Seismicity, Buildings' Seismic Vulnerability, And People's Risk Awareness and Preparedness In General Santos City, Philippines

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***Abstract*—**The seismicity of General Santos City, the buildings' seismic vulnerability, and people's risk awareness and preparedness were evaluated. The data from Philippine Institute of Volcanology and Seismology from 2000 to 2012 showed that General Santos was seismically active with 197 felt earthquakes or an average of 1.3 tremors per month and 7,760 unfelt earthquakes. The first level seismic risk evaluation of 68 buildings showed that 35.3% were exposed to high risk, while 63.2% were exposed to moderate risk necessitating a second level assessment to include more seismic factors. The Richter-Gutenberg model indicated that at least one earthquake of Magnitude 7 or greater will occur in General Santos in the next five years with probability of 64%.The sample of 198 people showed that their awareness and preparedness on seismic risk were only moderate. Therefore, building of earthquake-resistant structures and inculcation upon people the value of earthquake awareness and preparedness were recommended.

***Keywords*—**Earthquake hazard mitigation, earthquake preparedness, earthquake prediction, seismic vulnerability, seismicity, walkdown survey.

I. Introduction

EARTHQUAKES occur as part of the natural behavior of the earth. Some regions or countries are more susceptible to seismic vibrations than others because of their relative location from earthquake faults. The Philippines lies within the Pacific Ring of Fire which causes the country to have frequent seismic and volcanic activity [1].

In the island of Mindanao, the Moro Gulf Earthquake on August 16, 1976, had a magnitude of around 7.9, generated local tsunamis and was followed by at least fifteen aftershocks. The reported casualties included 5,000 to 8,000 lives lost, around 10,000 injured and about 90,000 rendered homeless [2].

General Santos is a part of Mindanao which is seismically active as evidenced by the occurrences of major earthquakes in the recent past.

The data from Philippine Institute of Volcanology and Seismology (PHIVOLCS) station at Mindanao State University-General Santos, Tambler Campus, indicate that from year 2000 to June 2012, one hundred ninety-seven (197) "felt" earthquakes occurred in the City or an average of more than once a month at intensities ranging from I to VI or at magnitudes from 1 to 7.

The worst earthquake that hit General Santos occurred on March 6, 2002. Triggered by the Cotabato Trench, the earthquake was of shallow focal depth at 15 km, of magnitude 6.8, and with the epicenter located at 92 km Southwest of Isulan. It affected General Santos at intensity VI based on Phivolcs Earthquake Intensity Scale (PEIS).

There are many essential structures in the city such as hospitals, schools, public buildings, utilities for water and electric services, bridges, and telecommunication systems. The safety of these structures is essential to the risk reduction and mitigation efforts during and after earthquakes. There is a need therefore for adequate seismic safeguards and people must be aware and prepared on the hazards posed by earthquakes.

These concerns led the researcher to conduct a study on the seismicity of General Santos City and estimate the probability of a destructive earthquake occurring in the next five years. The study also evaluated the seismic vulnerability of some buildings in the city, and consequently assessed the level of awareness and preparedness of the people in case a strong earthquake occurs.

II. Methodology

This study was conducted in General Santos City which lies at the southernmost part of the Philippines. It is located at 6°7'N Latitude and 125°10'E Longitude. Per 2010 census data, General Santos is the 15th most populous city in the country with a population of 538,086 and has been classified as highly-urbanized first class city [3].

To determine the seismicity of General Santos, data containing records of "felt" earthquakes from 2000 to 2012 were obtained from PHIVOLCS station at Tambler, General Santos City. The data were analyzed based on the frequency of occurrence of the earthquakes, their magnitudes, intensities, and the focal and the epicentral distances. The data were also used to establish the probability of a destructive earthquake occurring in General Santos City in the next five years assuming the probability distribution follows the Poisson stochastic model.

Survey form was used in determining the preliminary seismic vulnerability of buildings in General Santos City using the "walk down" street survey. This study was delimited only to this first level method of assessment that does not require quantitative structural analysis. Its main goal is only to establish which buildings need to be prioritized for more in-depth assessment in the second level using some measured

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structural data. The researcher conducted the survey himself and accomplished the survey form.

In doing the first level survey of the buildings, the parameters considered were the number of storeys, existence of a soft storey, existence of heavy overhangs, existence of short columns, and pounding effects. Although not considered in the analysis, the survey also considered the number of persons occupying the building, the building type as to the construction materials used, and the nature of occupancy as to commercial, government, industrial, office, residential, assembly, or emergency services. The survey form is adopted with revisions from the Rapid Visual Screening (RVS) procedure developed by the Federal Emergency Management Agency (FEMA) of the United States [4].

The parameters chosen are delimited to those which are easily observable from an ocular evaluation from the street. Since the parameters considered are positively correlated to the level of seismic risk, the evaluation of the results are primarily based on the number of yes answers, that is, the more yes answers, the higher is the risk level. The scaling of the seismic risk level in this study are adopted as follows:

TABLE I
SEISMIC RISK SCALE

No. of Yes Answers	Risk Level
0-2	Low risk
3-4	Moderate risk
5 or more	High risk

To evaluate the seismic vulnerability due to height of the building, the following scheme is adopted:

TABLE II
BUILDING HEIGHT VULNERABILITY

Storey Height	Vulnerability Index
≤ 2	0
3 to 4	1
5 to 6	2

To evaluate the people's level of awareness and preparedness in case earthquake occurs in General Santos City, a questionnaire was used consisting of two parts. The first part contains ten statements to measure the level of peoples' knowledge and awareness on what to do during earthquakes. The second part consists also of ten items to measure the level of preparedness of the people on what to do before the occurrence of earthquake to reduce and mitigate the risks. To measure the level of awareness, the following measurement scaling was adopted:

TABLE III
SCALE FOR LEVEL OF AWARENESS

4	Very much aware
3	Moderately aware
2	Less aware
1	Not aware

To measure the level of preparedness, the following measurement scaling was adopted:

TABLE IV
SCALE FOR LEVEL OF PREPAREDNESS

4	Very much prepared
3	Moderately prepared
2	Less prepared
1	Not prepared

III. RESULTS AND DISCUSSIONS

A. *Seismicity Of General Santos City*

The seismicity of General Santos was based on five parameters of earthquakes namely earthquake intensity, earthquake magnitude, frequency of occurrences, the depth of focus, and the epicentral distances. These parameters were determined on the basis of the PHIVOLCS record of earthquake occurrences in General Santos City from year 2000 to 2012. It presents the intensities of the felt earthquakes, their magnitude, focal depth, epicenter coordinates in terms of latitude and longitude, and the location of epicenters. It also shows the time the earthquake was felt and the sources where the earthquakes were triggered. The results for the five parameters are presented in Tables V to IX.

1. The Earthquake Intensities

The size of an earthquake is measured in terms of the site-specific intensity level [6]. Table V presents the summary of the intensities of earthquakes that occurred in General Santos from year 2000 to 2012. In the Philippines, the earthquake intensity at a site is measured using the PHIVOLCS Earthquake Intensity Scale (PEIS).

TABLE V
THE EARTHQUAKE INTENSITIES IN GSC (2000-2012)

Intensity(PEIS)	Frequency	%Frequency
I	52	26.4
II	92	46.7
III	38	19.3
IV	10	5.1
V	4	2.0
VI	1	0.5
Total	197	100
Maximum intensity	6	
Minimum intensity	1	

Source: PHIVOLCS Bulletin of Earthquakes

As shown in Table V, the highest percentage of earthquakes that occurred in GSC (46.7%) were felt at Intensity II. This is followed by 26.4% of the earthquakes which were felt at Intensity I.

The table also shows that 19.3% of the earthquakes were felt at Intensity III. In sum, majority of the earthquakes in General Santos City (92.4%) were felt at intensities from I to III while the remaining 7.6% were felt at intensity IV (5.1%), intensity V (2%), intensity VI (0.5%).

This means that 92.4% of the earthquakes that hit General Santos were weak earthquakes and only 7.6% were strong to very strong earthquakes. This is consistent with the normal trend because much larger numbers of earthquakes of smaller magnitude occur very regularly due to the slow movements of major tectonic plates in a region. The very strong and destructive earthquakes occur less often as a matter of natural course because the accumulation of strain energy is gradual and takes time before accumulating into a destructive quantity [7].

2. The Earthquake Magnitudes

The size of an earthquake is also measured in terms of its magnitude. Many countries worldwide, including the United States of America and the Philippines, use the Richter Magnitude Scale to measure the earthquake magnitudes [6].

TABLE VI
THE EARTHQUAKE MAGNITUDES IN GSC (2000-2012)

Magnitude (Richter Scale)	Frequency	%Frequency
1 - 1.9	1	1%
2 - 2.9	3	2%
3 - 3.9	27	15%
4 - 4,9	59	33%
5 - 5.9	60	34%
6 - 6.9	23	13%
7 - 7.9	4	2%
Total	177	100
Maximum magnitude	7.6	
Minimum magnitude	1.8	

Source: PHIVOLCS Bulletin of Earthquakes

Table VI shows the frequency distribution of the earthquake magnitudes in GSC from year 2000 to 2012. The PHIVOLCS has complete data on magnitude for only 177 of the 197 recorded in the GSC station. There were 119 earthquakes (67%) with magnitudes of 4 to 45.9. Only 31 earthquakes have magnitudes of 1 to 3.9. It is important to note, however, that 23 earthquakes (13%) occurred with magnitudes in the interval from 6 to 6.9 and there were four earthquake events with magnitudes above 6.9. The actual maximum magnitude recorded in the PHIVOLCS data was 7.6 while the minimum was 1.8.

This result indicates that General Santos City was subjected to many strong (Magnitude 6 to 7) and major (Magnitude 7 to 8) earthquakes that should have caused considerable or widespread damage in the area and could have generated tsunamis. However, what was good going for General Santos was that the epicenters of these earthquakes were far such that the intensities felt at the site were much weaker than it would have been had the epicenters been near.

3. The Frequency of Earthquakes

This study also determined the frequency of earthquake events in GSC from year 2000 to 2012. Table VII shows the results based on the records from PHIVOLCS.

A total of 197 "felt" earthquakes occurred during the specified period resulting to an average of 15.2 tremors per year or 1.3 per month. The years 2002 and 2010 registered the highest number of occurrences at 25 each.

Also shown in Table VII is the number of unfelt earthquakes per year, indicating numerous but silent seismic activity. Excluding the years with incomplete data (2005 and 2006), the silent tremors occurred 705 times per year or almost two (2) times per day.

TABLE VII
THE FREQUENCY OF EARTHQUAKES IN GSC (2000-2012)

Year	Felt Earthquakes	Not Felt Earthquakes
2000	14	1291
2001	14	1357
2002	25	1594
2003	8	650
2004	8	393
2005	16	194*
2006	10	36**
2007	18	537
2008	13	371
2009	19	469
2010	25	400
2011	9	195
2012	18	503
Total	197	7760

* 6 months no record due to defective instrument
** 10 months down time due to grounded electrical wires

Source: PHIVOLCS Bulletin of Earthquakes

Table VII also shows that the years 2000 to 2002 indicate an increasing trend of large number of unfelt earthquakes and a sudden drop in year 2003. Interestingly, the largest earthquake which General Santos experienced, at Intensity VI, within the period of study (2000-2012), occurred in the year 2002 with a magnitude of 6.8, triggered by the Cotabato Trench at shallow depth of 15 km and epicenter at 92 km southwest of Isulan. Whether this earthquake was correlated to the buildup of numerous unfelt earthquakes is an interesting subject for further study. This is significant in the light of recent studies and findings of scientists that "silent" or slow slip quakes can be a precursor of a major earthquake in the area [8].

The frequency of earthquake events can be also presented in terms of the geographical or spatial distribution with respect to the GSC area. This is shown in Figure 1.The farthest earthquake occurred in Eastern Samar from the North, and Indonesia from the South with respective magnitudes of 7.6 and 6.7. Intensities in General Santos, however, were recorded only at III and II, respectively. It can be observed also that most earthquakes originate from offshore which could imply higher chances of tsunami events.

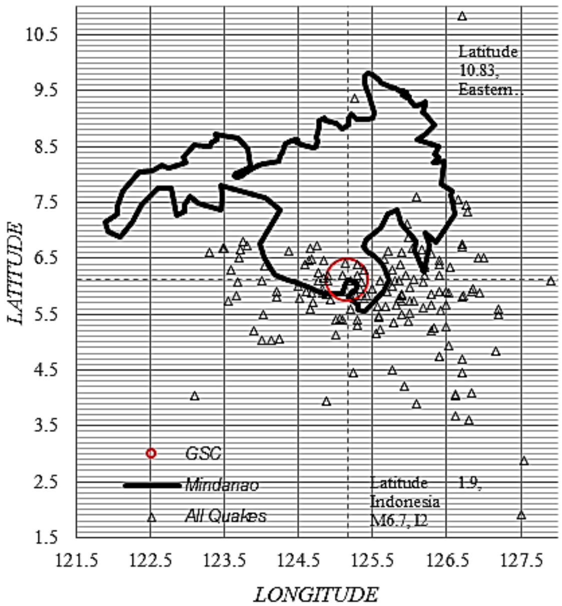

Fig. 1 Geographical locations of GSC earthquakes (2000-2012).

4. The Focal Depths

This study also analyzed the focal depths of earthquakes that occurred in GSC from 2000-2012. The classification according to focal depths of the earthquakes of General Santos City is shown in Table VIII which shows that of the 156 earthquakes with complete data on focal depths, 59% of the General Santos earthquakes are shallow earthquakes, while 35% are intermediate, and the rest (6%) are deep.

TABLE VIII
FOCAL DEPTHS OF EARTHQUAKES IN GSC (2000-2012)

Depth (km)	Category	Frequency	Relative Frequency
0 – 69	Shallow	92	59%
70 – 299	Intermediate	54	35%
>300	Deep	10	6%
Total		156	

The focal depths can be presented with the corresponding magnitudes of the earthquakes. These are shown in Figures 2 and 3. Figure 2 shows that the deep and intermediate earthquakes were scattered far from GSC. The deep earthquakes were mostly from the west along the Cotabato Trench while the intermediate earthquakes were mostly from the East along the Davao Trench and the Philippine Trench.

It is worthy to note that Figure 2 shows that the shallow earthquakes with magnitudes greater 5.5 were far from General Santos while Figure 3 shows that the shallow earthquakes with magnitudes less than 5 were clustered nearer to General Santos. This was good for GSC because shallow earthquakes, as already stated above, are generally more destructive than the deeper ones.

The shallow earthquakes which were clustered nearer to GSC had magnitudes lower than 5 while the shallow earthquakes with magnitudes greater than 5.5 were far from GSC as can be observed from Figures 2 and 3. However, this was for the earthquake events from 2000 to 2012. The same pattern will not necessarily persist in the years to come. It only takes one major earthquake to cause widespread devastation in the area. These shallow earthquakes combined with the numerous unfelt ones should be a cause of concern because it could indicate a slow buildup of strains or deformations, and over time could precede a major and devastating earthquake [7].

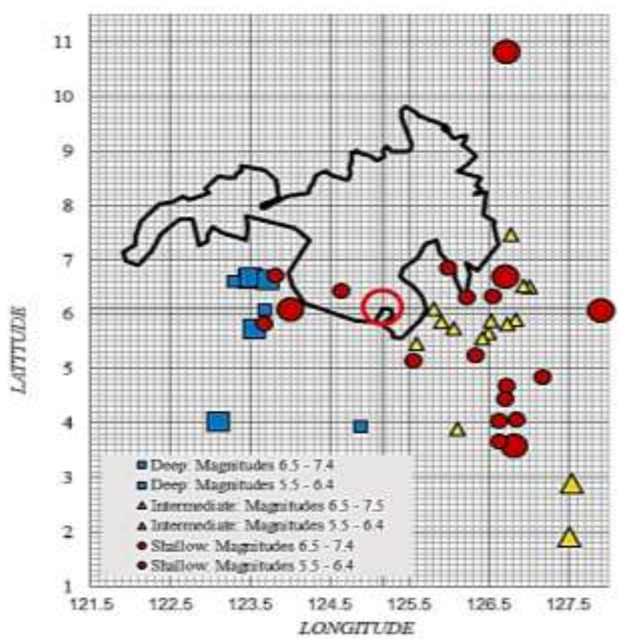

Fig. 2 Focal depths of earthquakes in GSC (2000-2012).

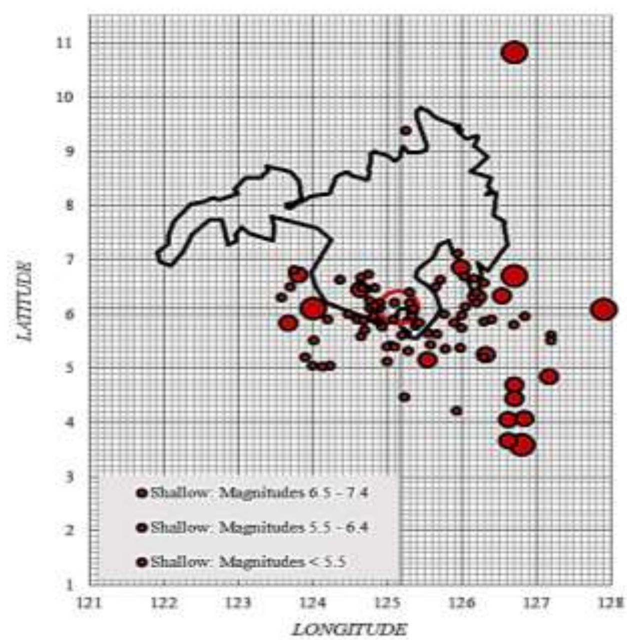

Fig. 3 Earthquakes with shallow focal depths and corresponding magnitudes (GSC 2000-2012).

5. The Epicentral Distances

This study also determined the distance of GSC from the epicenter of the earthquakes. The distances are computed based on the latitude and longitude coordinates per PHIVOLCS data.

Table IX shows that about 15% of the earthquakes had epicenters less than 100 km from General Santos and about 47% are within 101 to 300-kilometer radius from General Santos. This means that more than 62% of the earthquakes were triggered within the 300-kilometer radius from GSC and about 97% were triggered within 500 kilometers from GSC.

TABLE IX
EPICENTRAL DISTANCES OF EARTHQUAKES IN GSC (2000-2012)

Distance (km)	Frequency	Relative Frequency	Cumulative Relative Frequency
Less than 100	23	15.1%	15.1%
101-300	71	46.7%	61.8%
301-500	44	28.9%	90.8%
501-700	10	6.6%	97.4%
701-900	2	1.3%	98.7%
>900	2	1.3%	100%

To summarize, the results shown in Tables V to IX, and Figures 1 to 3, show that General Santos City belongs to a seismically active region. This is consistent with the data and information provided by PHIVOLCS that Mindanao Island, of which General Santos is a part, is seismically active as indicated by the Philippine Seismicity Map prepared by PHIVOLCS.

A primary factor contributing to the seismicity of General Santos is the presence of five (5) major sources or generators of earthquakes aside from the local faults within the vicinity. The Philippine Trench and the Davao Trench generate earthquakes from the east side; the Cotabato and Sangihe Trenches would shake General Santos from the west side and the south; and the Mindanao Fault generates earthquakes inland. These sources of earthquakes are depicted in Figure 4.

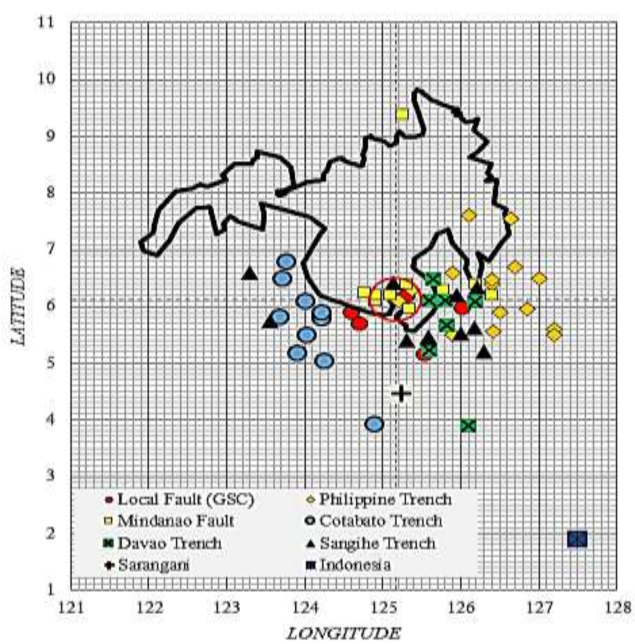

Fig. 4 Sources of earthquakes in GSC (2000-2012).

The Cotabato Fault and Sulu Trench are major sources of strong earthquakes in Mindanao, and the City of General Santos, being proximate to these, is therefore exposed to seismic vulnerability.

Although from 1952 to present, the Sulu Trench has been notably quiet, its tectonic setting has not been properly established. Hence, better understanding of this region is needed [9]. It could be just a matter of time before it again breaks to release whatever strain energy it might have accumulated for more than fifty years of calm and quiet.

The data from PHIVOLCS indicate the sources of 76 earthquakes only. Without considering the earthquakes whose sources are not indicated, the record shows that about 60% of the tremors come from the Philippine Trench (24%), Cotabato Trench (18%), and Sangihe Trench (18%).

The Cotabato Trench, Sangihe Trench, and Mindanao Fault in addition to the local faults, should be a cause of concern because these are within a short striking distance to GSC.

B. Probability of Destructive Earthquake in General Santos

This study also attempted to determine the probability of a destructive earthquake occurring in General Santos City in the next five years. Despite the limitations, and in the absence of better alternatives, earthquake probabilities are simply based on some assumed statistical model that is combined with certain statistical characteristics of some earthquake parameters [10]. In this study, due to the small amount of data, it is assumed that the occurrence of earthquake is random in terms of space and time. The Frequency-Magnitude Distribution (FMD) for the General Santos earthquakes covering the study period of 13 years, is shown in Table X and graphed in Figure 5 using a semi-logarithmic scale.

TABLE X
FREQUENCY-MAGNITUDE DISTRIBUTION OF GSC EARTHQUAKES

Magnitude (M)	Number of Earthquakes with magnitude >M	λ_m (Annual mean)	Return Period
1	177	13.6	0.073
2	176	13.5	0.074
3	170	13.1	0.076
4	139	10.7	0.094
5	79	6.1	0.165
6	26	2.0	0.500
7	4	0.3	3.250

Table X shows that the annual mean for a magnitude 7 earthquake is 0.3, with a return period of 3.25 years. This means that on the average, General Santos will experience a magnitude 7 earthquake at least once every 3.25 years.

The graph in Figure 5 is used to determine the parameters *a* and *b* of the Gutenberg-Richter equation. As shown in the graph, a = 5.6 and b = 0.74.

The Gutenberg-Richter equation can be written as

$$N = 10^{a-bM} \tag{1}$$

where M is the earthquake magnitude and N is the cumulative number of earthquakes with magnitude greater than M, while *a* and *b* are the constants which define the linear characteristics of the semi-logarithmic plot.

If equation (1) is divided by the number of years, T, the average annual rate of occurrence of the event, γ_M, for a selected magnitude M is obtained. Thus,

$$\gamma_M = \frac{10^{(a-bM)}}{T} \tag{2}$$

where a and b are estimated using the straight line plot in Figure 5, from which the estimated values of parameters a and b are respectively, 5.6 and 0.74. Substituting these values of a and b, and for time T = 13 years, the annual mean rate of occurrence, for magnitude M = 7, is

$$\gamma_7 = \frac{10^{(5.6-0.74x7)}}{13} = \frac{2.632}{13} = 0.202 \tag{3}$$

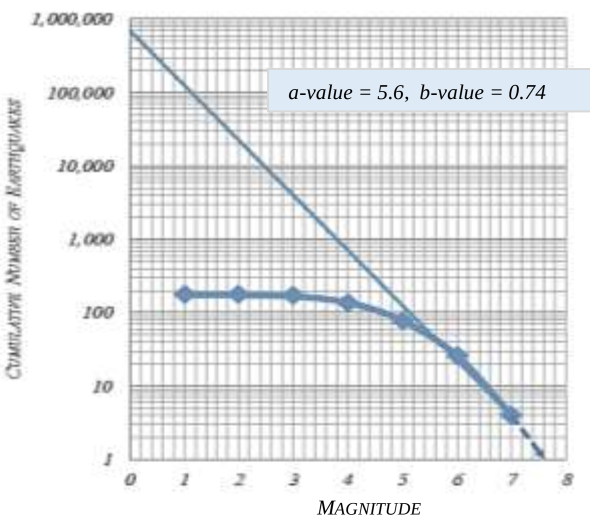

Fig. 5 FMD of earthquakes in GSC (2000-2012).

Using now the Poisson model to represent the temporal distribution of the earthquakes in General Santos, the probability distribution for a selected magnitude M is

$$P(N=n) = \frac{e^{-\gamma_M t}\,(\gamma_M)^n}{n!} \tag{4}$$

Applying the Poisson's probability function, for time t = 5 years, the probability of exactly one earthquake event of magnitude 7 occurring within 5 years is

$$P(N=1) = \frac{e^{-0.202(5)}(0.202(5))^1}{1!} = 0.368 \tag{5}$$

The probability that at least one earthquake event of magnitude 7 or greater will be felt in General Santos within the next five (5) years is

$$P(N \geq 1) = 1 - e^{-0.20x5} = 0.636 \tag{6}$$

This probability computation does not include the location of the epicenter. This means that even if an actual earthquake of magnitude 7 or greater occurs, it does not necessarily follow that the intensity in General Santos will be as destructive.

The computation on probability of strong earthquakes occurring in General Santos City is simply based on the statistical analysis of the PHIVOLCS dataset which is not large or extensive enough to make a reliable analysis. This treatment, however, is similar to the studies undertaken in San Francisco Bay region where scientists studied the large number of earthquakes to determine the probability of similar seismic activities occurring in the region [11]. The clustering of earthquakes led the scientists to estimate that the probability of a magnitude 6.8 or higher occurring in the next 30 years in San Francisco Bay region was estimated to be 67%.

C. Seismic Vulnerability of Selected Buildings

This study also attempted to assess the seismic vulnerability of buildings in General Santos in terms of five parameters, namely, the number of storeys, the presence of a soft storey, the presence of heavy overhangs, the presence of short columns, and the pounding effects of adjacent buildings. Sixty-eight (68) buildings in various areas of General Santos were selected for the "Walkdown" street survey. It appears in Table XI that all buildings considered in the street survey have short columns, a large number (65 out of 68) have soft storeys, and majority (40 out of 68) exhibit heavy overhangs and pounding effects.

TABLE XI
PRESENCE OF THE INDICATED STRUCTURAL PARAMETERS

Parameters	Number of buildings with parameter	%Frequency
Soft storey	65	96%
Heavy overhang	40	59%
Short Column	68	100%
Pounding effect	40	59%
N = 68 buildings		

According to (Datta, 2010), the seismic vulnerability of a building is indicated by the presence of certain structural and architectural configurations which include among others the number of storeys, existence of a soft storey, the existence of heavy overhangs, existence of short columns, and the possibility of pounding effects due to inadequate separation with adjacent buildings.

The results relative to each of these parameters are discussed in the subsequent paragraphs.

1. Number of Storeys

In this study, the height of the building is considered as one of the seismic vulnerability parameters [4]. The heights of the buildings are measured in terms of the number of storeys, and to assess the height seismic vulnerability, an arbitrary scheme is adopted wherein the height vulnerability index is set equal to 0, 1, and 2, respectively for storey heights 2 or less, 3 to 4, and 5 to 6.

Table XII shows the frequency distribution of the sampled buildings in terms of the number of storeys. Fifty-three(53) of the buildings have 3 to 4 storeys, nine (9) have 5 to 6, and only six (6) are two-storey. Correspondingly, fifty-three (53) of the sampled buildings have vulnerability index of 1 while nine (9) have vulnerability index of 2, and six buildings have vulnerability index set to zero.

The seismic vulnerability of a building due to its height depends on the period, T, (or frequency, $f = 1/T$) of vibration of the earthquake that will occur. If the period of vibration of the earthquake coincides with the natural period of vibration of the building, resonance occurs, and the seismic vulnerability of the building is heightened. The taller the building, the higher is its natural period. Therefore, if the earthquake period is high, the taller buildings are exposed to

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higher seismic risk. On the other hand, if the earthquake period is low, the buildings of smaller height would be more vulnerable. But in any case the taller buildings will be more susceptible particularly because of the larger dead weight or mass that will result to higher inertial forces against the structural components of buildings.

TABLE XII
HEIGHT VULNERABILITY INDEX

Number of storeys	Number of buildings	Vulnerability Index
2	6	0
3	33	1
4	20	1
5	7	2
6	2	2
N = 68 buildings		

Low-rise buildings or one- to two-storey buildings are also vulnerable to seismic risk especially when the earthquake period of vibration will coincide with the building's natural period. However, in this study, the type of earthquake as to its period of vibration, the type of building materials and soil conditions are not considered in the assessment of the seismic risk. Hence, the one or two-storey buildings are assigned a seismic vulnerability of zero.

2. Soft Storey

In this study, the building seismic vulnerability was also observed in terms of the presence of a soft storey in the building. Out of the 68 buildings surveyed, as shown in Table 11, sixty-five (65) have first storeys which are seen as soft storeys. These buildings are mostly of either commercial or residential (Hotel) type of occupancy which, usually, would need a larger open space in the first floor. Most of the soft storeys observed are the first storeys which are taller in height compared to the upper storeys.

The presence of a soft storey in a building will contribute to its seismic vulnerability. A storey is considered soft when its stiffness is significantly less compared to the other adjacent or upper storeys, making it weak against lateral loads [12]. It behaves much like a slender pole carrying a heavy mass on top. In this study, a vulnerability index of 1 is added to a building with a soft storey.

3. Heavy Overhangs

This study also considered the presence of heavy overhangs as contributory factor to the building seismic vulnerability. The street survey, as shown in Table XI, showed that 40 buildings out of the 68 surveyed were observed to have heavy overhangs. The heavy overhangs are mostly due to cantilevered floors purposely to maximize the use of space in the upper floors facing the street. Most of the commercial buildings have this feature. A heavy overhanging portion of a building will exacerbate the seismic risk because it will tend to shift the center of mass upwards resulting to an increased overturning moment when the building is subjected to the lateral seismic loads [13]. This is aggravated when only one side of the building has the heavy overhang.

4. Short Columns

The study also considered the presence of short columns in a building as one measure to determine its seismic risk. During the street surveys, as shown in Table XI, all 68 buildings were observed to have short columns. When the columns in a particular storey are the same in all other properties except for the heights, the shorter columns will carry a larger part of the total shear force in the storey. Particularly, it can be shown that, typically, when a column in a storey is one-half shorter than another column in the same storey, the shorter column will carry a shear force that is eight (8) times greater than the shear carried by the latter [12]. If the short column is not designed properly to carry such shear force, it runs the risk of ensuant failure due to the large earthquake shear forces. The short columns that were noted during the survey were mostly due to window openings and partitions that have altered the effective lengths or unsupported lengths of the columns relative to the other columns in a particular storey. Several buildings were observed to have short columns in the first floor which are also soft storeys.

5. Pounding Effects

Adjacent buildings can cause damage against each other during earthquakes when the separation or lateral distance between them is not enough to accommodate their respective lateral amplitudes of vibration. They will pound each other, particularly when they are vibrating out of phase, more so, if the heights are different [14]. This aspect was also considered in this study. The result is shown in Table XI. During the street survey, 40 out the 68 buildings considered, were observed to have adjacent buildings which could possibly cause earthquake damage due to the pounding effect. Some buildings were observed to have almost no separation at all.

6. Summary of Vulnerability of Sampled Buildings

To assess the overall seismic vulnerability of each building, a vulnerability number index is devised by adding the vulnerabilities for each building with a parameter assigned a vulnerability index of 1, if present, and 0, if none.

The overall assessment of the seismic risk of the selected buildings included in the street survey of this study is summarized in Table XIII.

Table 13 shows that 43 or 63.2% of the buildings are exposed to moderate risk while 24 or 35.3% are exposed to high risk.

It is necessary to emphasize that the above assessment is merely based on observation from the street and that the results are only preliminary indicators of possible seismic vulnerabilities based on the limited number of parameters

TABLE XIII
SUMMARY OF SEISMIC VULNERABILITY OF SAMPLED BUILDINGS

Vulnerability Number	Risk Level	Number of Buildings	Percent
1	Low risk	1	1.5
2	Low risk	0	0
3	Moderate risk	12	17.6
4	Moderate risk	31	45.6
5	High risk	21	30.9
6	High risk	3	4.4

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As next step to the street surveys, the buildings classified as high risk should be prioritized for further preliminary assessment and analysis using some measured or quantified building and earthquake parameters.

To summarize, the results of the seismic risk assessment of the buildings show that the structural parameters of the buildings, such as the presence of soft storeys, heavy overhangs, short columns and pounding effects, are prevalent in the as-built environment of General Santos City and can aggravate the seismic vulnerability of the City of General Santos. The National Earthquake Hazards Reduction Program (NEHRP) Handbook in the U.S. stipulates the idea that commercial buildings with open fronts (soft storey) and office with specially tall first storeys are more prone to be damaged by earthquakes. This is also consonant with the study of Yazgan and Sucuoglu (2003) that heavy overhangs increase vulnerability of buildings during earthquakes because overhanging floors in a building shift the center of mass of the building upwards and consequently increase the lateral forces and overturning moments during earthquakes [13].

Moreover, these findings support the ideas of Raheem (2006) that pounding effects due to inadequate separation with adjacent buildings increase the seismic vulnerability of buildings. This is because adjacent buildings, especially those of different heights could vibrate out of phase, and if the distance or space between them is not sufficient, will collide and produce large forces and stress concentrations enough to cause damage upon one or both buildings [14].

D. Level of Awareness and Preparedness of the Respondents

This study also determined the level of awareness and preparedness of the people of General Santos City in case an earthquake occurs. From about 200 respondents who were given questionnaires, a total of 193 questionnaires were retrieved.

1. Level of Awareness

Data from the questionnaires showed the respondents are very much aware ($\bar{x}$=3.7) that they should cover under a sturdy table or furniture when at home during earthquake. They are also very much aware ($\bar{x}$=3.7) that they should move to clear area away from trees, signs, buildings or electrical wires when outdoors.

Similarly, the respondents are also very much aware ($\bar{x}$=3.6) that they should evacuate immediately when cracks occur in the walls of the building during an earthquake. Regarding aftershocks, they responded that they are also very much aware of its possibility ($\bar{x}$=3.6). They are also very much aware ($\bar{x}$=3.6) that tsunami or tidal wave can possibly occur near the seashores or lakes. The respondents, however, are only moderately aware ($\bar{x}$=3.4) that they should not rush to the exit when in a stadium or theater. They also have moderate awareness ($\bar{\bar{x}}$=3.3) that when driving, they should pull over to the side of the road and stop and stay inside until the shaking stops.

They are only moderately aware ($\bar{x}$=3.4) that elevators should not be used in high buildings when earthquake occurs. Moreover, they are moderately aware ($\bar{x}$=3.5) that they should watch for possible landslide in sloping areas. Lastly, they are moderately aware ($\bar{x}$=3.2) that when trapped in a collapsed building they should take cover in the space beside a fallen beam or column.

The over-all mean of 3.5 indicates that, generally, the respondents are only moderately aware of what to do in case an earthquake occurs in General Santos City. This is consistent with the findings of the study of Tekeli-Yesil (2001) entitled, "Earthquake Awareness and Perception of Risk among the Residents of Istanbul", which showed that although the level of knowledge of 1,123 respondents regarding earthquake awareness and preparedness was promising, it could be improved [15].

2. Level of Preparedness

The results from the questionnaire showed that the respondents are much prepared ($\bar{x}$=3.6) in only one item on preparedness – that electric switches, circuit breakers, and the main panel board should be easily located for switching off when the need arises during earthquake. They are only moderately prepared in terms of placing heavy items and breakables in the lower portion of shelves or cabinets ($\bar{\bar{x}}$=3.4) and in avoiding hanging of heavy pictures and framed tapestries over beds ($\bar{\bar{x}}$=3.4). They are also moderately prepared in attaching securely the ceiling fans and light fixtures ($\bar{x}$=3.5) and in placing bookcases away from beds or places where people sit or sleep ($\bar{x}$=3.4).

The respondents, likewise, manifest moderate preparedness in securing electronic appliances on surfaces with flexible straps or fasteners ($\bar{x}$=3.4) and in fastening glass decors on surface by non-damaging adhesives ($\bar{x}$=3.3).

Moreover, they are only moderately prepared in providing emergency kit at home which should include water, food, and safety kits ($\bar{x}$=3.3) and in providing their houses with alternative doors for emergency exits ($\bar{x}$=3.5). Lastly, they are only moderately prepared ($\bar{x}$=3.4) that there should be available sturdy tables or pieces of furniture where they can take cover while earthquake shaking is going on.

The over-all mean of $\bar{x}$=3.4 indicates that, generally, the respondents are only moderately prepared in case earthquake occurs in General Santos City.

To summarize, the people of General Santos are only moderately aware of the risks posed by earthquakes and are only moderately prepared in case an earthquake occurs.

These results are similar to the findings of Tekeshi-Yesil (2001) in Istanbul where they conducted a field survey among 1,123 people regarding earthquake awareness and perception of earthquake risks. They found out that the people's knowledge was limited and needs improvement, and the respondents considered media as the leading source of information [15]. Shaw (2001), on the other hand, emphasized the importance of school in raising awareness among students, teachers, and parents, and suggested two components in earthquake education – first, to provide correct knowledge to the students about earthquake disaster and second, to provide them with practical training on how to protect themselves [16].

IV. Conclusion

The result of this study indicates that General Santos City is seismically active and vulnerable to being struck by a strong earthquake that can cause widespread damage. The actual occurrence of a damaging earthquake, however, cannot be predicted and its damaging effects can only be mitigated.

What is crucial is being prepared always to reduce the risk and mitigate the impact when earthquake actually comes. Based on the findings of this study, strategies or programs may be adopted to enhance efforts towards earthquake hazard mitigation and instituting and instilling earthquake discipline among the people of General Santos.

V. Recommendations

Based on the findings and conclusions of this study, the following actions or programs are recommended:

A. To address the findings that General Santos is seismically active, and that the probability of occurrence of a destructive earthquake is high within the next five years, the following programs/strategies are proposed:

1. Concerned agencies should be required to conduct an inventory and documentation of all types of damage caused by earthquakes in General Santos in the past and conduct the same for the future earthquakes that may occur. The documentation should include reports of damage and technical analysis on the damage of infrastructures and the damage caused on geological deformations;
2. The local government should work closely with PHIVOLCS and commission the conduct of a Geological survey and inventory that would include a detailed soil mapping to determine the specific areas prone to liquefaction and landslide; and
3. A study to look into the data gathered by the PHIVOLCS in General Santos since the start of its operation should be commissioned. This will allow a more comprehensive analysis of the earthquake data and should result to the determination of the appropriate earthquake parameters for use in the design and to be incorporated in the local building code. Specifically, a design response spectrum for General Santos can be developed. In addition, together with the soil mapping, earthquake hazards map can be developed for General Santos.

B. To improve the level of seismic risk awareness and preparedness of the people of General Santos, the following programs or strategies are recommended:

1. The role of the LGUs, the City Disaster Risk Reduction Management Council (CDRRMC), and the Regional Disaster Risk Reduction Management Council (RDRRMC) to educate the people and to mitigate the impact of earthquakes, should be complemented with seismic preparedness through proper planning for development that incorporates seismic zoning;
2. Regular earthquake drills should be undertaken not only for schools and government institutions but also for *Barangays* and *Puroks* with the active involvement of the residents;
3. Earthquake education should be incorporated into academic curricula in all levels, more importantly in the tertiary level; and
4. Human population in areas identified as danger zones for landslides, liquefaction, and tsunamis should be relocated.

C. On the assessment that many of the buildings in General Santos could be exposed to moderate to high level of seismic vulnerability, the following recommendations are proposed:

1. A more comprehensive and wider assessment of the seismic risk vulnerability of buildings in General Santos should be conducted, including the risks due to local soil conditions and topography, due to type of construction materials, and more importantly the parameters of earthquake and the applicable response spectra, as well as the expected maximum or peak ground acceleration;
2. Through a local ordinance, a Local Building Code requiring the submission of seismic structural analysis and design before a building permit is granted for all engineered structures regardless of the height should be adopted;
3. Seminars or workshops that will enhance the knowledge and skills of professionals involved in earthquake planning, analysis, and design, including the geotechnical aspects should be conducted; and
4. The City Engineering Office should have a separate section that will focus on the compliance of seismic provisions of buildings or infrastructure projects submitted for application of building permits.

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