Australian Earthquake Engineering Society
2023 National Conference, 23-25 November 2023
Brisbane, Queensland, Australia

Structural Assessment on Buildings Vulnerability to Seismic Hazards in the Lae City, the Industrial Hub of Papua New Guinea

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Abstract

Papua New Guinea (PNG) is a highly tectonically active region that experiences over 100 earthquakes of magnitude five or greater each year. The latest national seismic hazard assessment shows a particularly high hazard beneath Lae, PNG's second-largest City. The City and its port are the country's central economic hub, which sits astride the Ramu-Markham fault system. The recent 7.6 magnitude earthquake on the 11th of September 2022 was alarming. With a population of more than 100,000, a large but credible earthquake may result in the loss of many lives, impact livelihoods and cause broader economic losses to PNG. PNG has had a national earthquake hazard map for building design since 1982, but this no longer accurately reflects the latest understanding of bedrock hazards. Inadvertently, buildings that may be very vulnerable to earthquake ground motion have been designed and built. Identifying these buildings has been a vital component of the "Lae Earthquake Risk Project", undertaken as a collaboration between Geoscience Australia and the Papua New Guinea University of Technology (UniTech) in Lae City. The research aims to assess the earthquake risk of the City and explore how Lae can proactively mitigate the vulnerability of high-risk buildings. This research has entailed a targeted survey of Lae buildings that are expected to have been the subject of engineering design. This work was undertaken by UniTech using electronic tablets with built-in GIS software and survey templates to capture the building attributes. This paper describes the building survey activity, its motivation and future strategies for promoting earthquake engineering at UniTech.

Keywords: earthquake, risk, Ramu-Markham fault, building, infrastructure, modelling.

1 Introduction

According to Kulig et al. (1993), the crustal block south of the Lae Seismic Zone (LSZ) may rise relative to the Huon Peninsula. The rapid Quaternary uplift rates estimated for the Lae coastal region may be higher than the uplift rate of the Huon Peninsula, which reveals a tear of slight offset in the Huon terrane but may be similar to a structure that produced a magnitude 7 earthquake near Madang in 1970. Their assessment was made by exploring tectonic processes at the leading edge of the island arc during collision by operating a portable seismic network for six weeks near the City of Lae at the eastern end of the Ramu-Markham Valley (RMV). For this reason, Lae is one of those places that may experience a magnitude more than 5 and reach more than 7 magnitudes.

The recent 7.6 magnitude earthquake on the 11th of September 2022 was alarming. With a population of more than 100,000, a large but credible earthquake may result in the loss of many lives, impact livelihoods and cause broader economic losses to PNG. Studies have shown that PNG, since 1994, has experienced over 1700 earthquakes, which are greater than the magnitude (Mw) of 5, including 20 above Mw of 7. It ranks PNG as the tenth most disaster-prone country globally and is regularly rattled by earthquakes (Stanaway, 2008). An earthquake of magnitude 7.5 in the remote highlands region of PNG (Southern Highlands Province) claimed the lives of more than 125 people when their houses were buried by a landslide as a result of this earthquake (Graue, 2021). Figure 1 shows the earthquake distribution from year 2000 to 2016, ranging from magnitude 4 and above. Which depicts the extent of earthquake occurrence around where Lae City is.

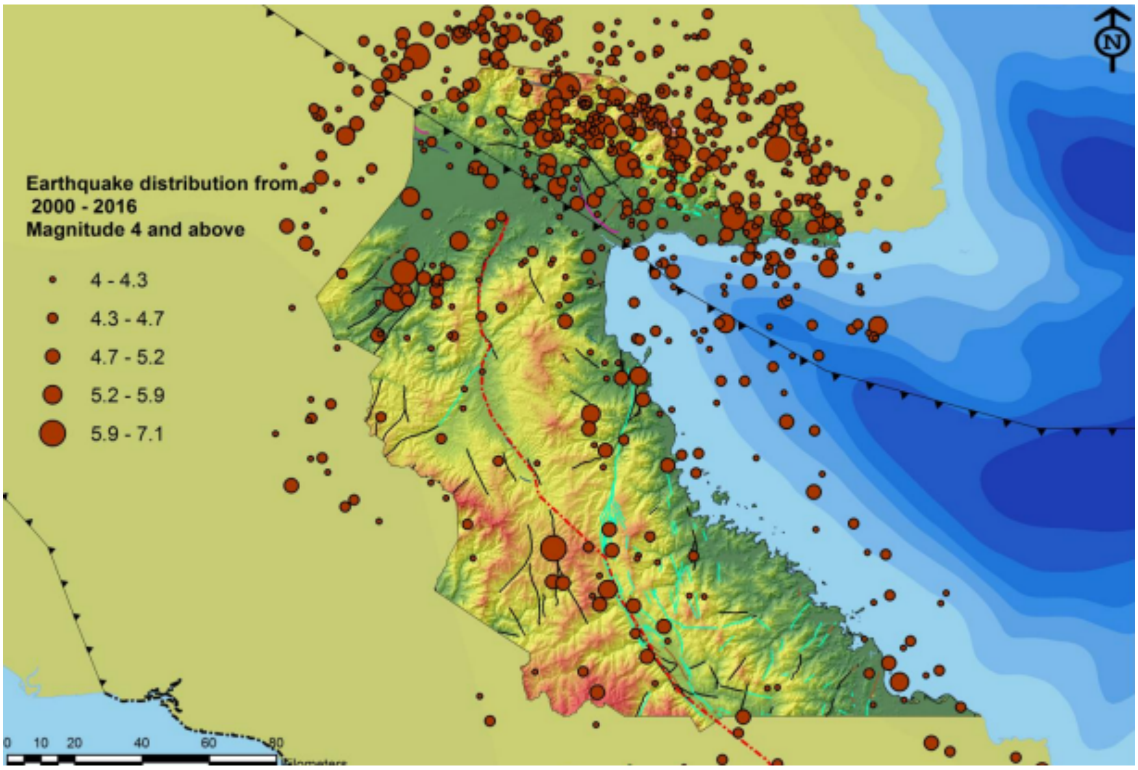

Figure 1. The seismicity distribution from 2000 to May 2016 (Sekac et al., 2018).

The earthquakes in Papua New Guinea are due to their location near the geologically active Pacific Ring of Fire. According to USGS (Pager, 2022), the predominant vulnerable building types are usually metal, timber and unreinforced brick masonry construction, which the population in this region resides in structures that are a mix of vulnerable and non-earthquake resistant construction. Table 1 shows the list of earthquakes that happened in the Province of Morobe. Lae City is the economic hub of the province.

Table 1. List of earthquakes in Lae City, Morobe Province

Date	Region	Magnitude	MMI	Death	Injuries	Remark
2022-09-11	Morobe	7.6 M_w	VIII	21	42	Extensive damage (M7.6,U SGS,2023)
2019-05-06	Morobe	7.1 M_w	VI			Minor damage in Lae (M7.1,USGS,2023)
2005-06-04	Morobe	6.1 M_w	VI	1	Several	Many buildings were damaged or destroyed in Lae. (M6.1,USGS,2023)
2002-04-01	Morobe	5.3 M_w	IV	36		Deaths from a landslide (M5.3,USGS,2023)
1993-10-13	Morobe	6.9 M_w	9	60	200	Landslide (M6.9, USGS,2023)
1987-02-09	Morobe	7.4 Ms		3		Landslide (M7.4, USGS,2023)

UNESCO is continually promoting the Sendai Framework for Disaster Risk Reduction 2015-2030, which recognizes the need to "substantially increase the availability of, and access to, multi-hazard early warning systems and disaster risk information and assessments to the people by 2030". The primary element of disaster reduction is an early warning system to prevent loss of life and reduce the economic and material impacts of hazardous events, including disasters caused by earthquakes.

PNG has had a national earthquake hazard map for building design since 1982, but this no longer accurately reflects the latest understanding of bedrock hazards. Inadvertently, buildings have been designed and built that may be very vulnerable to earthquake ground motion. Identifying these buildings has been a vital component of the "Lae Earthquake Risk Project", undertaken as a collaboration between Geoscience Australia and the Papua New Guinea University of Technology (UniTech) in Lae City.

The research aims to assess the earthquake risk of the City and explore how Lae can proactively mitigate the vulnerability of high-risk buildings. This research has entailed a targeted survey of Lae buildings that are expected to have been the subject of engineering design. The study will describe the building survey activity, its motivation and future strategies for promoting earthquake engineering at UniTech.

Materials & Methods

The building assessment method used survey teams composed of a maximum of 30 civil engineering students and a minimum of 12 civil engineering students supervised by a lecturer and two other technical officers at any one time.

The materials used in capturing the building attributes were Samsung Galaxy TAB 10.5 tablets enclosed in rugged protective cases running ESRI's Survey123 software. This software was loaded with a survey template to capture the building attributes and building locations via built-in GPS. A data dictionary was also embedded into the software. Figure 2, shows the tablet and a hardcopy of the data dictionary being used in the field.

Figure 2. A team discussing and capturing data on a tablet.

2.1 GIS Software

The Geographic Information System (GIS) is a system that creates, manages, analyses, and maps all types of data attributes. It connects data to a map, integrates location data (where things are) with all types of descriptive information (what things are like there) and provides a foundation for mapping and analysis. GIS also helps users understand patterns, relationships, and geographic context to improve communication and efficiency and better management and decision-making based on the data captured.

According to ESRI (2023), the GIS is a technology that applies geographic science with tools to help gain actionable intelligence from all types of data. The maps (Figure 3a) are the geographic container for the data layers and analytics, which are accessible virtually everywhere by everyone on your mobile phones, tablets, web browsers, and desktops (Figure 3b). It is easily shared and embedded in apps such as the electronic tablet used in the building survey. The apps provide focused user experiences, such as building surveyors for getting work done by collecting data. The GIS integrates many data layers using spatial location (Figure 3c). Most data have a geographic component, which includes imagery, features, and base maps linked to spreadsheets and tables. The spatial analysis (Figure 3d) evaluates suitability and capability, estimate and predict, interpret and understand new perspectives of insights and decision-making.

Figure 3. The GIS by ESRI, a) map, b) Apps, c) Data, d) Analysis.

2.2 Building Attributes

The fields in the building attributes are discussed below:

a. The type of building
b. Number of stories
c. Ground slope
d. Building name
e. Building age
f. Building usage
g. Construction Material
h. Structural System Type
i. Sub-building
j. Confidence Level

Table 2 below shows the building attributes and fields used in the assessment embedded in the apps installed on the tablet.

Table 2. Table of building attributes

FIELD	Attributes 1	Attributes 2	Attributes 3	Attributes 4	Attributes 5	Attributes 6	Attributes	
Date	*Time & Date*							
Assessor	*Text field*							
Number of Stories	1	2	3	4	5			
Ground Slope	Flat	Moderate	Steep					
Building Separation	0	5 cm	10 cm	20 cm	0.5 cm	1.0 cm	1.0+ cm	
Building Name	Text Field							
Building Age	Pre-independence 1975	1975-1985	1985-2000	Post-2000	unknown			
Building Usage	Commercial	Industrial	Strata/ Apartment	Public/ Institutional	Residential House	Mixed usage	other	
Construction Material	Concrete	Steel	Masonry	Timber				
Structural System Type	Moment resisting frame	Shear wall	Tilt- up	Free roof	Single portal frame	Masonry wall	Braced Frame	Pole Structure
Sub-Building	yes							
Confidence Level	Please review 0%	Good 60%	Confident 100%					
Comments	Text Field							

The survey team members use a data dictionary to discuss and then compile the information in the above list to identify the building attributes. A total of three photos of the building at different angles could also be taken at the time of the building capture.

2.3 *Processing of Data (cleaning)*

The building attributes that are captured are processed according to:

a. Duplication- Due to having a large group of surveyors in the field with up to 14 tablets in use, there are cases where the captured building is duplicated because another team had surveyed it unknowingly. Nevertheless, it is better to have a duplicate record that we can delete or clean later than having no record at all.

b. Capturing the buildings through photo – included in each individual building survey was an attribute field named 'Confidence Level'. If this level was captured at 0% then this allowed remote/in-office review of the buildings attributes via those photos.

c. Footprinting of individual buildings based on GPS location - during the survey of the building, a GPS location was recorded using satellite imagery. This location point then allows which building required footprinting using ESRI's software.

3. Results & Discussion

The UniTech Civil Engineering students team consisted of over 100 participants. Over a 4 week survey they have captured 3800 buildings within the Lae extent (Some buildings were captured multiple times due to training in the field). After data cleaning, the number of captured buildings totalled 3591, to fill any unsurveyed buildings within the Lae extent another dataset (SOPAC) will be appended. Building photos taken during the survey as part of the capture process amounted to 7454 individual shots, totalling over 7GB of data.

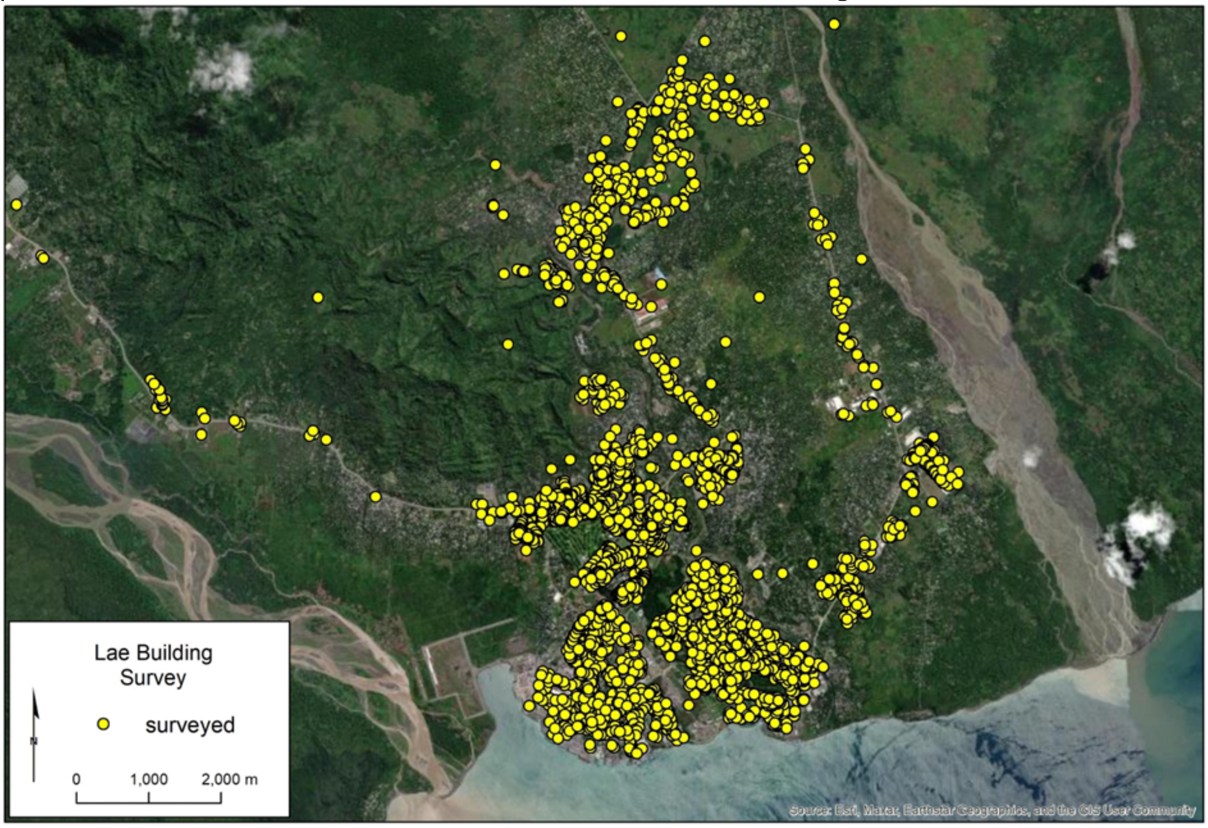

Figure 4. The extent of Lae Building Survey

Most buildings are vulnerable to the disaster that an earthquake may bring at any moment. Figure 5 shows the statistics of the building surveyed. It is due to its location where PNG is located in one of the most complex tectonic regions in the world. The Papua New Guinea

University of Technology (UniTech or PNGUoT) Department of Civil Engineering recently offered the refreshed Bachelor's Degree in Civil Engineering (Honours), a subject Structural

Dynamics and Earthquake Engineering under a provisionally accredited program with the guidance of Engineers Australia is a signatory to Washington Accord.

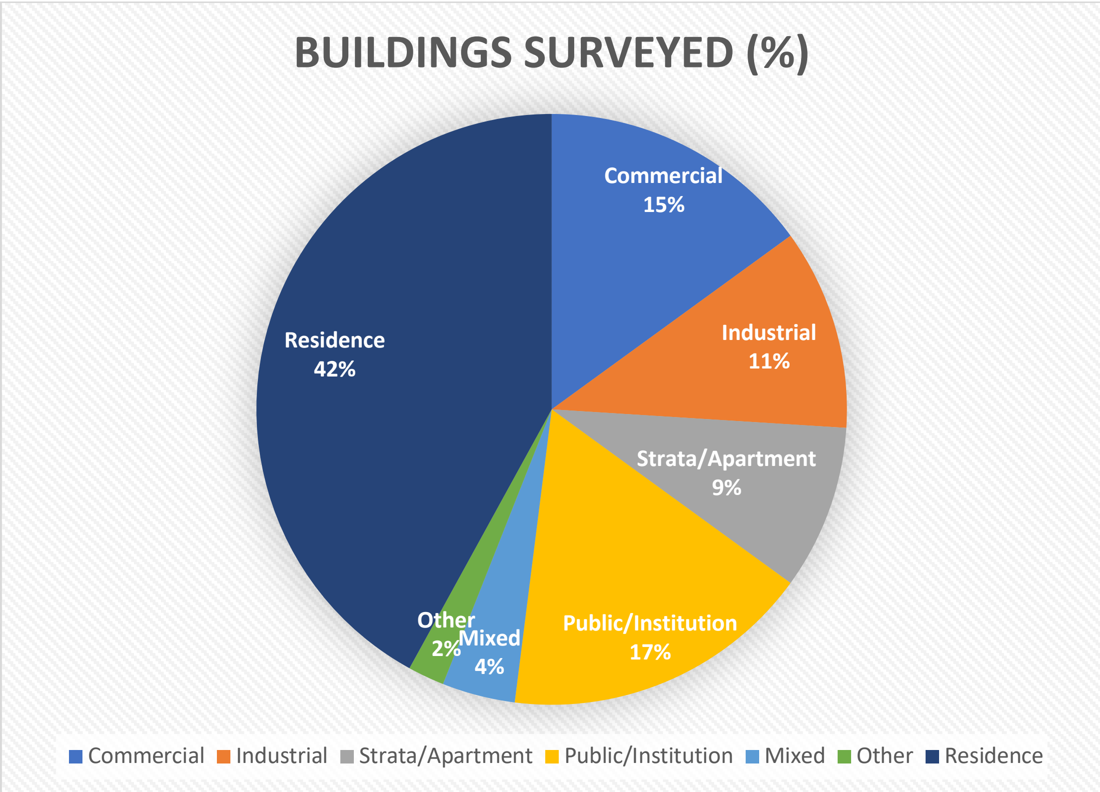

Figure 5. The Total percentage breakdown of buildings surveyed.

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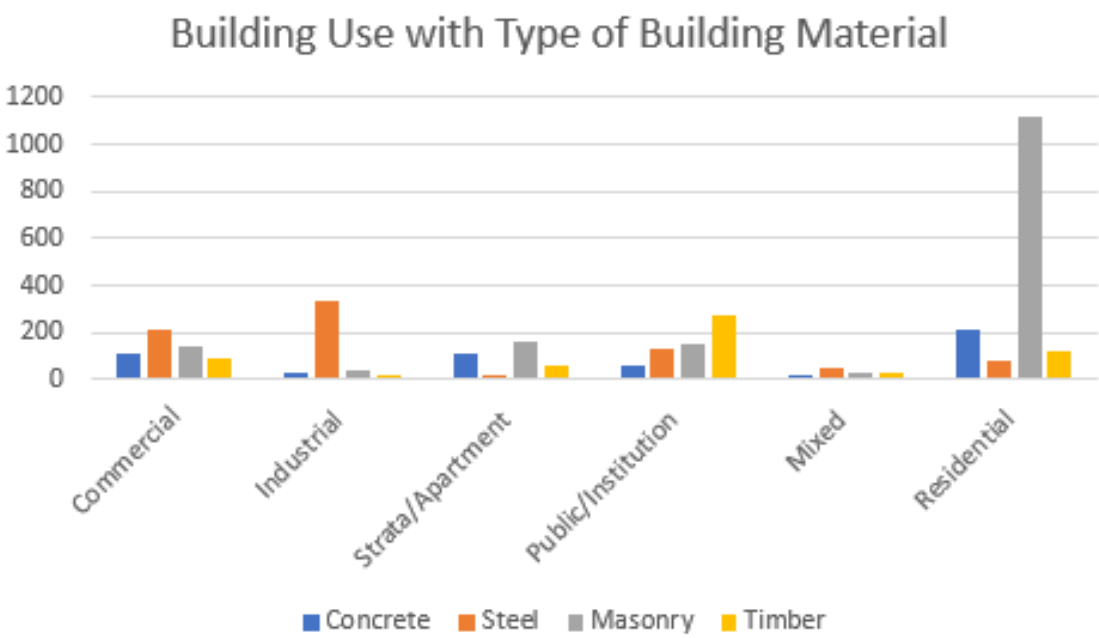

Figure 6. Building Use with Type of Building Material.

To take part in the prevention or to reduce the impact of the upcoming disaster, the UniTech Department of Civil Engineering plans to provide support to Papua New Guineans by providing information on the risk of earthquakes by observing real-time monitoring in a 24-hour time and alert the public in the impact of the hazard in collaboration with Geoscience Australia and other overseas aid programs. As the only technological University in the country, we hope to develop a consistent database of earthquake information to prepare the public and respond to the impact of earthquakes. By understanding the hazards and vulnerability of the built environment, the vulnerable part of the country susceptible to the earthquake risk will be supported by its aim to reduce the damage and cost. The proposed plan to create an Earthquake Research Centre is discussed below.

4. Conclusion & Recommendation

The information collected from the survey of the buildings that are built in the area where earthquake risk is high can show that the information gathered from it can support future decisions to mitigate the hazards and impact of earthquakes. The data can be further used if continuous monitoring and assessment are established in Unitech in the Department of Civil Engineering, which has the capacity and understanding of the lurking disaster. Therefore, It is recommended that Unitech be given continued support to participate in the development of the Earthquake Monitoring & Disaster Response Centre in Papua New Guinea.

Earthquake Research Centre

The Centre aims to conduct cutting-edge research on the dynamic characteristics of structures under dynamic and earthquake loads. Our collaboration with Geoscience Australia (through DFAT) may support the Department's participation in the country's Earthquake Monitoring and Response Team. The work collaboration with Geoscience Australia and DCE in 2023 is surveying the vulnerability of the buildings to Earthquakes in Lae City. In 2024 there will be the microzonation project.

Papua New Guinea experiences frequent earthquakes and one captured in a station constructed by the Department of Applied Physics located at Unitech in September is shown below, Figure 7.

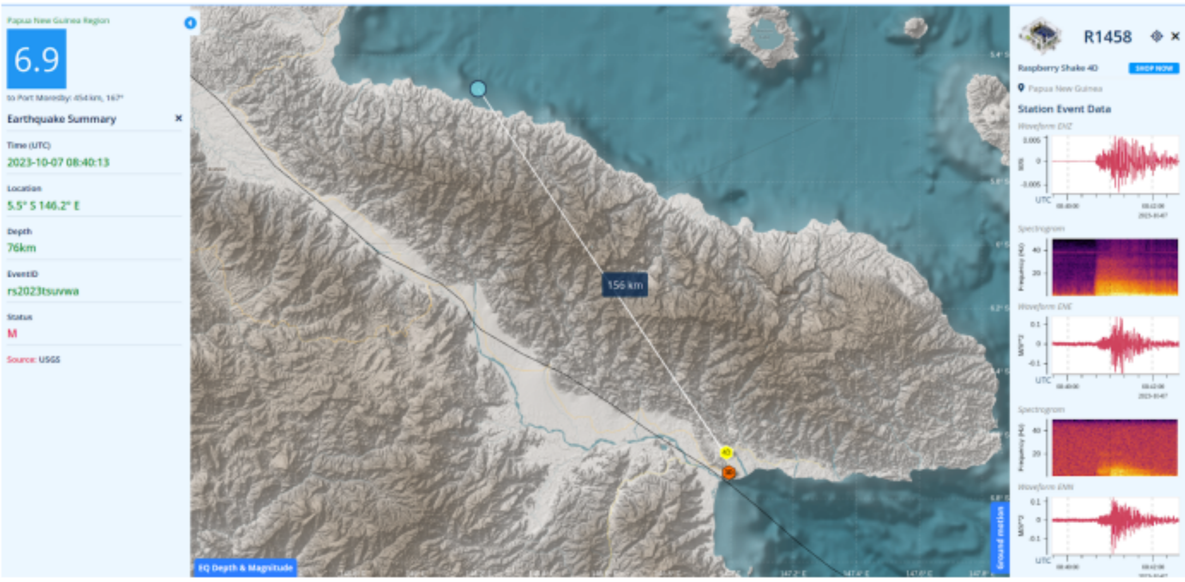

Figure 7. Recording of Earthquake captured at Unitech station PNG dated October 9, 2023

The above figure is a screenshot of the recent Magnitude 6.9 earthquake recordings by the Unitech station. The earthquake occurred ~55km SE of Madang and Unitech station was 156 km away from the epicenter. The level of ground acceleration at the university has exceeded 1 (%g) indicating a weak to light level of ground shaking with no expectation of damage to well-designed buildings. It is another example of high-quality data registered by CBSN-PNG.

All the structures and facilities could be affected by the impacts of the earthquakes in the long term. Though the laboratory is planned with the elective subject CE 323 Structural Dynamics and Earthquake Engineering for the undergraduate program, the research centre is planned for conducting research on structural response to earthquakes and mitigation of the effects of seismic forces on structures and facilities developed by civil engineering industries. The laboratory setup for structural dynamics will be under the structural laboratory to serve all the Civil Engineering UG and PG students. This laboratory is planned especially for earthquake research of national and industrial-interested PG and PhD students as well as the academic community and government institutions.

A proposed shake table (shown in **Figure 8**) will be used for an experimental study on the effects of earthquakes on structural models to develop earthquake-resistant structures for Papua New Guinea and other vulnerable to earthquake areas. The approximate price from MTS System Corporation, USA for the 2.2m x 2.2m 3500kg Multi-Axial Test System (shake table) is 3.34 million USD. A 3.0m x 3.0m Bi-axial shake table costs 1.99 million USD. A 3.0m x 3.0m 6DoF shake table costs 6.36 USD, and a 4.0m x 4.0m 6DoF shake table costs 7.71 USD.

Figure 8. Shaking table system installation (photo courtesy by MTS System Corporation)

The establishment of the shake table at the Department of Civil Engineering for testing the earthquake's impact on the structural model through the 6 DOF earthquake simulating test system will assist in understanding the structural behavior of building systems vulnerability to earthquake.

Having a monitoring system for PNG will assist in mitigating the disaster to occur with bigger damages.

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