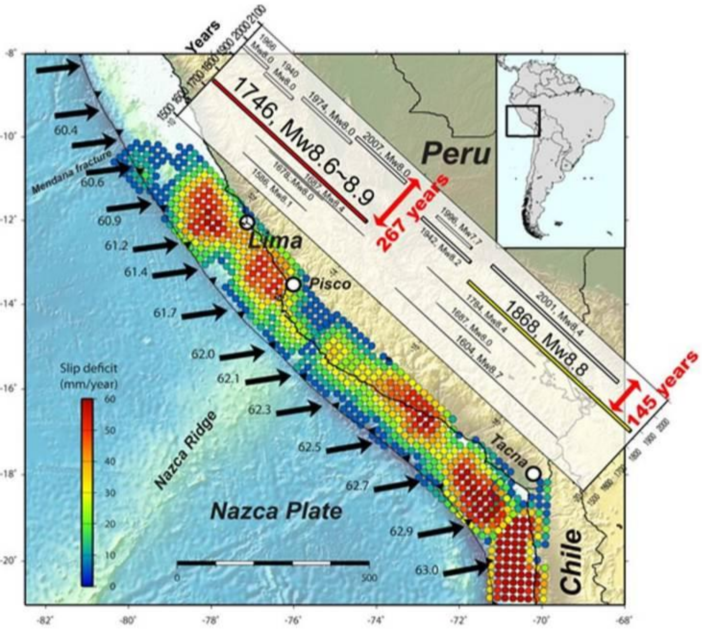

Fig. 1 – Lima earthquake scenario [2,3]

However, Lima is located in a seismic gap zone [3], a city of young people, where around 75% of the population have never experience a strong earthquake and only 25% experience and have a memory of the damage in Lima areas due to a severe earthquake (Lima quake 3/10/1974).

2. CISMID seismic records database and occurrence in time

Since 1999 the seismic records catalog started to be built by Dr. Aguilar at CISMID-FIC-UNI [5]. This catalog use the collected seismic data from the accelerometer network REDACIS, which include historical earthquakes, that has been digitalized from paper records, simulated historical events, and also the largest earthquakes that strike Peru. Historical data has been collected also from the National Network of IGP (Institute of Geophysics of Peru), CERESIS network and UNI-CIP- network.

In order to study the frequency of earthquakes considering the time of occurrence, a filter of the data base by event size and also time of occurrence has been study. Number of events during night, morning and afternoon for magnitude Mw from 4 to 7+ is presented in Table 1. Here is possible to read for Peruvian seismic activity is more frequent for earthquakes produced in the evening, than in the morning than in the afternoon respectively. Therefore, a severe will be earthquake likely produce during the evening.

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Fig.2 presents the occurrence of earthquake for magnitude Mw > 7+ in terms of percentage, from the number of total events for this group. Here 51% of the events occurs in the evening, 31% occurs in the morning and 17% occurs in the afternoon.

There are some ideas or popular folklore telling that October is the month of the earthquakes due to big earthquakes were produced during this month. In order to know which is the month of the year where most earthquakes occur according with CISMID-Database. Fig. 3 presents the results of occurrence by month and occurrence by time. These curves confirm the data set of Table 1, and it is possible to read that June is the month with more activity, follow by May and October.

Table 1 – Frequency of events occurrence by time

Mw > 7	Night	Morning	Afternoon	Total Events	Mw > 5	Night	Morning	Afternoon	Total Events
Events	36	22	12	70	Events	771	578	430	1779
Frecuency	51%	31%	17%		Frecuency	43%	32%	24%	
Mw > 6	Night	Morning	Afternoon	Total Events	Mw > 4	Night	Morning	Afternoon	Total Events
Events	55	35	23	113	Events	5131	3088	2299	10518
Frecuency	49%	31%	20%		Frecuency	49%	29%	22%	

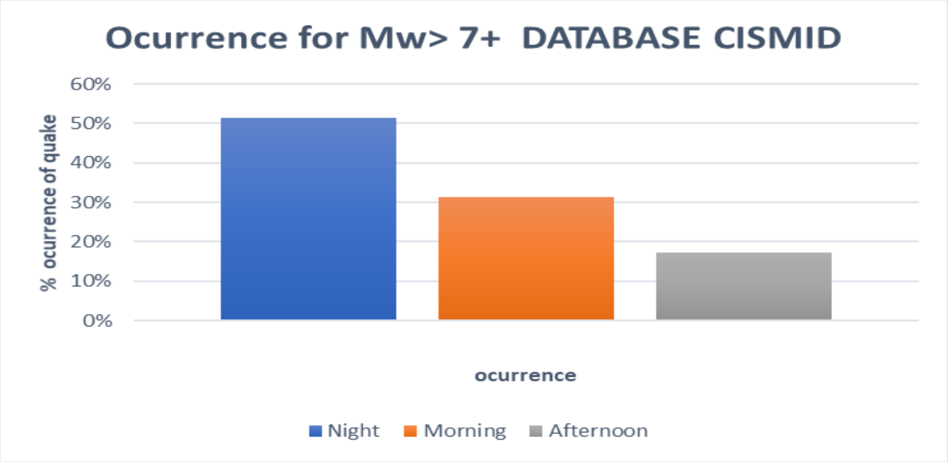

Fig. 2 – Earthquakes records by occurrence

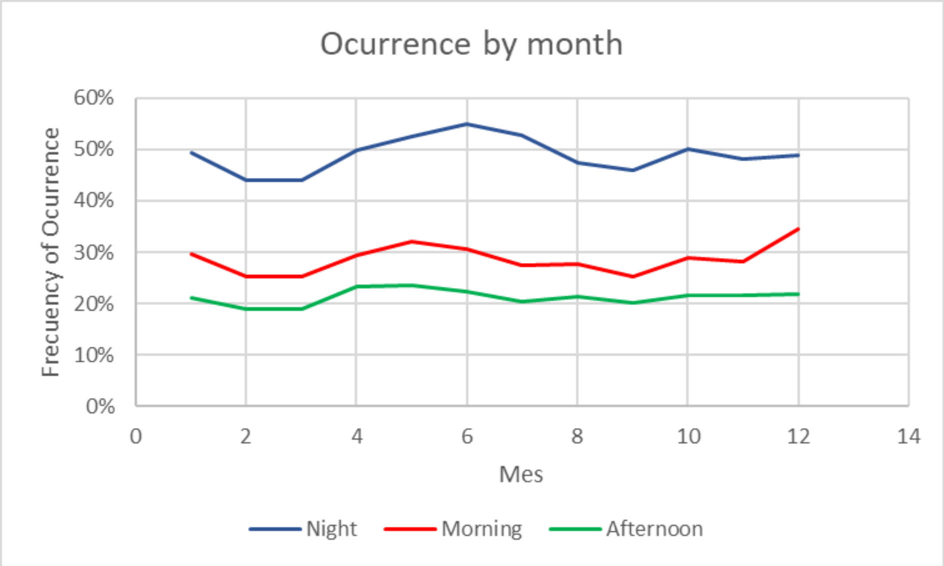

Fig. 3 – Earthquake records by month

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3. Lifestyle of Lima citizens and Time occurrence

Cities in the world have a diversity of cultures, customs and habits that differentiate them from each other. Therefore, the life style of the population in Lima city, considering the resting time at home, working or study hours, transportation, and others is studied in to find where population is located at an earthquake occurrence target time.

The lifestyle of Lima citizens is mainly affected by transportation problem. Lima city have a big problem of public and private transportation, where traffic jam are quite useful every day. The time spend in transportation by Lima´s citizen was studied on [7], where Fig. 4 presents the percentage of population versus the time they spend in transportation. Therefore, there is a influence on transfer hours spending more than 60 minutes the 53% of the population, then, if an earthquake happened during transfer time the amount of population on the streets will make collapse the traffic, fact that will me worst if event occurs in early evening due to loss of electricity will produce chaotic situation in a scenario without signals on the roads. Also, metro stations, bus stations and others transportation will be in similar situation.

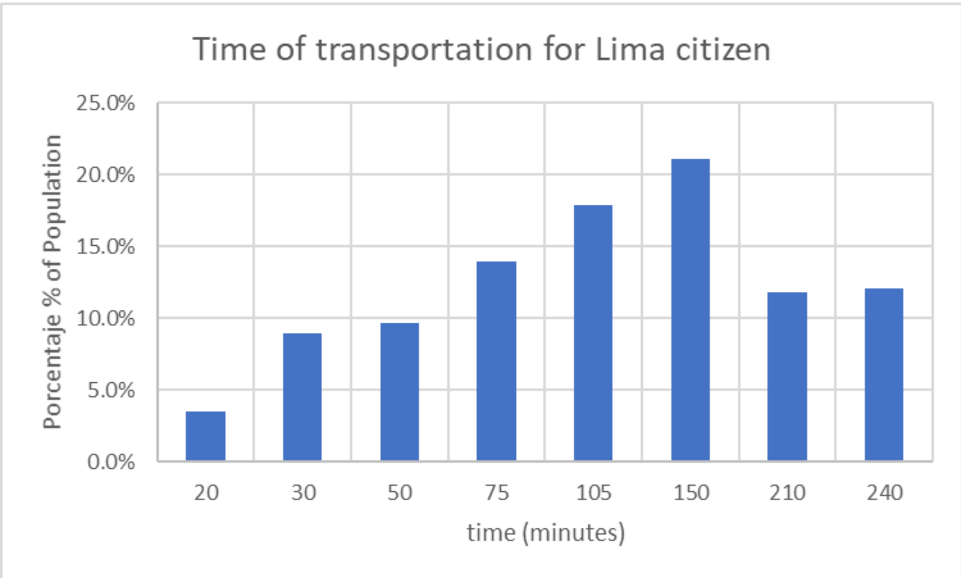

Fig. 4 – Transportation time spend by Lima Citizen in average [6]

In this report we consider four activities characteristic for Lima´s citizen:

- Workers: In this category are the office workers, business workers, professionals, technicians, factory workers, construction workers and nonformal workers.
- Students: This category is for kindergarten, primary school, high school students.
- U Students: Here are consider the university students in particular.
- Home and Freelance: Under this category are the housewife, freelance workers, retire workers who develop activity or work at home.

The citizens will use public transportation or self-transportation, that spend time in go and back from their activities. An special case is the home and freelance who usually make morning shopping, make home activities, move to deliver kids or elderly to school or center, then back to work at home, then move again to

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pickup kids from schools and back home for work, move to make shopping or part time job and finally move to home. This behavior is different for the usual of students, u-students and workers who just move twice form home to their activities and activities to home.

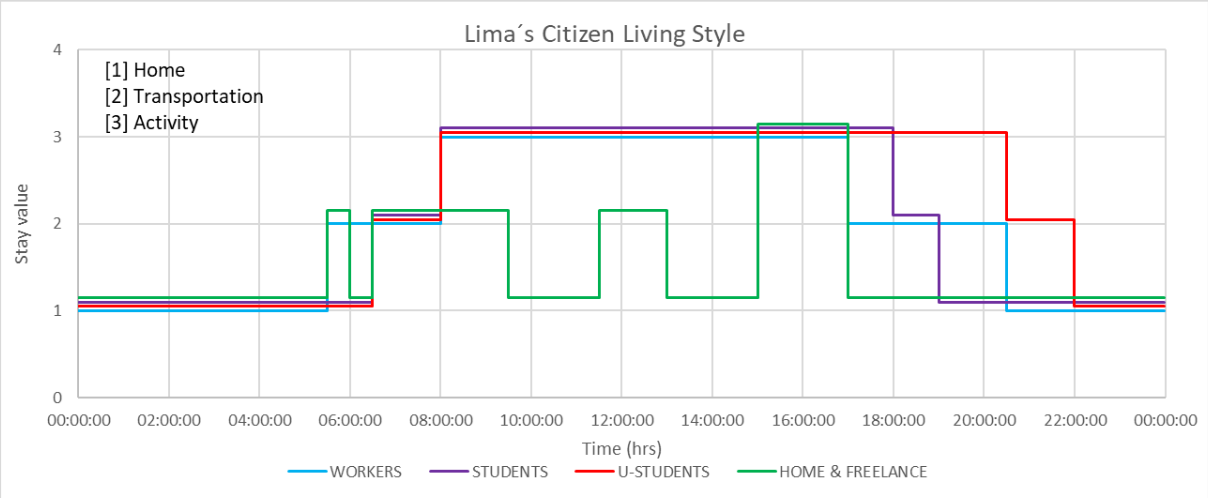

Fig. 5 –Lima´s Citizen living style in hours

This behavior was found with an origin destination survey data, elaborate by the authors, where the results are presented in Table 2. Fig.5 presents the Lima´s citizen living style in hours, where is possible to read that most of people stay at home from 20:30 to 6:30. It means the amount of people at home during that time will be put in risk the life of this citizens if seismic risk is high in their homes, which is mainly function of the seismic scenario, structural system, local peak ground acceleration on the soil where home has been build.

Table 2 – Results of origin destination survey

Destination Group	% Stay Morning M	% Stay Late Morning M-T	% Stay Afternoon T	% Stay Late Afternoon T-N	% Stay Night N	Late Night N-M
HOME	15%	20%	25%	50%	74%	45%
SCHOOL	40%	32%	23%	19%	15%	28%
OFFICE	30%	30%	30%	18%	5%	18%
COMERCIAL	10%	15%	20%	11%	1%	6%
OTHERS	5%	4%	2%	4%	5%	5%

In Table 2 due to the movement of the destination group to commercial malls, buildings services and others, we consider 2 additional categories on the survey: stay time in commercial places and other places. Here the results are present in percentage of the population and classify by place and time of the activity. It means where they are located in time and activity.

Taken into account the occurrence time during a real earthquake, we took the data from Pisco earthquake (15/98/2007), which occurs at 18 hrs 41 min, in the evening (Night in Table 2), so in this case we can consider the distribution in location of time by normalizing with the importance value of building (U) of the NTE-E-030-2018, due to the occurrence time will find the population at school, office, commercial area of at

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home. Then Fig.6 presents the result of the distribution time factor normalize for Pisco earthquake (18 hrs 41 min at 15/08/2007). Then any other time can be use for normalize the factor and produce a series of curves for time distribution for the stay population presented in Table 2. Therefore, it is possible to present the influence of time and stay of the population using the Eq. (1) where U represent the importance of the building, Stay means where the population stay at earthquake time, and Norm is a normalize factor regarding with time of calibration event, in our case Pisco earthquake time.

$$Ft = U \times Stay \times Norm \tag{1}$$

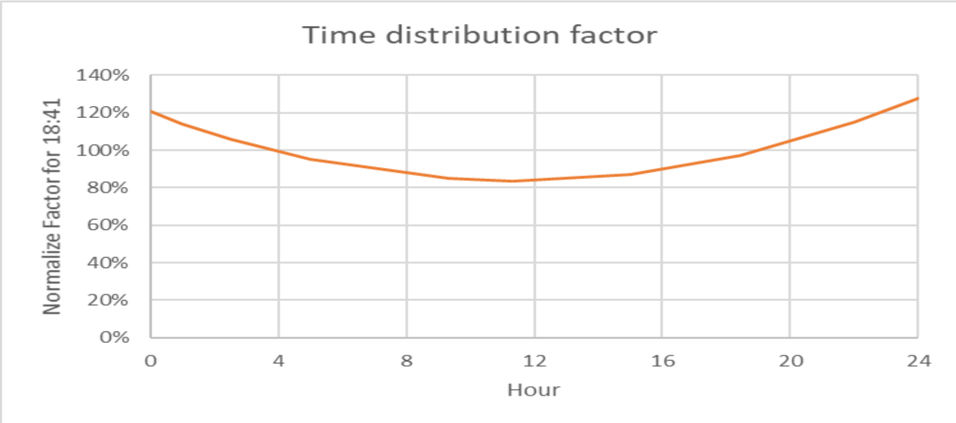

Fig. 6 –Normalize Time factor for 18:41 Pisco Quake

3. Seismic Risk Analysis

The evaluation of seismic risk depends of seismic hazards, microzoning, soil effects, structural type, predominant material, irregularities on the structure among others parameters. In order to estimate the risk analysis, SRSND [7] and DALILA [8] self-developed software by the authors for compute deterministic and probabilistic risk analysis respectively using likely used structural systems in Peru and Peruvian earthquake scenarios, computing the risk analysis to estimate the amount of damage dwellings, death, casualties and concentration of the population by time.

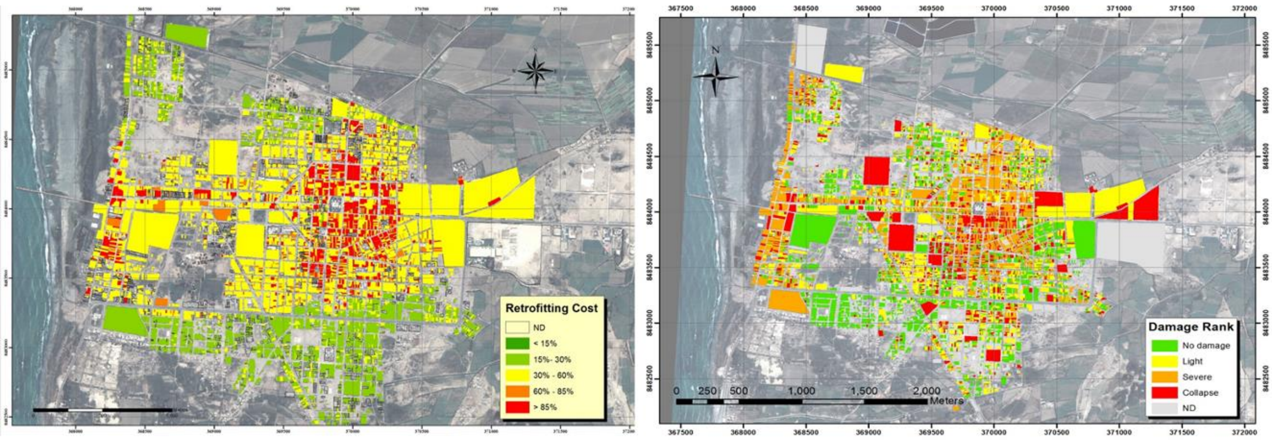

Fig. 7 –Pisco quake SRSND results and Field Survey [9]

Using the data base generated from the field survey and the results SRSND damage level, we can find the rate of death and casualties from this earthquake which ate resume in Table 3.

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Table 3 – Results of Pisco earthquake (15/08/2007) – Survey and SRSND results

Risk Level	Habitants	Blocks	Area (m2)	Densidad	Death	Death/Tpopu	Injure	Injure/Tpopu
Level I	18529	62	333424	0.1108	0	0.00000	63	0.00050
Level II	21752	72	282489	0.0800	3	0.00002	374	0.00297
Level III	32729	75	433283	0.0815	57	0.00045	187	0.00148
Level IV	18882	85	381692	0.1245	114	0.00091	285	0.00227
Level V	33987	409	3327802	0.6031	423	0.00336	1382	0.01098
TOTAL	**125879**	**703**	**4758689**	**1.0000**	**597**	**0.00474**	**2291**	**0.01820**

In Table 3, results of SRSND here presented as the rank of risk Level, from I (low risk) to V (high risk with collapse), is presented. Here the habitants of each of the area has been linked, in order to find the density of population for each of the rank risk levels. Then the distribution of death people and injure people found of the survey is linked with the total population of Pisco city (Tpopu) in this case 125879 habitants on urban area. Therefore, we found the rate related with total population to make it non-dimensional ratio, for death and also injure.

For the use of the non-dimensional death and injure ratio in Lima city, we choose the district named Chorrillos which is a representative due to concentrate the five social that represents the population of Lima city. Table 4 and Fig. 8 shows the social economical structure of Lima´s population [10], where is possible to see the structure of social levels in Chorrillos district (presented in Fig. 8 as number 8 zone, which is quite similar to Total Lima distribution (presented in Fig.8 as number 12 zone).

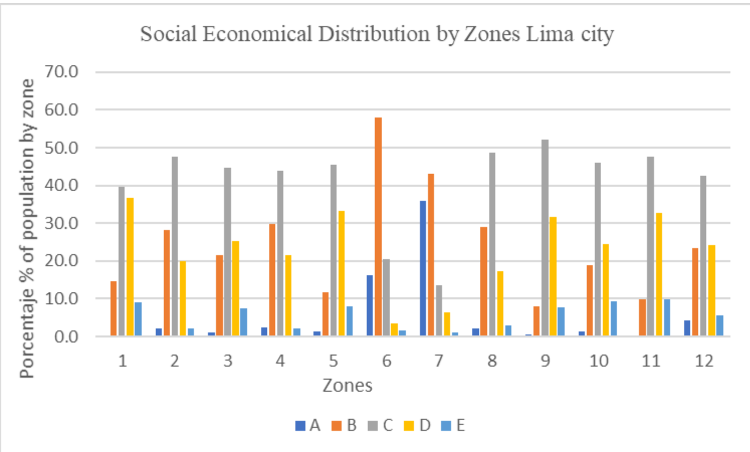

Fig. 8 –Social economical distribution of Lima´s population [10]

Also, Table 4, presents the data of each of the social economical class, where A represents high income class, B represents middle-low income class, C represents middle class, D emerging class and E represent last level. Here is possible to read that Chorrillos district will represent total Lima, considering working with sample value in an study.

Table 4 – Lima social economical distribution by zones [10]

Nro.	Zone	District	Thousands	Porcentaje	A	B	C	D	E
1	North-1	Puente Piedra, Comas, Carabayllo	1309.3	12.5%	0.0	14.6	39.7	36.6	9.1
2	North-2	Independencia, Los Olivos, San Martin de Porres	1318.3	12.6%	2.1	28.3	47.6	19.9	2.1
3	East	San Juan de Lurigancho	1157.6	11.0%	1.1	21.5	44.6	25.3	7.5
4	Old Town	Centro, Rimac, La Victoria, Breña	771.2	7.4%	2.5	29.9	43.9	21.5	2.2
5	North-East	Chaclacayo, Lurigancho, Santa Anita, San Luis, El Agustino	1477.6	14.1%	1.4	11.6	45.6	33.3	8.1
6	Center Town & West	Jesus Maria, Lince, Pueblo Libre, Magdalena, San Miguel	377.7	3.6%	16.2	58.1	20.5	3.5	1.7
7	South & South East	Miraflores, San Isidro, San Borja, La Molina	810.6	7.7%	35.9	43.2	13.6	6.3	1.0
8	South	Chorrillos, Barranco, Surquillo, San Juan de Miraflores	878.3	8.4%	2.0	29.1	48.8	17.3	2.8
9	South far	Villa El Salvador, Villa Maria del Triunfo, Lurin Pachacamac	1098.7	10.5%	0.5	7.9	52.2	31.6	7.8
10	West	Callao, Bellavista, La Perla, Carmen de la Legua, Ventanilla, Mi Peru	1100.4	10.5%	1.4	19.0	46.0	24.4	9.2
11	South-East	Cieneguilla y Balnearios	190.5	1.8%	0.0	9.9	47.6	32.7	9.8
	TOTAL LIMA		**10490.2**	**100.0%**	**4.3**	**23.4**	**42.6**	**24.1**	**5.6**

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Therefore, seismic risk analysis is computed with SRSND for Chorrillos district, and the results are presented in Table 5, where colors identification, range of risk in terms of retrofit cost (RC) considering that 100% represent the cost of a new building that means a collapse of the structure, and 85% represent the structure is in part collapse with high retrofitting cost, 60% the structure is still stand with middle to low possibility to be recover and need a engineering project to take a decision, 30% represents the structure could be retrofit with this percentage of cost of new structure, 15% or less represents cosmetic repair. Using the normalize ratio Death/Tpopu provided by Pisco earthquake (R) and considering correction factor by population (Fp), corrector factor of sample size (Fs) and corrector factor by social economical class (Fse), the results of death and injure are presented.

Equation (2), presents the compute of death people amount (D), RC is the retrofit cost, Fp is the correction factor due population, Fs represents correction factor by sample size, Fse represent the social economical distribution factor and Ft represents the time occurrence factor:

$$D = RC \times R \times Fp \times Fs \times Fse \times Ft \qquad (2)$$

For determine the number of injure people, we used the ratio Injure/Tpopu provided by Pisco earthquake (I), and considering correction with the factors presented in equation (2), in this case the equation (3) provides the number of injure people after the earthquake occurs, for Lima´s Chorrillos district:

$$I = RC \times I \times Fp \times Fs \times Fse \times Ft \qquad (3)$$

The amount of death (D) and injure people (I) for Chorrillos district is presented in Table 5, using equations (2) and (3). Results of the computation is presented in the maps Fig. 9, here concentration of death and injure are located in the south east of Lima´s Chorrillos district.

Table 5 – Results for Lima´s Chorrillos District

Color	Range	Risk Level	Block No.	RC (%)	Damage	No. Building	Death/Popu	Death	Injure/Popu	Injure
Light Green	< 15%	Level I	95	21.5%	Very Low	2850	0.00000	0	0.00050	178
Green	15% - 30%	Level II	4	0.9%	Low	120	0.00002	9	0.00297	1047
Yellow	30% - 60%	Level III	152	34.5%	Middle	4560	0.00045	160	0.00148	523
Orange	60% - 85%	Level IV	48	10.9%	Severe	1440	0.00091	320	0.00227	799
Red	85%-100%	Level V	142	32.2%	Colapse	4260	0.00336	1184	0.01098	3871
			441			**13230**		**1673**		**6419**

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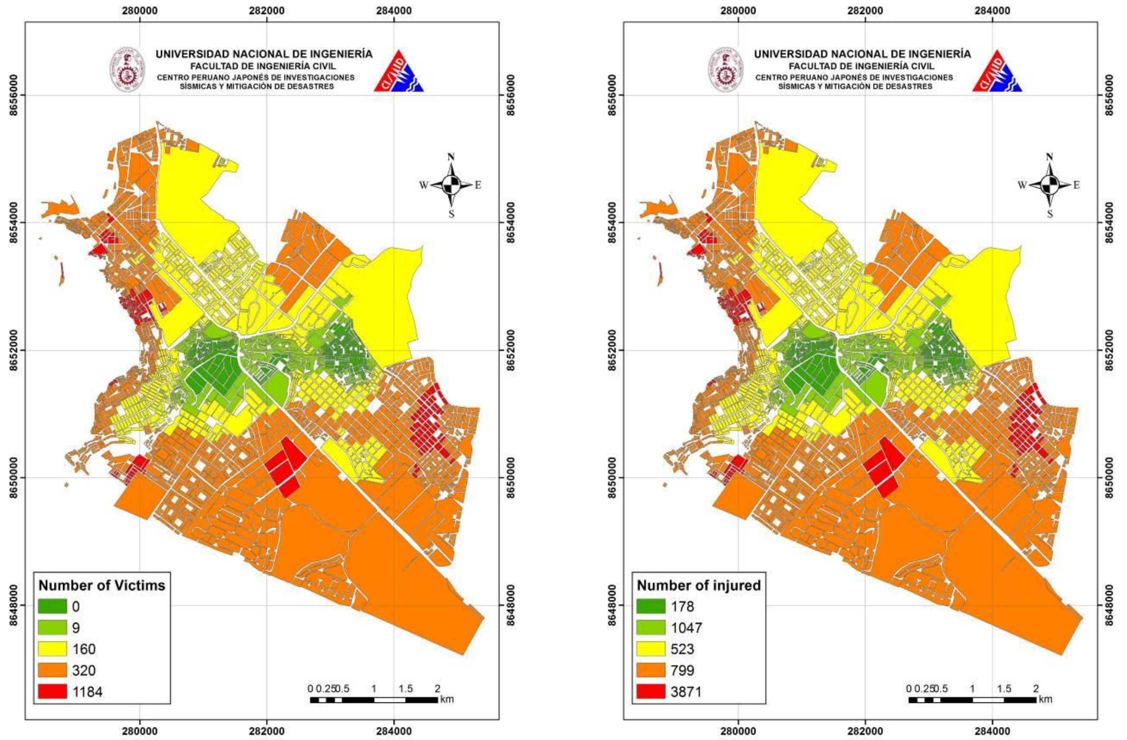

Fig. 9 –Graphically results of Victims and Injure at Lima, Chorrillos district

It is possible to use the normalize time factor to compute the number of victims and injure people during a severe event. Considering the normalized factor presented in Fig. 6, the number presented in Table 5 will have a variation as Ft factor.

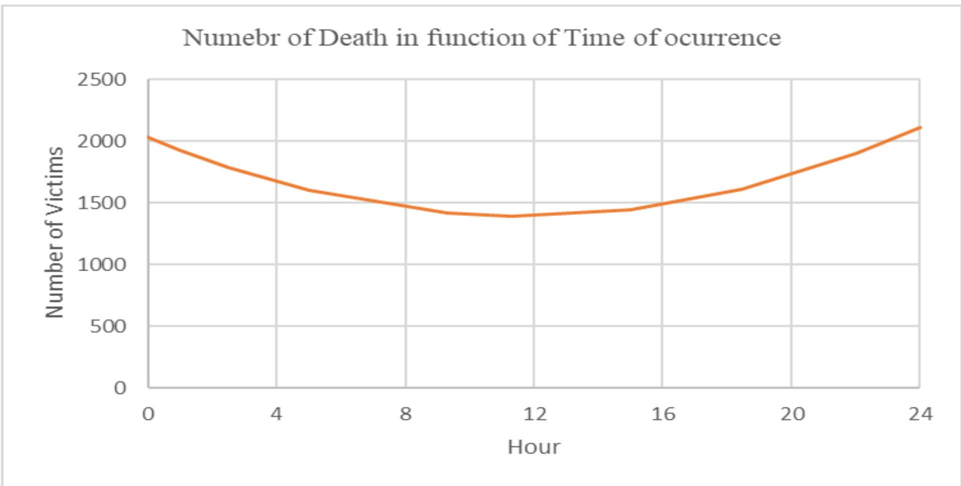

Fig. 10 –Victims as time function, Chorrillos district

Fig.10 presents the number of victims during a severe event for Lima´s Chorrillos district as function of time. Here is possible to read de variation of this number as people style of life and location and stay in a building, as we explained before. Less victims are found if the earthquake happened near noon time. However, when earthquake occurs in the evening the amount of victims increase in the case of Lima city seismic severe scenarios.

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5. Conclusions

- An analysis of CISMID seismic records database showed that earthquake occurrence is more likely to happened at night for Lima city. Also from the analysis, night events frequency range between 50% to 55% occurs on April to August.
- Influence of transportation on the living style of Lima´s citizens mark influence on the origin destination survey data, elaborate by the authors, that produce a normalize time factor with a reasonable procedure. This factor can be normalized with other time occurrence that will provides influence of lifestyle, time and occurrence affecting the seismic risk results.
- In the case of a severe earthquake social economical distribution will provide an important factor for the determination affecting the seismic risk results. The procedure presents an example of Lima's Chorrillos district, where the analysis of the results shows the dependence of time occurrence of earthquake in the estimation of damage and victims due to a severe seismic scenario. These results will help the decision makers to take into consideration for the disaster risk management and consider it for the planning and management prior the occurrence of a big event.

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